Science and Research Technical Manual TM–02 2016

A Bayesian risk assessment tool to quantify the probability of aquatic invasions in Ontario – User manual

Ministry of Natural Resources and Forestry

Ontario

Science and Research Technical Manual TM–02 2016

A Bayesian risk assessment tool to quantify the probability of aquatic invasions in Ontario – User manual

Sarah Nienhuis and Tim Haxton

Aquatic Research and Monitoring Section

2016

Science and Research Branch

Ministry of Natural Resources and Forestry

Copies of this publication are available from: info.mnrfscience@ontario.ca

Cette publication hautement spécialisée, A Bayesian risk assessment tool to quantify the probability of aquatic invasions in Ontario – User manual n'est disponible qu'en anglais conformément au Règlement 671/92, selon lequel il n'est pas obligatoire de la traduire en vertu de la Loi sur les services en français. Pour obtenir des renseignements en français, veuillez communiquer avec le ministère des Richesses naturelles et des Forêts au info.mnrfscience@ontario.ca.

Cover photo: compilation of zebra mussel (miseagrant.umich.edu), round goby (GNU Free Documentation) and water chestnut (biolib.de)

Some of the information in this document may not be compatible with assistive technologies. If you need any of the information in an alternate format, please contact info.mnrfscience@ontario.ca.

Cite this report as: Nienhuis, S. and T. Haxton 2016. A Bayesian risk assessment tool to quantify the probability of aquatic invasions in Ontario – User manual. Ontario Ministry of Natural Resources and Forestry, Science and Research Branch, Peterborough, ON. Science and Research Technical Manual TM-02.

Executive summary

A quantitative, detailed-level risk assessment approach for evaluating the likelihood of invasion and impacts of aquatic invasive species in Ontario. The framework follows a questionnaire-style format complete with detailed guidance and examples to comprehensively address all stages in the invasion process: arrival, survival, establishment, spread, and impacts. Answers follow a standardized rating system, require selection of an associated uncertainty level, and are justified through detailed documentation of supporting scientific evidence. A probabilistic modelling approach (i.e., Bayesian risk assessment tool) is applied to integrate answers and uncertainty ratings, combine the questions for all invasion stages, and obtain an overall estimate of risk (presented as probability distribution for the likelihood of invasion and impacts). This approach increases the likelihood that risk assessments are objective, transparent, reproducible, and easily updatable in light of new information.

Résumé

Outil bayésien d'évaluation des risques pour quantifier la probabilité d'invasions aquatiques en Ontario – Manuel de l'utilisateur

Méthode quantitative détaillée d'évaluation des risques d'invasions aquatiques et de leurs effets en Ontario. Le cadre suit un document qui prend la forme d'un questionnaire comprenant des directives détaillées et des exemples qui touchent à toutes les étapes du processus d'invasion : arrivée, survie, établissement, propagation et effets. Les réponses s'appuient sur un système de cotation normalisé, demandent la sélection d'un niveau d'incertitude associé et sont justifiées par une documentation détaillée des données scientifiques à l'appui. Une méthode de modélisation probabiliste (c.-à-d. l'outil bayésien d'évaluation des risques) est appliquée pour intégrer les réponses et les coefficients d'incertitude, combiner les questions concernant toutes les étapes d'invasion et obtenir une estimation d'ensemble des risques (présentée comme une distribution des probabilités d'invasion et de dommages). Cette méthode augmente les possibilités que les évaluations des risques soient objectives, transparentes, reproductibles et facilement mises à jour à la lumière de nouveaux renseignements.

Acknowledgements

We thank Mike Hoff (Regional Aquatic Invasive Species Coordinator, United States Fish and Wildlife Service), Cecilia Weibert (Aquatic Invasive Species Risk Assessment Analyst, Michigan Department of Agriculture and Rural Development), Tim Johnson and Shannon Fera (Aquatic Research and Monitoring Section, Science and Research Branch, Ministry of Natural Resources and Forestry [MNRF]), and Jeff Brinsmead and Francine MacDonald (Natural Heritage Section, Natural Resources Conservation Policy Branch, MNRF) for reviewing the risk assessment tool and contributing their valued expertise through comments and feedback.

This project was funded by the Ministry of Natural Resources and Forestry.

Contents

Overview

This document provides detailed instructions for the risk assessment tool developed to evaluate the probability of invasion and impacts of non-native aquatic species in Ontario. Specifically, the tool is applicable for fish, aquatic invertebrates, and aquatic plants. It has not been calibrated or tested for aquatic parasites, viruses, or other diseases that may be incidentally introduced along with other non-native taxa.

For ease of use and interpretation, the approach is divided into three sections:

- Background information
- Detailed-level risk assessment
- Probabilistic modelling of invasion risk

In the first section, the reason for conducting the assessment is identified and a summary of relevant background information on the species is compiled. The second section is a detailed-level risk assessment for the species that is guided by a questionnaire. The questionnaire comprises a series of 24 questions, divided into 5 subsections representative of the 5 stages in the invasion process (arrival, survival, establishment, spread, and impacts). For each question one standardized answer and its associated uncertainty level are selected. Detailed guidance and numerous examples are provided to assist answer selection. General guidance for selecting uncertainty ratings is provided with more specific guidance included within the document where warranted.

Information required to complete sections 1 and 2 is acquired through a comprehensive review of available published sources on the species being evaluated. Uncertainty ratings will reflect variability in the quality and quantity of information available for different species. In addition, it is important to identify significant knowledge gaps or controversial findings in the published literature that constitute major sources of uncertainty in the assessment.

The final component is a quantitative evaluation of the probability of widespread invasion and impacts. A probabilistic modelling tool based on a Bayesian network has been developed to: 1) combine the factors influencing invasion using conditional probabilities, and 2) incorporate and propagate uncertainty in risk estimations. The answers and uncertainty ratings selected in the questionnaire are entered as input and the modelling tool generates probability distributions for the likelihood that the species

arrives, survives, establishes, spreads, and has impacts in Ontario. Detailed instructions for the installation and use of the modelling tool are provided.

Detailed background documentation of the underlying structure and mathematical foundations of the model are presented in a companion document (Nienhuis and Haxton 2016) along with model testing results for several case study species.

Section 1: Background information

Rationale

Provide rationale for conducting the current risk assessment for the species in question. Identify if a screening-level risk assessment has recently been performed for the species being assessed, and if it poses a potential risk of becoming invasive in Ontario.

Note: A screening-level assessment may be warranted before continuing with the detailed-level assessment if one hasn't been conducted.

Time horizon

Identify the time horizon for which the current risk assessment applies (i.e., the time frame over which the risk of widespread invasion and impacts is being evaluated). This typically falls somewhere between 5–10 years and warrants being explicitly stated.

Species identification

Identify the species for which the current assessment is being conducted.

- Indicate organism type/taxa (e.g., fish, aquatic invertebrate, aquatic plant, etc.), list its scientific name, taxonomic classification, and common or trade names.

Species description

Provide a brief physical description of the species.

- Include description of distinguishing features (general shape, colour, number of fins/appendages, shape/number of leaves, flowers, seeds, etc.).
- Note if sexual dimorphism exists.
- Include an accurate line drawing/photo/image of the species if possible.

Distribution

Identify the native range of the species.

- Describe geographical region, list countries, or copy and paste a map of native range.

Identify current global distribution of the species (excluding Ontario).

- List continents, regions, and/or countries.
- Include list of North American states or provinces if applicable.
- Include a map of global distribution if available.

Indicate the current distribution of the organism in Ontario.

Biology and life history

Habitat

- Describe broad habitat (i.e., freshwater/brackish/marine, lentic/lotic, benthic/pelagic etc.).
- Identify type of water bodies inhabited (e.g., lakes, rivers, streams, ponds, canals, ditches, floodplains, backwaters, etc.).
- Indicate general habitat preferences (i.e., depth, substrate or vegetation types, water clarity, water flow) as well as physiological tolerance to water quality conditions (i.e., preferences and lethal limits for temperature, salinity, dissolved oxygen, pH, alkalinity, nutrient concentrations, pollution, etc.).
- Note whether the species displays different habitat use for different life stages or activities (e.g., spawning, adult/juvenile, feeding, overwintering, etc.) and describe the habitat, as appropriate.
- Include information from both native and introduced range (if applicable).

Diet

Note: For animal taxa only

- Describe general feeding strategy (omnivore, herbivore, filter feeder, piscivore) and diet breadth (specialist, generalist/opportunist).
- Include list or range of common diet/prey items in native and invaded range, if this information is available, as well as differences in diet across life stages (ontogenetic changes).
- Describe feeding behaviours, including any specialized adaptations that allow for efficient hunting or foraging, or successful exploitation of novel food resources.

- Include information on diurnal or seasonal changes in feeding activity, noting temperature dependency of feeding rates/activity.

Reproduction

Describe key features of the species' reproductive strategy:

- Note whether asexual reproduction is possible.
- For animal taxa include information on age/size at maturity (and whether there are differences between sexes), generation time, frequency of sexual reproduction, fecundity (# of eggs per female, size of eggs), noting any differences that may exist between native and invaded range.
- For plant taxa include information on the size and number of seeds/propagules produced, description of reproductive organs, identify whether any life stage can remain dormant/viable over extended periods to create a seed bank, etc.
- Highlight timing of reproductive events, including temperature requirements for oogenesis, initiation of spawning behaviours, egg incubation/seed germination, seed maturation, etc.
- Describe mating/spawning behaviour, and specify whether the species displays parental care (mouth brooding, nest guarding, etc.).
- Identify whether the species is dependent on other organisms (pollinators, hosts, incubators) for successful reproduction to occur.

Growth

- For animal taxa, describe size at hatch, growth rates, maximum sizes achieved (length/weight), typical and maximum life span (note if different between sexes).
- Note if differences exist between sexes, or between native and invaded range.
- For plant taxa, identify whether the species is annual, biennial, or perennial, describe growth rates, mechanism of growth, typical/maximum seasonal biomass, typical life cycle, and seed viability.
- Identify whether dormancy period exists.
- For all taxa, describe temperature requirements (min/max/ideal) for growth.

Movement/dispersal

- Describe known mechanisms for movement/dispersal.
- Identify which life stage(s) have the capacity for movement/dispersal, and whether movement is active or passive.
- Specify whether the species is migratory and describe seasonal or diurnal changes in movement patterns.

- Identify typical/maximum dispersal distances of various life stages, and range/population expansion rates if available.
- Note whether movement of the organism is impeded by natural or anthropogenic barriers.
- In addition to natural dispersal, identify and describe any known or documented human-assisted dispersal mechanisms.

Parasites and disease

- Identify, or list, known bacterial, fungal, parasitic and/or viral pathogens to which the species is susceptible, or can carry, noting in particular whether any are listed by World Organization for Animal Health (OIE) as reportable diseases (oie.int/animal-health-in-the-world/oie-listed-diseases-2016/).
- Specify whether the species is known to have transmitted novel diseases and/or parasites to areas outside of its native range where it has been introduced.

Section 2: Detailed-level risk assessment

The model requires that one standardized answer rating and its associated uncertainty be selected for all questions (unless otherwise stated, and unless the answer is unknown in which case no uncertainty rating is required). For transparency and possible future re-evaluation of the risk assessment it is also important that justification in text be provided for all answers and associated uncertainty ratings (i.e., summary and citation of all sources of information used as evidence to support the answer rating). Guidance for answer selection is included for all questions with general guidance for uncertainty ratings provided in Table 1 below.

***Table 1**: Guidance on selection of uncertainty rating*

Uncertainty	Interpretation /meaning	Examples to justify the uncertainty rating	Certainty
Low	There is little doubt about the assessment and the risk rating	• There is direct relevant evidence to support the assessment • There is substantial/extensive and reliable scientific/systematic information (e.g., multiple, independent peer-reviewed data sources/information) • The situation can be easily predicted • The interpretation of data/information is straightforward • Data/information are not controversial or contradictory • Personal communication is from experts regarded as specialists on the question raised	**High**
Medium	There is some doubt about the assessment and the risk rating	• There is some evidence to support the assessment • There is a moderate level of scientific information, but this could include first hand, unsystematic observations • Some evidence for the prediction of the situation is available, but this prediction may be unreliable • Some information is indirect (e.g., data from another phylogenetically or functionally similar species has been used as supporting evidence) • The interpretation of the data is to some extent ambiguous or contradictory	**Medium**
High	There is considerable doubt about the assessment and the risk rating	• There is no direct evidence to support the assessment (e.g., only data from other species have been used as supporting information) • There is little or limited scientific information (e.g., circumstantial evidence) • The situation cannot be readily predicted because the evidence is poor and difficult to interpret (e.g., it is strongly ambiguous) • The information sources are considered to be of low quality or contain information that is unreliable (e.g., it is strongly contradictory)	**Low**

Modified From: Therriault et al. 2010; Chan et al. 2011; MacLeod 2011; Blackburn et al. 2014

Stage 1: Probability of arrival

Introduction: The first point to consider in a risk assessment for a potentially invasive species is whether the organism has the potential to arrive in Ontario and subsequently be introduced into the natural environment. It is therefore necessary to consider the pathways or vectors through which the species could potentially be introduced to Ontario waters.

The intent of this section is to identify whether at least one potential pathway for live transport of the species into Ontario exists or is proposed. At this stage, an evaluation of

the likelihood or frequency of transfer from the pathway to the natural environment is not considered (this is subsequently addressed in Q.2.04).

1.01 Arrival status in Ontario

1.01 Does the species currently exist in the natural environment in Ontario?

Answer options: no, yes

Note: This question aims to identify whether the species (e.g., a single individual, several individuals, a single population, or multiple populations) has been documented in the natural environment in Ontario. For the purpose of this question, consider *currently exists* to mean that reports of its presence have been confirmed within the last 5 years. This does not include consideration of whether the species can survive year-round or reproduce in the wild in Ontario (this is evaluated elsewhere). Answer no if uncertainty exists, or if there are no reputable sources confirming/documenting the presence of individuals in the natural environment in Ontario.

1.02 > 1.04 Potential pathways for arrival

1.02 Is the species known to be in an existing or proposed pathway through which any life stage of the organism could be transported live into Ontario, either intentionally or unintentionally?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

Note: Identify all relevant potential pathways of arrival. This can include either intentional or unintentional transport/movement of live individuals into Ontario.

Examples of intentional pathways include existing or proposed:

- Sale or trade of the species at aquarium/pet/water garden stores in Ontario, or by online or mail order
- Commercial culture of the species in Ontario
- Deliberate stocking/planting of the species in Ontario
- Import into and sale of species at markets or wholesalers in Ontario as part of the live food trade

Examples of unintentional pathways include:

- Occurrence of species near (<100 km) or within waterbodies connected to Ontario waters by natural or anthropogenic corridors/channels/canals

- Transport of species into Ontario as a result of entrainment in ballast water or hull fouling
- Transport of species into Ontario through other anthropogenic vectors, i.e., boats, fishing gear, tire treads, etc.

1.03 Has the species been introduced elsewhere, intentionally, or unintentionally, through at least one of the pathways identified above?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

1.04 Is the species known to be a fellow traveller accompanying other species or products that are in an existing or proposed pathway?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

Note: This would include species that contaminate shipments of other goods or are transported along with other species.

Examples

- Aquatic plants can contaminate other plants sold in the aquarium/water garden industry (e.g., hydrilla has been found in shipments of water hyacinth in the United States because it is harvested from areas where they co-occur [Francine MacDonald, *personal communication*]).
- Aquatic plants can also contaminate water used to transport fish from aquaculture facilities or fish hatcheries
- Plant seeds can be transported as contaminants of soil

Stage 2: Probability of survival

Introduction: After identifying potential pathways for introduction, it is necessary to evaluate survival probability. Temperature is typically the most important climate variable dictating whether a species will survive year-round if it is introduced outside of its native range. For the risk assessment area under consideration (i.e., freshwater environments in Ontario) salinity requirements could also influence survival. The timing and state of health of organisms upon release into the natural environment are also relevant to consider.

The purpose of this section is to evaluate the likelihood that the species could survive in Ontario waters if introduced. Consider only survival not growth or reproduction (these are evaluated in subsequent stages).

2.01 Survival status in Ontario

2.01 Is the species already known to survive year-round in the natural environment in Ontario?

Answer options: no, yes

Note: This question aims to identify whether the species (e.g., a single individual, several individuals, a single population, or multiple populations) has been documented/observed to survive year-round in the natural environment in Ontario. This does not include consideration of whether the species can reproduce in the wild in Ontario (this is evaluated elsewhere). To answer yes, reputable evidence/documentation of its survival year-round in Ontario is required. Answer no if uncertainty exists, or if there are no reputable sources confirming/documenting the species' year-round survival anywhere in the natural environment in Ontario.

2.02 Temperature tolerance

2.02 Can any life stage of the species (e.g., eggs, adult, larvae, resting stage, seeds, turions/over-wintering buds) tolerate/survive temperatures <5.5°C?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

Note: This question is meant to assess whether or not any life stage of the organism could overwinter in Ontario (based on the general temperature criterion for year-round survival of aquatic organisms in the Great Lakes [Kolar and Lodge 2002; Rixon et al. 2005]). Consider thermal requirements for survival only (i.e., not for growth or reproduction). To answer this question, identify the lower lethal temperature limit or minimum temperature tolerance reported for the species, accounting for potential thermal plasticity. If relevant information is not available for the species, answer unknown.

2.03 Salinity requirements

2.03 Can the species survive in freshwater environments?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

Suggested rating guidance:

No: Species is strictly marine (i.e., it is associated only with marine habitats) and can therefore be ruled out as posing an invasion risk in freshwater environments in Ontario.

Yes: The species occupies freshwater or brackish habitats or is known to be euryhaline (adapted to a wide range of salinities).

Unknown: Relevant information is not available for the species.

2.04 Survival during transfer from a pathway and introduction to the natural environment

2.04 Is the species likely to survive transfer from a pathway and introduction to the natural environment?

Answer options: no, yes, unknown

Level of uncertainty: low, medium, high

Note: Whether release is accidental or intentional, survival will depend upon the timing of the event and on the state of health of individuals. Consider the season when accidental or intentional release would be most likely, the life stage(s) being released, and whether climate and habitat conditions at the time of release would promote survival.

Suggested rating guidance:

No: Examples would include individuals intentionally released or discarded owing to disease, high mortality levels in shipments, or which are otherwise stressed or moribund. This answer would also apply to cases where release events are expected to occur only in the winter and individuals or life stages subject to release are intolerant to winter climate conditions or in cases where other habitat requirements of the organism are not met.

Yes: Species/individuals that: 1) actively escape or disperse into Ontario waters through connected waterways; 2) are intentionally released in good health; 3) are capable of surviving out of water for significant periods of time; 4) are released during periods of hospitable climate and into suitable habitats; or 5) are known to have successfully survived introductions via pathways identified above in regions with similar climate to Ontario.

Unknown: Relevant information is not available for the species.

Stage 3: Probability of establishment

Introduction: Beyond an ability to successfully arrive and survive introduction in a new environment, a species must also be able to establish in order to become invasive. Established invasive species are those with self-sustaining populations (Kolar and Lodge 2001) that persist in a new area over some period of time after arrival (Jerde and Lewis 2007).

In order for establishment and population growth to occur, the introduced species must be able to increase in abundance in the invaded locality (Marvier et al. 2004). Most introduced species that fail to establish do so as a result of mortality or reproductive failure (Vélez-Espino et al. 2010). Consequently, both abiotic and biotic interactions at any new location have the potential to increase or decrease the probability of establishment (Jules et al. 2002; Von Holle 2005).

A number of factors or biological traits can predispose a species to becoming established if introduced outside of its native range. For example, species are more likely to become established in areas where climate and habitat conditions match those of their native range (Bomford et al. 2010). In addition, species must be able to find food or other necessary resources, overcome competition or predation by native species, and successfully reproduce in the introduced environment. A species' history of establishment success elsewhere can also be an important predictor of establishment success in novel environments (Bomford et al. 2010), serving as a proxy to estimate human affiliation and propagule pressure (Jeschke and Strayer 2006; García-Berthou 2007).

The purpose of this section is to evaluate the likelihood that the species could establish self-sustaining populations in Ontario waters. The following set of questions was compiled to reflect the current understanding of important drivers of establishment success.

3.01 Establishment status in Ontario

3.01 Is the species already known to have become established in the natural environment in Ontario?

Answer options: no, yes

Note: This question aims to identify whether the species has been documented/observed to have become established in the natural environment in

Ontario. To answer yes, reputable evidence/documentation of its ability to reproduce and establish at least one self-sustaining population in Ontario is necessary. Answer no if uncertainty exists, or if there are no reputable sources confirming/documenting an established population of the species in the natural environment in Ontario**.**

3.02 > 3.03 Climate and habitat suitability

It is well-recognized that environmental suitability is a critical driver of establishment success. Environmental suitability "invokes the concept of the species' niche and uses information about a species' known environmental tolerances to predict whether that species will establish in a given region" (Bradie and Leung 2015). Consequently, nearly all predictive models of establishment probability consider the similarity of environmental conditions between an organism's existing range and areas of potential introduction (e.g., Howeth et al. 2015), and the physiological tolerance limits/ range of the species.

3.02 How similar are the climatic conditions that would affect establishment of the species in Ontario to those in the species' current (native and introduced) geographical range?

Answer options: Not similar, Somewhat similar, Moderately similar, Largely similar, Completely similar, Unknown

Level of uncertainty: low, medium, high

Note: When comparing climates in a species' current distribution with those in Ontario, ensure that the variables being compared are relevant to the species' ability to successfully grow and reproduce. Consider that the species' current distribution may be poorly known or uncertain, and that climate as measured by weather stations may not reflect the microclimate inhabited by the species. Account for these factors when selecting the level of uncertainty associated with the answer rating.

To answer this question, identify the current distribution of the organism (includes both native and invaded range) and compare climatic conditions therein to the climate in Ontario. This can be done in one of two ways: 1) through visual comparison of climate zone maps, or 2) through quantitative comparison of climate data using climate-matching software. Several options for conducting climate comparisons are provided in Appendix 1.

Suggested rating guidance:

Not similar: None of the climatic conditions in the native or introduced range of the species are at all similar to those in Ontario.

Examples:

- The current distribution of the species is only in equatorial (Group A) or arid (Group B) climate zones with desert (M) or monsoonal (m) precipitation patterns (Köppen-Geiger map), or the species is currently distributed only in plant hardiness zones 10–13.
- Climate match (i.e., Climatch) scores for all Ontario stations are less than 4 (such low levels represent unsuitable habitats where establishment is unlikely [Bomford et al. 2010]), or Climate 6 ratio is 0.000 (see Appendix 1).

Somewhat similar: Few of the climatic conditions in the native or introduced range of the species are similar to those in Ontario.

Examples:

- Climate zones defining the species' current distribution do not include Group D, and only a limited area of the species' distribution is represented by Group C; or species' distribution is largely represented by plant hardiness zones 8–10.
- Most of the province has Climatch scores less than 4, some stations have climate match scores between 4-5, none with a score of 7 or greater. Climate 6 ratio <0.005.

Moderately similar: Several of the climatic conditions in the native or introduced range of the species are similar to those in Ontario.

Examples:

- World hardiness zones in species' current distribution are close to, but not exactly, those represented in Ontario (i.e., Köppen-Geiger classifications Dfa, Cfb, or Cfa; plant hardiness zones 7 or 8).
- Numerous stations in Ontario with Climatch scores greater than 5; at least 20% of scores at level 6 or higher (Bomford et al. 2010; Mandrak et al. 2013). Climate 6 score 0.005-0.103.

Largely similar: Most of the climatic conditions in the current native or introduced range of the species are similar to those in Ontario.

Examples:

- Climatic similarity is indicated if Ontario shares a Köppen-Geiger climate classification or world hardiness zone with any of those represented by the species' current distribution.
- Mean Climatch score (across all stations in Ontario) of at least 7 (Britton et al. 2010). Climate 6 score >0.103.

Completely similar: All of the climatic conditions in the species' current native or introduced range are similar to those in Ontario.

Examples:

- Indicated if Ontario shares more than one Köppen-Geiger climate classification or world hardiness zone with those represented within the species' current distribution.
- All stations in Ontario have climate match scores greater than 7 (Britton et al. 2010). Climate 6 score = 1.

3.03 How similar are abiotic factors that would affect establishment of the species in Ontario to those in the species' current geographical range?

Answer options: Not similar, Somewhat similar, Moderately similar, Largely similar, Completely similar, Unknown

Level of uncertainty: low, medium, high

Note: This question evaluates the suitability of habitats in Ontario based on important abiotic factors. Consider the physical and chemical characteristics of the aquatic habitat (e.g., temperature, pH, salinity, nutrient concentrations, water clarity, current or flow rate, depth, water level fluctuations, substrate composition, etc.), as well as disturbance, environmental pollution (i.e., eutrophication, heavy metal contamination, organic pollutants, etc.), topography, and/or land use. Focus on factors that define the species' habitat requirements for survival, development, and reproduction. By extension, this question pertains to the physiological tolerance limits and/or adaptability of the species to various abiotic conditions.

Suggested rating guidance:

Not similar: None of the species' critical abiotic habitat conditions are similar to those characteristic of aquatic habitats in Ontario. The species is a habitat specialist, is not considered to be highly adaptable, has only a narrow physiological tolerance range, and is intolerant of anthropogenic or natural disturbance.

Examples:

- Species that require saltwater/marine habitats for spawning or to complete their lifecycle.
- A species that thrives only in highly alkaline conditions (such as the highly specialized Alcolapia cichlids that live in the extreme environment of Lake Natron in Kenya).

Somewhat similar: Certain abiotic habitat conditions in Ontario are similar to those required by the species while others are not (or are very rarely occurring). The organism is not considered to be highly adaptable, has only a narrow physiological tolerance range, or is intolerant of natural or anthropogenic disturbance.

Example:

- A riverine species that would find appropriate temperature conditions for survival and growth in southwestern Ontario, but requires clean, silt-free riffle habitat devoid of pollutants or agricultural impacts (continued degradation and limited occurrence of these habitats is currently a limiting factor for the recovery of a number of fish and mollusc species at risk in Ontario).

Moderately similar: The species' physiological tolerance to various abiotic factors is somewhat broad (reported to survive in wide range of temperature, salinity, oxygen, or nutrient levels). Abiotic habitat conditions in Ontario fall within physiological tolerance range of the species, but are not commonly within the physiological optima for feeding, growth, or reproduction.

Largely similar: Most of the necessary abiotic habitat conditions for successful feeding, growth, and reproduction of the species occur in waterbodies in Ontario. Some conditions may fall outside of the reported physiological optima for the species, but evidence suggests that it is highly adaptable. The species is considered a habitat generalist or has very broad physiological tolerance to a wide range of abiotic factors.

Completely similar: All necessary abiotic habitat conditions for successful feeding, growth, and reproduction of the species are common across waterbodies in Ontario. The species is considered a habitat generalist capable of inhabiting a variety of aquatic habitat types, is tolerant of or benefits from natural or anthropogenic disturbance and has very broad physiological tolerance to a wide range of abiotic factors (i.e., reported to survive and reproduce across a wide range of temperature (0–30°C), salinity (0–16 ppt), oxygen (0 mg/L — saturated) and nutrient (oligotrophic-eutrophic) levels).

3.04 > 3.06 Biotic interactions/ecological suitability

Establishment success is not only determined by environmental or climatic suitability, it is also influenced by ecological context. The underlying community structure of the receiving environment (i.e., the identity and abundance of species that already exist within it) can play an equally important role in promoting or preventing the successful establishment of an introduced species. Existing species not only represent potential food resources or hosts, but also potential competitors or predators. The ecological factors that govern biotic interactions in natural communities are complex and difficult to quantify a priori. As a result, estimates of the role that they will play in determining establishment success will likely be associated with a significant degree of uncertainty.

3.04 How likely is it that the species would find other organisms necessary for its survival, growth and reproduction within the natural environment in Ontario?

Answer options: very unlikely, unlikely, moderately likely, likely, very likely, unknown

Level of uncertainty: low, medium, high

Note: This question is meant to ascertain whether the species is likely to find suitable plant or animal resources in waterbodies in Ontario. This includes all organisms necessary for food, habitat, or as hosts or pollinators. Consider the feeding habits and diet preferences, breadth and plasticity of the species in its current range, and evaluate the likelihood that it will find suitable food resources in Ontario. Identify whether it is obligately dependent upon specific species for food or prey, as habitat, hosts, root symbionts, or for pollination, egg incubation, etc., and whether these organisms are likely to be encountered in Ontario.

Suggested rating guidance:

Very unlikely: Species is a dietary specialist with a limited and inflexible diet that feeds only on plant or animal species that do not currently exist in natural waters in Ontario. The species' survival or reproduction requires the presence of specific host plants or animals, specific pollinators, or other symbiotic or mutualistic species that do not currently exist in Ontario.

Examples:

- Unionid mussels that require specific fish hosts that are not native to or present in Ontario in order to successfully develop from larvae (glochidia) to adults and thereby complete their lifecycle.
- A plant taxon that is obligately dependent on a specialist pollinator taxon for sexual reproduction, and that pollinator is not present in Ontario.

Unlikely: Species is largely a dietary specialist with limited or inflexible diet. Potential food resources, prey organisms, or host species are scarce and/or search time is high in Ontario.

Example:

- A species that preferentially feeds on or otherwise requires the presence of another specific non-native species that has been introduced in Ontario but has only a very limited occurrence or distribution.

Moderately likely: Potential food resources, prey organisms, or host species exist in moderate abundance and/or search time is moderate in Ontario. Species is considered a dietary generalist to some degree with a broad, assorted or flexible diet.

Example:

- The Bitterling *Rhodeus sericeus* cannot reproduce unless a suitable freshwater mussel is present in which to incubate its eggs. While the species displays a lack of specificity or discrimination for the type of mussel host that can be used, the distribution of freshwater mussels in Ontario is declining and is generally limited to cleaner waters.

Likely: Most nutritive items available in Ontario waterbodies could be considered potential food resources, prey organisms, or host species. These are abundant and/or search time is low in most waterbodies in Ontario. Species displays diet breadth in its current range or is an autotroph that is not dependant on specific pollinators.

Example:

- A plant taxon that is pollinated by generalist pollinators, such as flies or honeybees.

Very likely: All potential food items are highly abundant and/or could be easily found in any waterbody in Ontario. The species is a dietary generalist or opportunistic feeder capable of shifting its diet or prey base in order to exploit abundant or novel plant or animal resources or is an autotroph with no dependencies on other specific organisms for growth or reproduction. It is a highly efficient forager/hunter that has highly refined

adaptations to allow for successful detection and capture of prey under a wide range of conditions. Species displays diet or isotopic niche plasticity across its current range.

Examples:

- Plant taxa that reproduce without pollinator assistance (i.e., wind pollinated) and do not otherwise require specific symbionts for growth.
- Round goby (*Neogobius melanostomus*) have been shown to have a broad and plastic diet (and isotopic niche) across invaded ranges in North America and Europe (Pettitt-Wade et al. 2015) allowing for exploitation of locally abundant food sources in invaded locations. In addition, this species also has a well-developed sensory system that enhances its ability to detect water movement, allowing it to feed in complete darkness and giving it an advantage over other fish in the same habitat.

3.05 How likely is it that the species could establish in Ontario despite potential competition from existing species?

Answer options: very unlikely, unlikely, moderately likely, likely, very likely, unknown

Level of uncertainty: low, medium, high

Note: This question evaluates whether the species would be capable of survival, successful growth, and reproduction if introduced within natural communities in Ontario, considering the presence of any or all pre-existing species that might compete for limiting food or habitat resources. Consider the potential for both direct (e.g., interference) competition, and indirect (e.g., apparent) competition between the organism and other species in Ontario that could result in reduced survival, recruitment, and/or per-capita growth rate. Take into account both the species' competitive ability within its existing range, as well as the existence of strong native competitors in Ontario that would share a similar niche. It is also important to note whether shared or common resources are, in fact, limited.

Suggested rating guidance:

Very unlikely: The species is a very poor competitor for limiting resources in its existing range and is known to have strong competitors that are very widely distributed and very abundant in Ontario, or another species is already very widely distributed in Ontario that occupies the same niche as the organism.

Example:

- A small, timid benthic fish species that would occupy the same niche and be dependent on the same habitats as those occupied by the highly aggressive and widespread round goby.

Unlikely: The species is a poor competitor for limiting factors in its existing range, and is known to have competitors that are widely distributed and abundant in Ontario or another species is already widely distributed in Ontario that occupies the same niche as the organism.

Example:

- A slow-growing, small submerged aquatic plant that only exists in small, sparse patches in its existing range and requires significant light penetration throughout the growing season (i.e., it could only establish in areas devoid of faster growing, or canopy forming taxa).

Moderately likely: The species is known to have competitors that are locally distributed and occasionally common in Ontario or another species is locally distributed in Ontario that occupies the same niche as the organism.

Likely: The species is a good competitor in its existing range. Even if the species has potential competitors in Ontario, these are rare or are unlikely to prevent establishment. Other species present in Ontario occupying the same niche are rare.

Examples:

- A species that (while not necessarily competitively dominant in its existing range) is taxonomically distinct from existing species in Ontario and occupies a unique niche, or is able to exploit a novel resource that is present but currently unused by other species in Ontario.
- Plant taxa that can survive in oligotrophic conditions or flourish in eutrophic conditions.

Very likely: The species is aggressively competitive for limiting factors in its existing range. Even if the species has potential competitors in Ontario, or if other species are present that occupy a similar niche, these are very rare and very unlikely to prevent establishment. The species can exploit resources that are not used by other species, or resources that would potentially be shared with existing species in Ontario are abundant and not limiting. For plant taxa, those that can fix nitrogen, are allelopathic, display fast growth, or form large dense canopies, floating mats, or monospecific stands that prevent light penetration for other aquatic plants would have a competitive advantage.

Examples:

- Hydrilla (*Hydrilla verticillata*) is highly competitive with most other aquatic plants, and is able to outcompete native submerged plants for light and nutrients as a result of its aggressive growth habit which intercepts sunlight and excludes other plants.
- The round goby (*Neogobius melanostomus*) is a highly aggressive competitor that has been shown to successfully outcompete other benthic fish species (such as sculpins) for food, space and spawning sites, resulting in the displacement and population declines of other species.

3.06 How likely is it that the species could establish in Ontario despite the presence of natural enemies (i.e., predators/herbivores/parasites or pathogens)?

Answer options: very unlikely, unlikely, moderately likely, likely, very likely, unknown

Level of uncertainty: low, medium, high

Note: The purpose of this question is to identify whether the species would be capable of survival, successful growth, and reproduction if introduced within natural communities in Ontario, considering the presence of any or all pre-existing species that might feed upon/parasitize or be pathogenic to it (any such species are broadly defined here as natural enemies). Take into account the number of potential enemy species in Ontario, their population densities, and their effectiveness as herbivores, predators or parasites. Consider predator-avoidance or herbivore-deterrent adaptations, or disease resistance possessed by the species in its existing range, as well as the life-stages of the species that would be susceptible to natural enemies.

Suggested rating guidance:

Very unlikely*:* The ability of one or more natural enemies to prevent establishment (or limit population sizes) of the species where it is native or introduced is well-documented and this enemy is very abundant and widespread in Ontario. The species is not known to possess adaptations for predator or herbivore avoidance, and all life stages are highly susceptible to predation/herbivory. The species is naïve to piscivores or other common predators in Ontario. The species possesses no immunity to, and is highly vulnerable to common parasites or pathogens.

Unlikely: The ability of one or more natural enemies to prevent establishment (or limit population sizes) of the species where it is native or introduced is suggested in the literature and this enemy is abundant in Ontario.

Moderately likely: There have been only a few cases reported of an existing natural enemy preventing or limiting the establishment of the species elsewhere, or known natural enemies have low abundance in Ontario. Potential natural enemies exist in Ontario, but these have not been conclusively shown to effectively prevent establishment or limit population size of the species.

Likely: The species has few natural enemies capable of preventing establishment or limiting population size, and these or similar species are rare in Ontario. The species is unpalatable to or is unrecognized as a food source by most grazers in Ontario. The species can attain large sizes, thereby reaching a size refuge from most potential gape-limited piscivorous predators (i.e., the period of vulnerability to predation is relatively short).

Very likely: Owing to effective predator-avoidance, herbivore-deterrent adaptations, or immunity to common pathogens or parasites, the species has very few natural enemies capable of preventing establishment or limiting population size in its existing range, and these or similar species are not present in Ontario. The species is unpalatable or toxic to existing predators or grazers. The species grows quickly to attain very large sizes thereby reaching a size refuge from all existing gape-limited piscivorous predators (i.e., the period of vulnerability to predation is very short).

3.07 Reproduction

Life history characteristics will directly influence a species' ability to reproduce and establish a self-sustaining population in a new area. Consequently, knowledge of the species' reproductive strategy is critical in order to evaluate its potential for establishment.

3.07 How likely is it the reproductive strategy of the species to aid or promote its establishment in Ontario?

Answer options: very unlikely, unlikely, moderately likely, likely, very likely, unknown

Level of uncertainty: low, medium, high

Note: Consider reproductive characteristics that would enable the species to reproduce effectively in a new environment. This does not include consideration of the species, dependence on other species or on specific habitat features for successful reproduction (these factors were evaluated previously in questions 3.0 and 3.04).

Answer the following 10 sub-questions either yes or no (some may not be appropriate for the taxon being considered; these should be identified and do not need to be answered). These sub-questions aim to ascertain whether the species possesses reproductive strategies/traits associated with establishment success for various taxa.

1) Can the species produce viable seeds/spores/offspring?

Consider whether individuals are likely to be sterile as a result of chromosome set manipulations, etc.

2) Could the species establish or maintain a viable population with a relatively low number of founding individuals or inoculums?

Allee effects, environmental or demographic stochasticity, competition and natural enemies may prevent population survival if only a small number of individuals are present. Conversely, the production of long distance attraction substances (i.e., pheromones) would considerably improve the probability of finding a mate even when densities are low (Vélez-Espino et al. 2010).

3) Does the species exhibit parental care (i.e., nest guarding, mouth brooding, live bearing)?
4) Is the species known to reduce age-at-maturity in response to environment?
5) Is the species capable of sexual reproduction at least once per year?
6) Is the species iteroparous (i.e., capable of more than one reproductive event in its lifetime), or does it have an extended spawning season?
7) Is the species highly fecund (fish: >10,000 eggs/kg [Copp et al. 2005]; freshwater molluscs: >162 offspring/female/yr [Keller et al. 2007]; plants: >1,000 seeds or spores/yr [Heffernan et al. 2001])?
8) Is the species' known generation time (i.e., time from hatching to full maturity) one year or less?
9) Is asexual reproduction (e.g., vegetative reproduction/fragmentation, self-fertilization, self-crossing, parthenogenesis) an important aspect of the species' reproduction?
10) Does the species have a resting or dormant stage during its life cycle that can be used to survive environmental conditions that are unsuitable for growth and development?

    Consider whether the species create a persistent seed bank (i.e., seeds remain highly viable for >3 years) or an offspring bank (e.g., resting eggs of the spiny waterflea).

Suggested rating guidance:

Very unlikely: no to all questions

Unlikely: yes to only one question

Moderately likely: yes to two questions

Likely: yes to three questions

Very likely: yes to four or more questions

Unknown: Insufficient information to answer yes or no to any of the questions

3.08 History of introductions/establishment/invasiveness elsewhere

Invasion history consistently emerges as one of the strongest predictors of establishment success in new environments (e.g., Gordon et al. 2008; Hayes and Barry 2008; Koop et al. 2012). If successful establishment outside of the species' native range has happened even once before, it is important evidence that the species has the ability to pass through most of the stages in the invasion process (i.e., association with the pathway at origin, survival in transit, transfer to the habitat at arrival, and successful establishment). If this has occurred often, it suggests an aptitude for transfer and establishment.

Propagule pressure (i.e., the number of individuals introduced) is also an important determinant of establishment success (Blackburn et al. 2015; Lockwood et al. 2009; Bradie and Leung 2015). In the absence of precise measures of propagule pressure for most taxa, a species' history of introductions/ establishment/ invasiveness elsewhere can serve as a proxy (e.g., Bomford et al. 2010; García-Berthou 2007; Jeschke and Strayer 2006). This can be quantified as the number of continents/countries/states/ provinces where introduction and establishment (or invasion) has occurred (Kolar and Lodge 2002, Copp et al. 2005, Moyle and Marchetti 2006, Bomford et al. 2010; Howeth et al. 2015).

3.08 How widely has the species been introduced and become established/invasive in areas outside of its native range?

Answer options: never, not widely, moderately widely, widely, very widely, unknown

Level of uncertainty: low, medium, high

Note: If possible, identify the number of instances (e.g., continents/countries/states/provinces) where the species has been reported to be successfully introduced and established or invasive.

Consider the species' distribution within the eleven biogeographic realms shown in Figure 1 (Nearctic, Panamanian, Neotropical, Palearctic, Saharo-Arabian, Afrotropical, Sino-Japanese, Oriental, Australian, Madagascan, and Oceanian realms).

Figure 1*: The eleven large biogeographic realms. Map by: University of Copenhagen.*

Suggested rating guidance:

Never*:* There have been no reports of the species having been introduced to or becoming established or invasive anywhere outside of its native range.

Not widely: The species has been reported as being introduced to/established or invasive in 1–2 countries/states/provinces outside of its native range, but within its native biogeographic realm.

Moderately widely: The species has been reported as being introduced to/established or invasive in 3–5 countries/states/provinces outside of its native range, but within its native biogeographic realm.

Widely: The species has been reported as being introduced to/established or invasive in 6–8 countries/states/provinces and/or in 1 or 2 biogeographic realms outside of its native realm.

Very widely: The species has been reported as having been introduced to/established or invasive in at least nine countries (Bomford et al. 2010), states, or province and/or has become established in 3 or more biogeographic realms outside of its native realm.

Stage 4: Probability of spread

Introduction: A species' ability to disperse or spread from its original area of introduction is a primary determinant of invasive ability (McAlpine and Jesson 2007); invasion rate is directly related to dispersal (Ruesink 1995). The more extensively an invasive species can expand its distribution, the greater its capacity for ecological impacts. The potential for widespread invasion ultimately depends on the extent of suitable habitat for the species, but is further governed by its ability to reach these habitats. Species can move to new areas through natural dispersal ability (which can be either active or passive) and/or through human-assisted transport (which can be either intentional or unintentional). The purpose of this section is to evaluate the likelihood that the species could become widespread in waterbodies across Ontario.

4.01 Maximum potential distribution in Ontario

4.01 How extensive is the distribution of aquatic habitats that would be suitable for the survival and establishment of the species in Ontario? (Based on the general habitat preferences of the organism described in SECTION 1, and the climate, habitat, and resource requirements of the organism considered in Stage 3)

Answer options: very limited, limited, moderately extensive, extensive, very extensive, unknown

Level of uncertainty: low, medium, high

Note: This question aims to delimit the overall potential area for establishment of the species in Ontario, i.e., the maximum distribution of suitable habitats in the province. Do not consider whether the species could spread/be introduced across all available habitats, as this will be evaluated in subsequent questions.

Consider the abundance, distribution and connectivity of waterbodies with suitable climate/habitat/resources within the province. For parasitic/symbiotic species consider the distribution of potential host species.

The proportion of waterbodies in areas with suitable climate for the species can be coarsely estimated by visual estimation of the percent of the total area of the province with Climatch scores greater than 7. Knowledge of the distribution or abundance of waterbodies having more specific habitat requirements for the species can refine estimates of available habitat. Select an uncertainty rating according to the degree of relevant habitat data available.

Suggested rating guidance:

Very limited: Less than 1% of the waterbodies in the province would provide suitable climate, habitat, and/or other necessary resources for the species. Less than 1% of the province has Climatch scores of at least 7, or species requires specific host or prey species whose distribution is limited to less than 1% of the province. Coarse-level climate comparison may reveal that none of the province provides suitable climatic conditions for the organism, though there may be climatic refugia in some locations (but these are extremely localized and/or rare).

Example:

- Most tilapia spp. cannot survive below 8–12°C such that climate (i.e., temperature minima) in Ontario would not be considered suitable for survival or establishment. Thermal refugia for these fish may exist but are rare and limited to very localized areas (e.g., heated water/thermal effluent plumes discharged from power plants on Lake Ontario, Lake Erie, Lake Huron, and the St. Clair River).

Limited: Only 1–5% of waterbodies in the province would provide suitable climate, habitat and/or other necessary resources for the species. Only 1–5% of the province has Climatch scores of at least 7, or, broad climate match exists throughout the province but the species requires highly specialized habitat to fulfill certain life stages that are rarely occurring in the province or species requires specific host or prey species whose distribution is limited to 1–5% of the province

Example:

- Species has sufficient climate matching with southern Ontario, but requires long stretches of large, unimpounded river reaches to complete its life cycle (unimpounded rivers are largely restricted to northern Ontario).

Moderately extensive: 5–10% of waterbodies in the province would provide suitable climate, habitat and/or other necessary resources for the species. Only 5–10% of the province has Climatch scores of at least 7, or, species requires specific host or prey species whose distribution is limited to 5–10% of the province.

Extensive: 10–25% of waterbodies in the province would provide suitable climate, habitat and/or other necessary resources for the species. 10–25% of the province has Climatch scores of at least 7 and the species displays broad physiological tolerance or is a habitat generalist, or, broad climate match but other factors would limit distribution to 10–25% of the province

Example:

- Zebra mussel (*Dreissena polymorpha*) distribution is limited to lakes with pH >6.9 and calcium ion concentrations greater than 10.0 mg/L , which in Ontario are generally limited to the region south of the Canadian Shield.

Very extensive: More than 25% of waterbodies in the province would provide suitable climate, habitat, and/or other necessary resources for the species. Climate matching analysis reveals that more than 25% of the province has a high climate match (e.g., Climatch scores of at least 7) and species displays broad physiological tolerance and/or is a habitat generalist capable of thriving in a variety of aquatic habitat types.

Example:

- Shield lakes in Ontario share similar climates and water chemistry to those in northern Europe where the spiny water flea (*Bythotrephes longimanus*) is highly prevalent. It has therefore been hypothesized that many thousands of these lakes in Ontario have the potential to support this species.

4.02 Natural dispersal

4.02 What is the species' capacity to disperse within Ontario by natural means?

Answer options: very low, low, moderate, high, very high, unknown

Level of uncertainty: low, medium, high

Note: Natural means for dispersal include active dispersal (via the organism's own capacity for movement; e.g., natural migration or rhizomal growth/vegetative spread) and passive dispersal (e.g., via water currents, wind, or through attachment or ingestion by insects, birds, or other animals). For plant taxa, spread by stem or stolon fragments would only be considered natural dispersal if the plant has a natural mechanism for fragmentation (i.e., fragmentation does not occur solely as a result of anthropogenic activity).

Consider dispersal modes and maximum dispersal distances for all life stages of the species (for animals: eggs, larvae/veligers, juveniles, adults; for plants: seeds, fruits, other plant structures). The likelihood of spread via natural dispersal will also be determined by the intrinsic rate of increase of the species (fecundity, survivorship, and development rate).

Consider the degree of isolation of breeding sites, the presence of natural or man-made barriers to movement, and/or whether suitable water bodies (or connected habitats) are subject to regular periodic flooding events that would promote natural routes of

dispersal. Finally consider whether the species inhabits open fast flowing water bodies, or closed water bodies.

The species' capacity for natural dispersal can be assessed in terms of reported dispersal distances, or population growth rates. Several types of data can be used, including field dispersion data (i.e., records of known migration distances), local reports of new populations or expansion within the species' current range (i.e., apparent rate of dispersal), or information on the time required for the species to successfully double its number in a discrete population or an affected area.

Suggested rating guidance:

Very low: Species has very minimal ability to spread naturally. Individuals have only been known to disperse or cover distances less than 50 m per year and/or populations expand at a rate of less than 10 m per year (D'hondt et al. 2014). This is more likely the case for immobile species (e.g., plants) that do not have life stages or structures that can be dispersed passively.

Example:

- Plant with large heavy seeds that are negatively buoyant, and have never been documented to attach or be ingested and dispersed by other organisms.

Low: Local dispersal only, not able to spread beyond original water body or current area (Government of Alberta 2008). Individual dispersal distances 50–500 m per year and/or population range expansion of 10–100 m per year (D'hondt et al. 2014).

Example:

- Plants that do not produce seed and spread only by creeping rhizomes.

Moderate: Individual dispersal distances 500 m–5 km per year and/or population range expansion of 100 m to 1 km per year (D'hondt et al. 2014). Infrequent or inefficient long-distance dispersal or adaptations exist for long-distance dispersal, but studies report that most individuals (90%) establish territories within 5 miles (i.e., ~8 km) of natal origin or within a distance twice the home range of the typical individual, and tend not to cross major barriers such as dams and watershed divides (Jordan et al. 2008).

Example:

- Despite the large body size of adult wels catfish (*Silurus glanis*), this species is non-migratory and individuals tend to remain highly localized within core areas or home ranges. The maximum distance travelled from resting places of individuals in the Ebro River was 736 m upstream and 767 m downstream, although such excursions were rare and of limited duration (Carol et al. 2007).

High: Regional dispersal; species has the potential to invade neighboring water bodies or spread up to 100 km in a single dispersal event (Government of Alberta 2008). Typical individual dispersal distances range from 5–50 km per year and/or population range expansion of 1–10 km per year (D'hondt et al. 2014).

Very high: Ability to spread beyond neighboring waterbodies and over very broad distances, including (but not limited to) the ability to cross major barriers such as dams (both upstream and downstream) and watershed divides. Species has numerous opportunities for and adaptations exist for long-distance dispersal or movement (e.g., species undergoes long-range migrations, or has adaptations such as hooked fruit-coats that allow for attachment to migratory birds etc.). Individual dispersal distances reported are >50 km per year and/or distance covered by the front of the organism's range (i.e., range expansion) is >10 km per year (D'hondt et al. 2014).

Examples:

- After the removal of critical barriers in potential invasions corridors (i.e., Main-Danube canal), the invasion of the killer shrimp (*Dikerogammarus villosus*) towards Western Europe was estimated to occur at an average spread speed of 112 km per year (Leuven et al. 2009).
- Plant taxa that are dispersed over long distances by birds or that can disperse over broad distances via wind-dispersed seed.

4.03 Human-assisted dispersal

4.03 What is the species' potential to be spread within Ontario by human activities?

Answer options: low, moderate, high, unknown

Level of uncertainty: low, medium, high

Note: Human-assisted spread or dispersal can occur both directly and indirectly. Consider all potential vectors for human-assisted spread that may occur in Ontario, including both direct (e.g., use as bait, aquaria release, deliberate illegal stocking or for pest control, deliberate release for cultural practices) and indirect vectors (entrainment/attachment on recreational or commercial boats or gear, entrainment in ballast water, aquaculture escapes, escape from garden ponds, contamination of bait buckets or of live bait catch). For all potential vectors, consider the frequency, timing, and numbers of individuals likely to be transported. It is also important to take into account the ease with which various life stages of the species can be transported, and the likelihood that these may be transported undetected or disguised. Indicate the

species' potential to disperse from (an) established population(s) within the province to vacant habitat patches, through human-mediated pathways.

This question is answered on a 3-point rather than a 5-point scale because it requires consideration of human behavioural patterns making it less straightforward to quantify/estimate than natural dispersal. A 3-point scale makes answer ratings more distinct (i.e., discrimination between answer options at a higher level of resolution would be difficult).

Suggested rating guidance:

Low: Human dispersal of the species to new areas occurs almost exclusively by direct means and is infrequent or inefficient. The probability that human-mediated dispersal could take any life stage of the species >50 km is expected to occur no more than once per decade (D'hondt et al. 2014). Individuals are not available for purchase (i.e., not in trade) and therefore very unlikely to be used as bait, or be released intentionally by aquarists or for cultural purposes. No life stages of the species have characteristics that would facilitate entrainment or attachment on recreational or commercial boating or fishing vehicles or equipment, or in ballast water and the species cannot survive out of water for any length of time. It is highly unlikely that the species would be present in areas where bait harvesting is conducted. The species is large and/or distinctive, is difficult to transport, and is very unlikely to be dispersed accidentally with other commodities.

Moderate: Human dispersal to new areas could occur by direct and indirect means to a moderate degree. Human-mediated dispersals events that could take any life stage of the species >50 km are expected to occur 1–9 times per decade (D'hondt et al. 2014).

High: Opportunities for human dispersal to new areas by direct and indirect means are numerous, frequent, and successful. Human-mediated dispersal events that could take any life stage of the species >50 km are expected to occur more than 10 times per decade (D'hondt et al. 2014). The species possesses characteristics that make entrainment or attachment on recreational or commercial boating or fishing vehicles or equipment highly probable and is capable of surviving out of water for extended periods of time. The species is inconspicuous and/or easily mistaken for other native species and is therefore likely to be dispersed accidentally with other commodities such as with harvested bait.

Stage 5: Magnitude of ecological impacts

Introduction: Non-native species can cause significant and sometimes irreversible impacts on recipient communities and ecosystems. Impact is defined as “a measureable change in the state of an invaded ecosystem that can be attributed to the [introduced] species” (Ricciardi et al. 2013). Ecological impacts can be measured across different scales: at the individual organism level (effects on growth, fitness, or mortality), population level (abundance, genetics), community level (composition, species diversity, richness, evenness, trophic structure), or ecosystem level (physical habitat, nutrient cycling, energy flow) (Ricciardi et al. 2013).

A predictive understanding of when, how, or where impacts of an introduced species are likely to occur has yet to be achieved (Kumschick et al. 2014). Relatively few studies have explicitly quantified the effects of non-native species on recipient communities (see Nienhuis et al. 2014) and very little empirical data on the ecological impacts of aquatic invasive species are available (reviewed in Jeschke et al. 2014; García-Berthou 2007). As a result, the impacts of invasive species on native populations, communities and ecosystems remain largely unknown or poorly understood.

The type and direction of many impacts can be forecasted from a species’ history of impacts elsewhere, but estimates of the magnitude of projected impacts are likely to be associated with a significant amount of uncertainty. To support estimates of potential impacts it is preferable to cite published impact reports from areas that are climatically and ecological similar to Ontario or from nearby geographic regions. If these do not exist, evidence of impacts from other areas of the species’ invaded range (or at the very least from its native range) can be used, but with a higher degree of uncertainty.

To assess potential impact, consider the impact of the species if it were to become abundant or widespread in Ontario. In this section, the difference between actual or potential distribution is not considered; the estimated magnitude of impact is area- or scale-independent (van der Veer and Nentwig 2015; Nentwig et al. 2010). Establishment and spread potential are assessed in previous sections, and these ratings are combined with the estimated magnitude of potential impacts using the accompanying modelling tool (SECTION 3).

For the purpose of this risk assessment, only ecological impacts are considered. Neither socio-economic impacts nor potential benefits of an introduction are assessed or evaluated.

The rating criteria defined here largely conform to the unified classification system outlined in Blackburn et al. (2014), which is based on the Generic Impact Scoring

System (GISS [Nentwig et al. 2010, Kumschick et al. 2012]). This system aligns with the impact scheme of the Global Invasive Species Database (GISD) implemented by the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) Invasive Species Specialist Group (Blackburn et al. 2014). Five broad but discrete impact mechanisms are defined: competition, predation/herbivory/parasitism, hybridization, disease/parasite transmission, and impacts to ecosystem structure/function.

For each impact mechanism, one of five sequential categories of impact is selected: Minimal, Minor, Moderate, Major, and Massive. These categories reflect increasing magnitudes of impact from the level of individual fitness, to the population level, and to the community level. Impact criteria for the different categories are based on the following general definitions, as presented in Blackburn et al. (2014):

Minimal: no effect on fitness of individuals of native species

Minor: causes reductions in individual fitness, but no declines in native population densities (or size)

Moderate: causes declines in population densities (or size), but no changes in community composition

Major: causes changes in community composition, which are reversible if the (introduced organism) is removed

Massive: causes at least local extinction of species, and irreversible changes in community composition; even if the (introduced organism) is removed the system does not recover its original state.

In the more specific guidance provided below, higher impact ratings are selected if the species has the potential to negatively affect species or ecosystems that are of conservation concern, e.g., provincially or federally listed species at risk, or globally outstanding ecoregions (Ricketts et al. 1999).

If any of the impact mechanisms do not apply to the species being assessed, score the impact as Minimal with Low uncertainty.

Notes on impact scoring and uncertainty ratings:

It is important to explicitly note the type of evidence used to inform the answers and uncertainty levels. The following information is relevant to include in answer justification:

The breadth and level of documentation of available impact studies

- Studies reporting quantitative information for widespread invasive species are often conducted in only a small portion of the species' invaded range (Kulhanek et al. 2011). This could hinder generalization to other invaded regions, (given substantive spatial variation in observed impacts [Ricciardi and Kipp 2008]). Data from multiple invaded sites across environmental gradients would be more useful for predicting particular types of impact (Ricciardi et al. 2013).

The local physical (climate, habitat) and ecological (species identity, community composition) context of any cited reports or impact studies

- A species' impacts in one region cannot necessarily be predicted from impacts in another.
- The outcome of invasions often depends on the diversity of functional groups in the receiving, native community. The presence of functionally similar native species (i.e., that share morphological or physiological traits) can be important in invasion resistance (Pokorny et al. 2005). Conversely, functional distinctiveness of an introduced species can enhance its impact "through novel resource use and exposure to ecologically naïve residents or by introducing new ecosystem functions" (Kumschick et al. 2014). Taxonomic or phylogenetic distinctiveness of the introduced species may serve as proxy parameters of functional distinctiveness (Ricciardi and Atkinson 2004; Strauss et al. 2006).

The experimental design and study location

- Well-designed and replicated experimental studies (e.g., before-after-control-impact design) provide more rigorous and scientifically defensible findings than correlational or simple observation studies.
- Experiments conducted in controlled or laboratory environments may not fully reflect variation in impact severity under natural conditions (Kulhanek et al. 2011).

The time period and spatial scale over which impact studies elsewhere were conducted

- Impact studies conducted at small scales or over long periods of time are likely to show stronger impacts than those conducted at larger spatial scales, and over shorter time periods (e.g., Gaertner et al. 2009).
- An introduced species can been present in an area for decades with no observable impact. A lag phase following introduction or ecosystem changes as a result of other stressors can mean that impacts may only become apparent at a later time (Sakai et al. 2001, cited by Wittmann et al. 2014).

5.01>5.05 Potential mechanisms of ecological impact

5.01 What impact is the species having or likely to have as a result of competition with native species in Ontario?

Answer options: minimal, minor, moderate, major, massive, unknown

Level of uncertainty: low, medium, high

Note: Consider the potential for both direct (e.g., exploitative or interference) and indirect (e.g., apparent) competition for one or more limited resources (e.g., food, sunlight, nutrients, habitat/space, pollinators, hosts, etc.). Competition also includes the release of chemical compounds that have antagonistic (or allelopathic) effects on other species.

Assess whether competition could result in reduced individual fitness (e.g., growth, reproduction, defence), survival or recruitment, cause population declines or extinction of native species (or valued naturalized species), and/or alter community composition (e.g., species diversity, evenness, dominance, etc.) in Ontario. Select higher impact ratings if there is evidence that the organism could have negative impacts on species of conservation concern (i.e., a provincially or federally listed species at risk).

Do not consider subsequent impacts to habitats or ecosystem processes (these are addressed separately in Q.5.05).

Competition among species is complex and ecosystem-specific. Predictive indicators of competitive success can be difficult to identify, corresponding to a higher level of uncertainty.

Suggested rating guidance:

Minimal impact: Negligible level of competition with native species is anticipated; no detectable reduction of fitness of native individuals is likely.

Minor impact: Competition has the potential to affect fitness of native individuals, but is not likely to cause a decline in their populations.

Example:

- While population declines were not noted, measurable declines in yellow perch (*Perca fluvescens*) growth in western Lake Michigan have been attributed to exploitative and competitive interference from round goby for food and habitat resources (Houghton 2015).

Moderate impact: Competition is likely to result in a decline in population size of at least one native species (that is not of conservation concern), but would not result in changes in community composition.

Example:

- Recruitment of brown trout (*Salmo trutta*) in Norwegian lakes has been negatively affected by competition with introduced common minnow (*Phoxinus phoxinus*) (Borgstrøm et al. 1996), resulting in population declines (Museth et al. 2007).

Major impact: Competition is likely to result in local or population extinction of at least one native species (that is not of conservation concern) leading to changes in community composition, but changes would be reversible if the non-native organism was removed or competition could result in population decline of a species of conservation concern.

Examples:

- Allelopathic weeds often have a competitive advantage and are more likely to cause longer term ecosystem and community alterations (Pheloung et al. 1999, cited by Carlson et al. 2008).
- The local extinction of mottled sculpin (*Cottus bairdi*) in Calumet Harbor, southern Lake Michigan as a result of recruitment failure has been attributed to competition (i.e., spawning interference) with the invasive round goby (*Neogobius melanostomus*) (Janssen and Jude 2001).
- Eastern mosquitofish (*Gambusia holbrooki*) has been shown to negatively impact the survival of two native toothcarp species through exclusion interference (i.e., competition for food resources), and its introduction is presumed to be the principle cause of population declines of these two species (one of which is categorized as endangered) in the Iberian Peninsula (Caiola and Sostoa 2005).

Massive impact: Competition is likely to result in replacement or local extinction of one or more native species and lead to irreversible changes in community or would result in local extinction of at least one species of conservation concern.

Example:

- Throughout its invasive range in northeastern North America, the European water chestnut has been documented to be replacing native macrophytes and their associated foodwebs (Ding and Blossey 2005). In the tidal Hudson River, the invasion of European water chestnut has been implicated in the loss of several other native, submerged macrophyte species (Kiviat 1993; Hummel and Findlay 2006).

5.02 What impact is the species having or likely to have as a result of predation, herbivory, and/or parasitism upon native species in Ontario? *This question could also be applied to cases where the species is expected to have impacts through poisoning or toxicity.*

Answer options: minimal, minor, moderate, major, massive, unknown

Level of uncertainty: low, medium, high

Note: Assess whether predation/herbivory/parasitism could result in reduced individual fitness (e.g., growth, reproduction, defence), survival or recruitment, cause population declines or extinction of native species (or valued naturalized species), and/or alter community composition (e.g., species diversity, evenness, dominance, etc.) in Ontario. Predation/herbivory could be direct or indirect (e.g., through mesopredator release, whereby the removal of top predators causes increased populations of medium-sized predators). Select higher impact ratings if there is evidence that the organism could have negative impacts on species of conservation concern (i.e., a provincially or federally listed species at risk).

Consider whether the species would predate native species previously subjected to low (or no) predation, whether native species possess predator-avoidance or herbivore-deterrent adaptations, and which life-stages of native species would be susceptible. Also consider whether predators are specialists or generalists. The effects of generalist predators on a community are generally greater than that of specialists (Symondson et al. 2002), although in some cases "a strong dependence on specific prey species could be a risk to food web stability following invasion" (Ricciardi 2001). In the case of parasites, consider whether they are specialists (i.e., dependant on specific host species) and whether native species in Ontario would be vulnerable.

Do not consider subsequent impacts to habitats or ecosystem processes (these are addressed separately in Q.5.05).

Suggested rating guidance:

Minimal impact: There is likely to be no or only a negligible level of predation/herbivory/parasitism on native species; reduction of fitness of native individuals is not likely to be detectable.

Example:

- Most plant taxa would have no impact on native species through predation or herbivory (unless it is a carnivorous aquatic species (e.g., bladderworts *Utricularia* sp. or the waterwheel plant [*Aldrovanda vesiculosa*]).

Minor impact: Predation/herbivory/parasitism has the potential to affect fitness of native individuals, but is not likely to cause a decline in their populations.

Moderate impact: Predation/herbivory/parasitism is likely to result in a decline in population size of at least one native species (that is not of conservation concern), but would not result in changes in community composition.

Major impact: Predation/herbivory/parasitism is likely to result in local or population declines/extinction of at least one native species (that is not of conservation concern) leading to changes in community composition, but changes would be reversible if the non-native species was removed or competition could result in population decline of a native species of conservation concern (i.e., a provincially or federally listed species at risk). If the species acts as a major predator on native species with few natural predators, this would also be a significant impact (Copp et al. 2005).

Examples:

- Direct predation on larval yellow perch by invasive alewife (*Alosa pseudoharengus*) contributed to reduced recruitment of the native species throughout the 1990s in Saginaw Bay, Lake Huron. Following the collapse and disappearance of alewife in 2003, perch reproduction and age-0 abundance increased. However, small perch then become forage for increasing populations of walleye which has prevented the abundant juvenile perch from surviving. Thus, owing to the complex ecological changes brought about by the invasion and collapse of alewife, the fundamental role of native perch in the food web has changed from that of a secondary predator to primarily that of a forage fish, a shift that has changed yellow perch abundance and growth throughout the bay.
- Norwegian lakes to which common minnow (*Phoxinus phoxinus*) has been introduced have experienced a marked decline in benthic invertebrate diversity through predation (Næstad and Brittain 2010).

Massive impact: Predation, herbivory, or parasitism is likely to result in replacement or local extinction of one or more native species (i.e., species vanish from communities at sites where they occurred before the organism arrived), and lead to irreversible changes in community or would result in local extinction of at least one species of conservation concern.

Example:

- The parasitic, invasive sea lamprey (*Petromyzon marinus*), was a major cause in the collapse of lake trout (*Salvelinus namaycus*), lake whitefish (*Coregonus clupeiformis*), and chub populations in the Great Lakes during the 1940s and 1950s and has also led to the extinction of three endemics in the Great Lakes:

the longjaw cisco (*Coregonus alpenae*), the deepwater cisco (*C. johannae*), and the blackfin cisco (*C. nigripinnis*).

5.03 What impact is the species having or likely to have as a result of hybridization with native species in Ontario?

Answer options: minimal, minor, moderate, major, massive, unknown

Level of uncertainty: low, medium, high

Note: Hybridization or introgression with non-native species can impact the genetic integrity, individual fitness, and/or population size of native species. Hybrid offspring could have genetic benefits relative to non-hybrids allowing them to outcompete native populations. This could lead to population declines or the replacement of native genotypes. Hybrid progeny could also reproduce with non-hybrids, reducing and diluting the presence of native alleles within the population (Rhymer and Simberloff 1996).

Evaluate whether hybridization could result in reduced individual fitness (e.g., growth, reproduction, defence), survival or recruitment, cause population declines or extinction, and/or alter community composition (e.g., species diversity, evenness, dominance, etc.). Higher impact ratings should be selected if there is evidence to suggest that the organism will have negative impacts on species of conservation concern (i.e., a provincially or federally listed species at risk).

Suggested rating guidance:

Minimal impact: Very little or no hybridization with native species likely; reduction of fitness of native individuals is not likely to be detectable.

Example:

- The species has no taxonomically close relatives in Ontario.

Minor impact: Hybridization has the potential to affect fitness of native individuals, but is not likely to cause a decline in their populations. Hybridization events between the introduced and native species may occur, but only rarely. Hybrids would be weak and would not be expected to reach maturity (reduced hybrid viability), with no decline of pure native populations (Blackburn et al. 2014).

Moderate impact: Hybridization would cause a decline in population size of at least one native species (that is not of conservation concern), but would not result in changes in community composition.

Hybridization is likely to occur, and hybrids are vigorous but sterile (reduced hybrid fertility), with limited gene flow between introduced and native populations. This could cause local declines in populations of pure native species, but pure native species would still persist (Blackburn et al. 2014).

Major impact: Hybridization is likely to result in local or population declines or extinction of at least one native species (that is not of conservation concern) leading to changes in community composition, but changes would be reversible if the non-native organism was removed or competition could result in a decline in population size of a native species of conservation concern (i.e., a provincially or federally listed species at risk). Hybridization between the introduced and native species is likely to occur in the wild and F1 hybrids are vigorous and fertile, but offspring of F1 hybrids are weak and sterile (hybrid breakdown, limiting gene flow between introduced and native populations (Blackburn et al. 2014). Individuals of introduced species and hybrids would be discernible from pure natives, and pure native populations could be recovered by removing introduced individuals and their offspring (Blackburn et al. 2014).

Massive impact: Hybridization is likely to result in replacement or local extinction of one or more native species (i.e., species would vanish from communities at sites where they occurred before the introduced species arrived), and lead to irreversible changes in community or would result in local extinction of at least one species of conservation concern. Hybridization between the introduced organism and native species would occur commonly in the wild, and hybrids are fully vigorous and fertile (Blackburn et al. 2014). Pure native species could not be recovered by removing the introduced species, resulting in replacement or local extinction of native species by introgressive hybridization (genomic extinction) (Blackburn et al. 2014).

Example:

- The hybrid watermilfoil is capable of reproducing both vegetatively and sexually (LaRue et al. 2013a). LaRue et al. (2013a) demonstrated that several populations of hybrid watermilfoils in Michigan produced seed that successfully germinated under laboratory conditions. Hybrid watermilfoils are more aggressive and invasive than either of the parental lineages, and exhibit faster and denser growth than the exotic parent Eurasian watermilfoil (*Myriophyllum spicatum*) (LaRue et al. 2013b). It is difficult to manage this species, as herbivory is altered in hybrid populations and biocontrol may be less effective (Moody and Les 2007), and the hybrid watermilfoils exhibit tolerance to several popular aquatic herbicides (Berger et al. 2015).

5.04 What impact is the species having or likely to have as a result of transmission of diseases/pathogens or parasites to native species in Ontario?

Answer options: minimal, minor, moderate, major, massive, unknown

Level of uncertainty: low, medium, high

Note: Evaluate the potential for impacts from disease or parasite transmission on native animal or plant species in Ontario that could result in reduced individual fitness (e.g., growth, reproduction, defence, immunocompetence), survival or recruitment, or that could cause population declines or extinction, and/or result in changes in community composition (e.g., species diversity, evenness, dominance, etc.). Higher impact ratings should be selected if there is evidence to suggest that the species will have negative impacts on species of conservation concern (i.e., a provincially or federally listed species at risk).

Identify diseases/pathogens or parasites that the species is known host, and whether these would be likely to affect individuals or populations of native species in Ontario. Pathogens or parasites may be of viral, bacterial, fungal or animal origin, and may either be endemic (i.e., already present in Ontario) or emerging (new or novel). Note if the species is a host or vector for notifiable diseases on the list maintained by the World Organisation for Animal Health (OIE) (oie.int/animal-health-in-the-world/oie-listed-diseases-2016).

Consider whether the species acts as a host or vector of existing or emerging pests. As a host, the introduced species could provide additional resources on which a known pest may feed, live and/or reproduce, potentially allowing existing pests to expand in range or population size (Government of Alberta 2008). As a vector, the introduced species could promote transfer of existing pathogens and parasitic organisms and increase the likelihood of exposure of native species to existing pests (Government of Alberta 2008).

Suggested rating guidance:

Minimal impact: The species is known to host various pathogens or parasites, but none are known or suspected to be shared with a native species in Ontario (i.e., the species is not a host of diseases or parasites that are suspected to be transmissible to native species or level of transmission is expected to be very low). A reduction in the fitness of native individuals is not likely to be detectable.

Minor impact: The species shares at least one known pathogen or parasite with one or more native species and transmission may affect fitness of native individuals, but would not be expected to cause declines in their populations.

Moderate impact: The species shares at least one known pathogen or parasite with one or more native species and transmission is likely to result in a decline in the population size of at least one native species (but not a species of conservation concern), but no changes in community composition are expected.

Example:

- (From: Great Lakes Aquatic Nonindigenous Species Information System 2015) "[The Topmouth Gudgeon] Pseudorasbora parva has 84 parasite species…typically zoosporic fungi…parasites such as Diplostomum spataceum…and viruses such as fry rhabdovirus (PFR)…The PFR virus, which causes acute disease of Esox Lucius fry, has been isolated from P. parva. The two most severe parasites found associated with P. parva in its invasive range are Anguillicola crassus and rosette agent Sphaerothecum destruans…These parasites if carried over after introduction could have destructive impacts on similar native Great Lakes species."

Major impact: The species shares at least one known pathogen or parasite with one or more native species and transmission is likely to result in local or population extinction of at least one native species (but not a species of conservation concern), leading to changes in community composition, but changes would be reversible if the non-native species was removed or transmission of disease could result in a decline in population size of a native species of conservation concern (i.e., a provincially or federally listed species at risk).

Massive impact: The species shares at least one known pathogen or parasite with one or more native species and transmission of shared pathogens or parasites to native species is likely to result in replacement or population extinction of at least one native species (which could include a species of conservation concern) leading to irreversible changes in community composition.

5.05 What impact is the species having or likely to have in Ontario as a result of alteration of habitats or ecosystem processes?

Answer options: minimal, minor, moderate, major, massive, unknown

Level of uncertainty: low, medium, high

Note: Consider the species' potential to cause changes in the chemical, physical and/or structural characteristics of aquatic habitats as well as its potential to alter ecosystem processes (e.g., nutrient cycling or sedimentation rates), energy flow, disturbance regimes and/or natural succession, or cause regime shifts. These changes could arise through one or more of the impact mechanisms considered above (e.g., competition, predation, hybridization, transmission of disease).

Assess whether potential habitat or ecosystem changes could result in reduced individual fitness (e.g., growth, reproduction, defence), survival, or recruitment, cause population declines or extinction, and/or result in changes in community composition (e.g., species diversity, evenness, dominance, etc.) in Ontario. Higher impact ratings should be selected if there is evidence to suggest that the species will have negative impacts on species of conservation concern (i.e., a provincially or federally listed species at risk).

Impacts of an introduced species on habitats and ecosystem processes can often be difficult to quantify or disentangle from other interacting factors and may be reported far less frequently in the literature than more obvious/recognizable impacts (Hayes and Sliwa 2003). The uncertainty level selected for the answer to this question should reflect these types of knowledge gaps.

Suggested rating guidance:

Minimal impact: Changes in chemical, physical and/or structural habitat characteristics, nutrient cycling, disturbance regimes, or natural succession caused by the species are not likely to be detectable, or changes would small with no apparent reduction of fitness of native individuals (Blackburn et al. 2014).

Minor impact: Changes in chemical, physical and/or structural habitat characteristics, nutrient cycling, disturbance regimes, or natural succession caused by the species are expected to be detectable, affecting the fitness of native individuals but without causing population declines (Blackburn et al. 2014).

Example:

- *Potamogeton crispus* growth contributes to the depletion of water nutrients (Catling and Dobson 1985) and affects the internal loading of a water body (Bolduan et al. 1994). When the spring foliage dies off in midsummer, the oxygen demand created by decomposition may severely deplete the levels of dissolved oxygen (Catling and Dobson 1985).

Moderate impact: Changes in chemical, physical and/or structural habitat characteristics, nutrient cycling, disturbance regimes, or natural succession caused by

the species are expected to cause declines in population size of at least one native species, but without resulting in changes to community composition (Blackburn et al. 2014).

Major impact: Changes in chemical, physical and/or structural habitat characteristics, nutrient cycling, disturbance regimes, or natural succession caused by the species are expected to result in local extinction of at least one native species leading to changes to community composition, but changes would be reversible if the non-native organism was removed (Blackburn et al. 2014) or such changes could result in a decline in population size of a native species of conservation concern (i.e., a provincially or federally listed species at risk).

Examples:

- Invasive carp (generalist herbivores) have been shown to cause lake-wide changes in water quality and macrophyte and macroinvertebrate abundance (reviewed in Miller and Provenza 2007).

- *Helicorophium curvispinum* (a species of amphipod crustacean) renders river bed substrates inaccessible to mussels and other taxa, with cascading effects on diving ducks that prey on them (Leewis et al. 2013).

- *Egeria densa* eliminates native species through nutrient limitation and shading (Chagas et al. 2008), and may affect seed banks of native macrophytes by preventing germination (Yarrow et al. 2009). While they overwinter, *Egeria densa* plants and fragments can cover the bottom of lakes from winter to spring (Jacobs 1946; Kadono 2004), and hinder the growth of native plants which are dormant in winter (Kadono 2004).

Massive impact: The species is expected to cause many changes in chemical, physical and/or structural habitat characteristics, nutrient cycling, disturbance regimes, or natural succession. These changes are likely to result in replacement or local extinction of native species (which could include one or more species of conservation concern) leading to irreversible changes in community composition (Blackburn et al. 2014).

Examples:

- Dreissenid mussels (i.e., zebra and quagga mussels) have had significant deleterious effects on local ecosystems within the Great Lakes basin. As filter feeders capable of reaching very high densities, they reduce the amount of phytoplankton available for other organisms (e.g., Diporeia) and increase water clarity causing changes to the ecological structure of the lake community. Dreissenids have also rendered Great Lakes mussel beds

unsuitable for native unionid mussels and may have facilitated the invasion of other non-native species such as round goby. Consequently, these invasive species have caused massive, ecosystem-wide changes throughout all of the Great Lakes, particularly in Lakes Michigan and Huron (University of Michigan 2011).

- (Excerpts taken from: Nienhuis 2015)
  By virtue of its dominating growth form and ability to attain extremely high densities in shallow wetland habitats, water chestnut (*Trapa natans*) has dramatic impacts on the structure and function of these ecosystems. The species significantly reduces incident light below the canopy, increases local sedimentation, and reduces turbidity. Water chestnut stands also influence nutrient dynamics, are a source of organic matter, and cause significant reductions in dissolved oxygen concentrations. As an extremely successful competitor, introduced *T. natans* has caused dramatic changes to local macrophyte communities and their associated macroinvertebrate food webs.

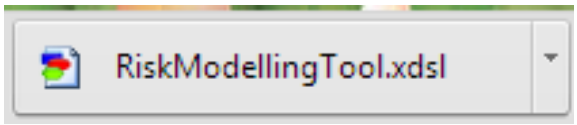
Section 3: Quantitative modelling

Introduction

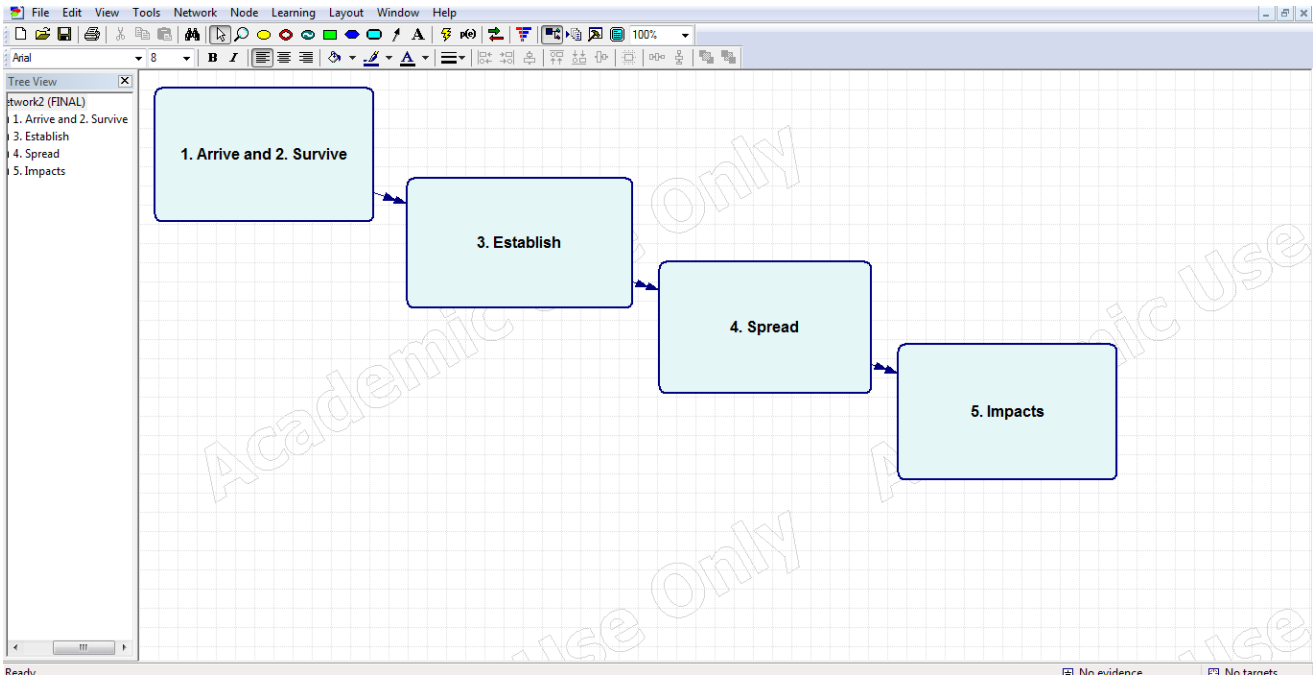
The final component of the risk assessment is a quantitative evaluation of the probability of widespread invasion and impacts. This is accomplished by incorporating the answers and uncertainty ratings to all questions in SECTION 2 as input into a probabilistic modelling tool. This model takes the form of a Bayesian network, which was built in and runs using the open source software package GeNIe Modeler available from BayesFusion, LLC (bayesfusion.com). Detailed installation instructions for GeNIe are provided in Appendix 2.

Opening the Bayesian risk assessment tool

- Download and install GeNIe software (see Appendix 2)
- Open the [GeNIe] Risk Assessment Tool file (.xdsl file from e-mail or USB key)
- Note: Final tool file may have a different name than that shown below (i.e., RiskModellingTool)

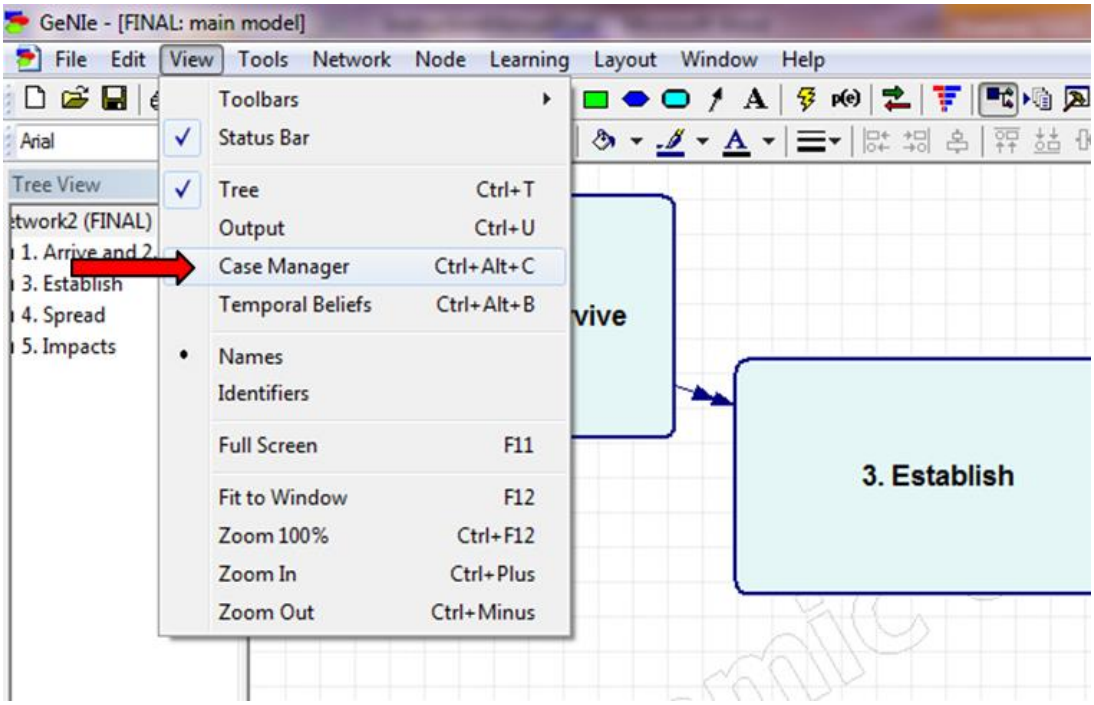


- The GeNIe program will open to the RA tool
- The following screen will appear, showing the full model partitioned into 4 submodels (created to make viewing output more user friendly)

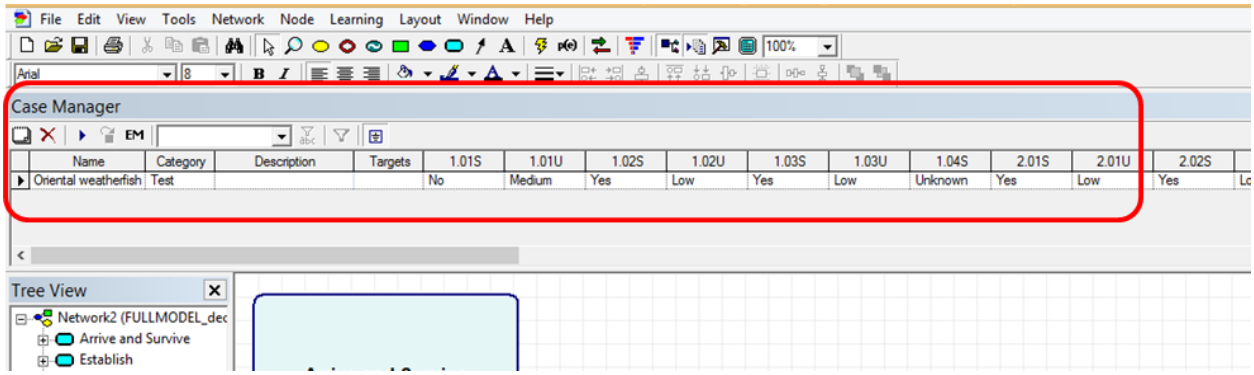


Entering input

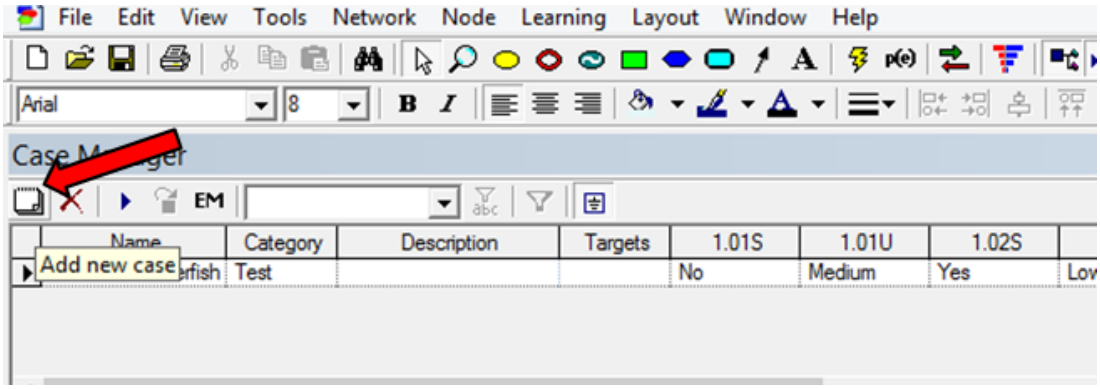
- Select the View menu from the main task bar
- From the drop down menu, select Case Manager



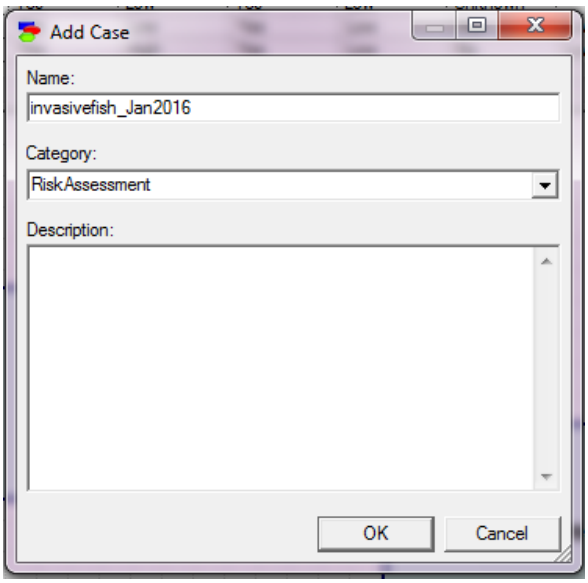
- The Case Manager window will appear



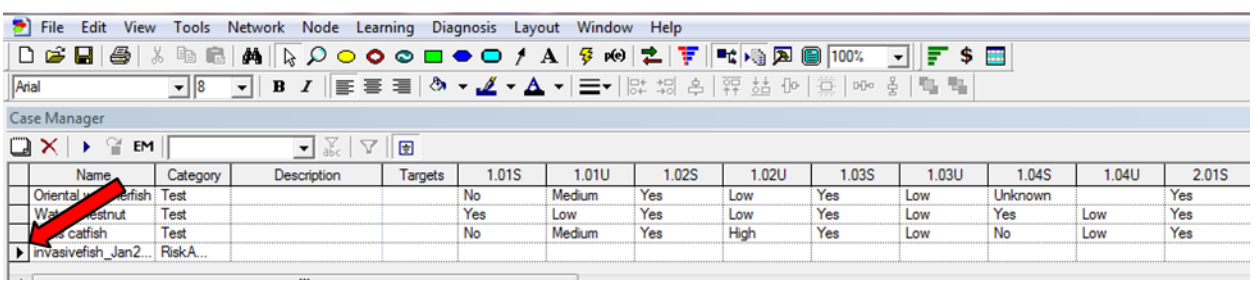
- Click Add new case icon at far left of the Case Manager task bar



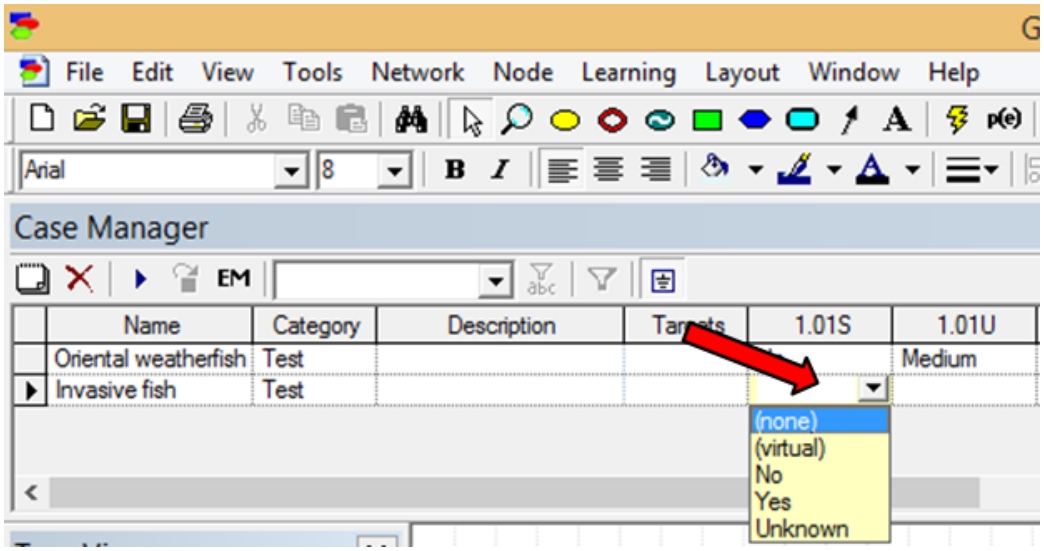
- When prompted, give the risk assessment a name: (Species name_ date)
- In Category field enter Risk Assessment
- In Description field enter Completed by:[risk assessor's name]
- Click on Okay



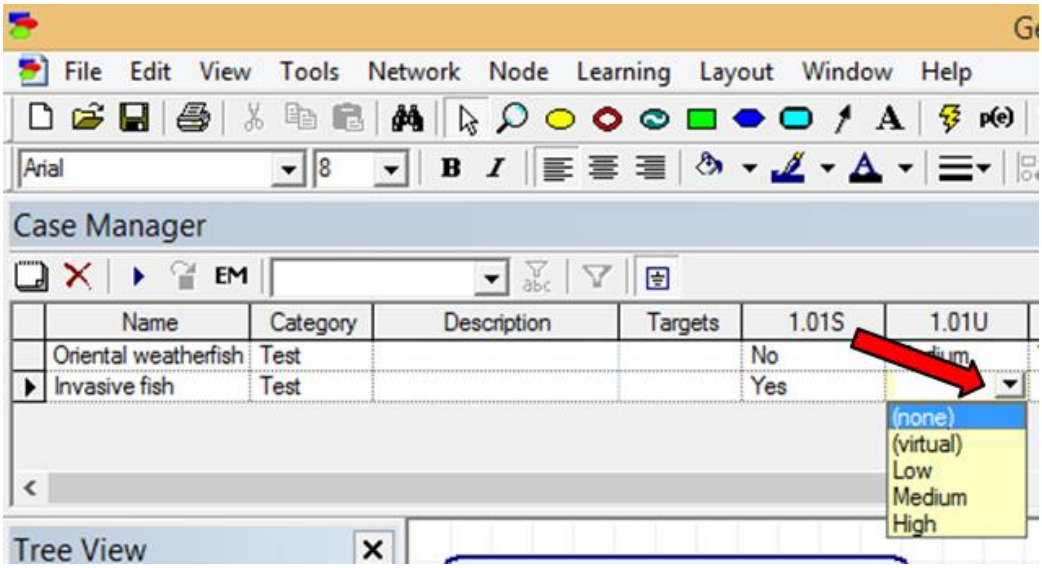
- The small black arrow indicates that you are entering input in a new case for your selected species
- Always ensure that your are entering your input in the correct row



- Click in first box (1.01S) and select appropriate answer from the drop down list (i.e., no, yes or unknown) according to your selection in the questionnaire in Section 2

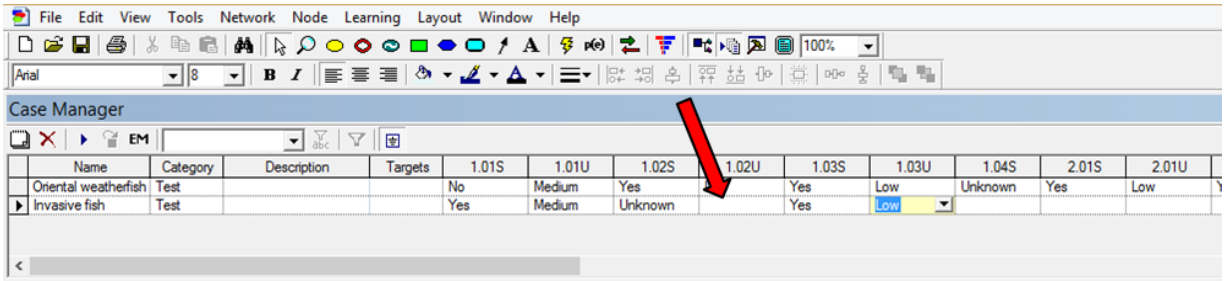


- Do the same for selected uncertainty level (1.01U) (i.e., select either Low, Medium or High)

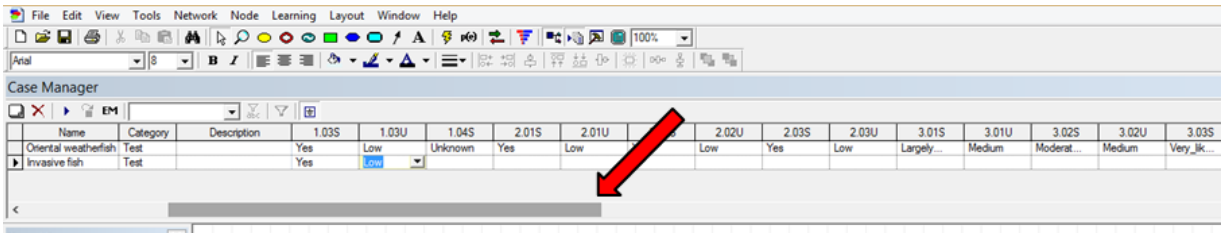


- Click in each of the rest of the boxes and select appropriate answer as per the completed questionnaire from Section 2

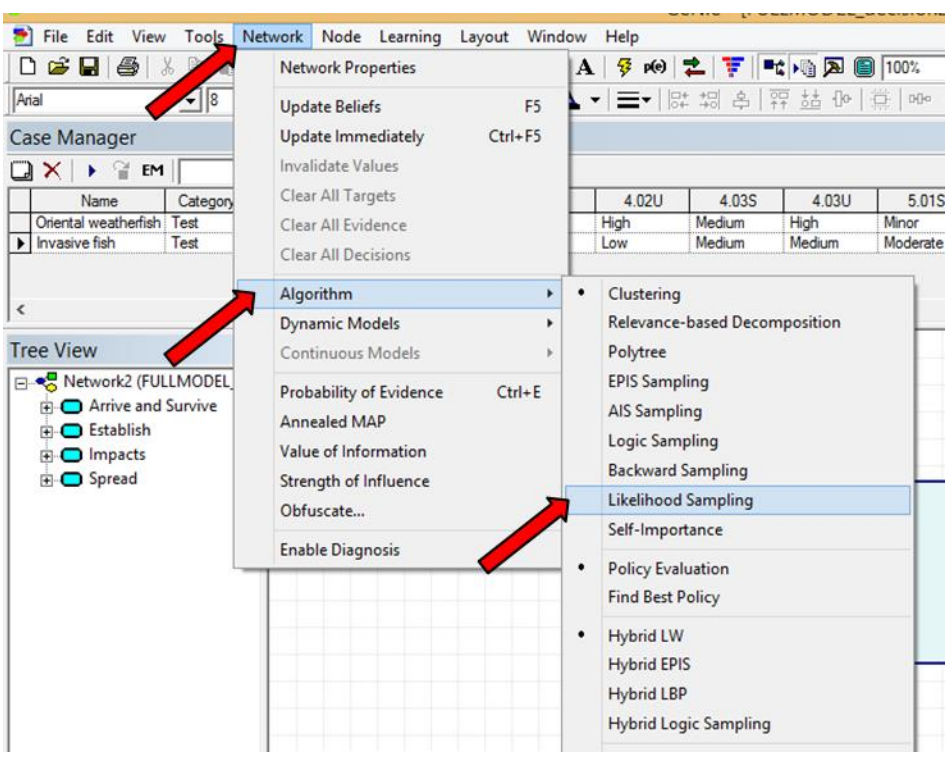
- Note: if the answer is Unknown, leave the associated uncertainty box blank (see below)



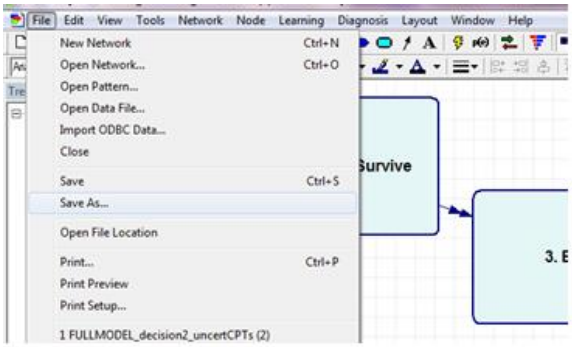
- Complete answers for all questions (Score and Uncertainty ratings)
- Use scroll bar at bottom of Case Manager window to move to other questions:



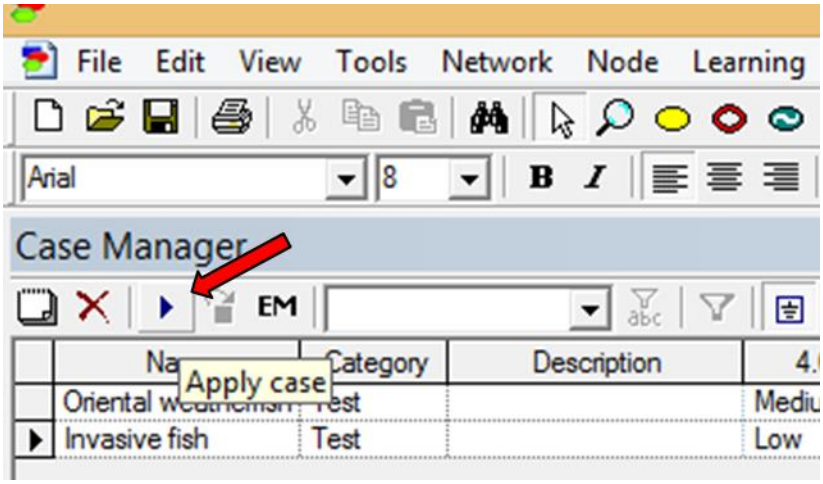
- When all questions are answered select Network menu from the main task bar
- From the drop down menu select Algorithm
- From Algorithm menu select Likelihood sampling



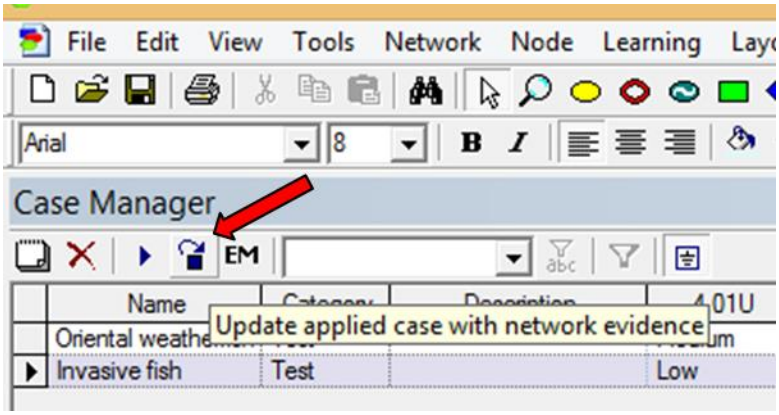
- From File menu in main task bar select Save As
- Rename the file with species and date and save to an appropriate folder or location (i.e., desktop for ease of access)
- Save as .xdsl file



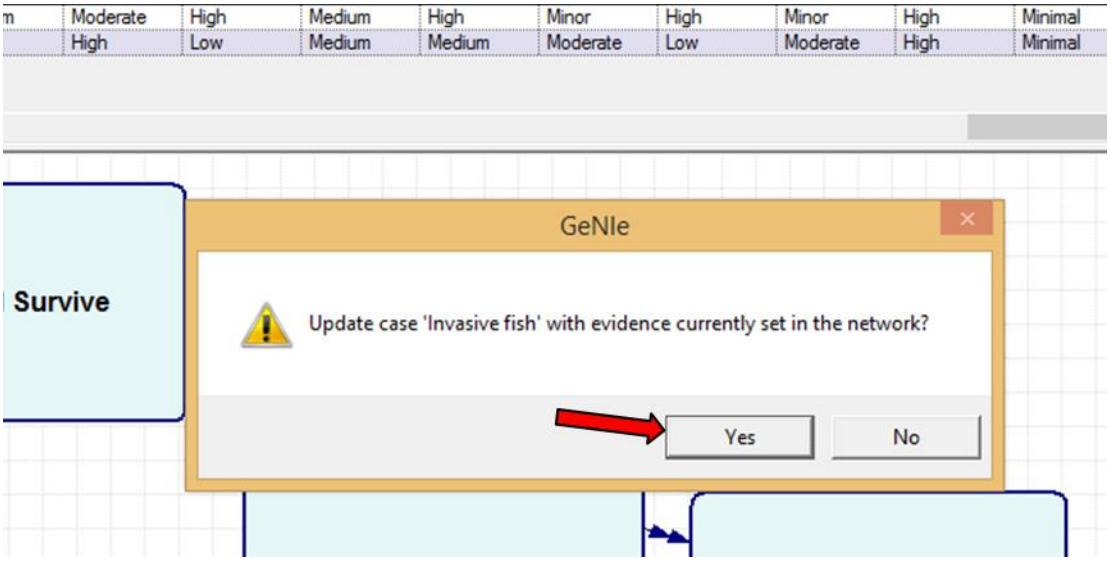
- After saving, click Apply case icon in Case Manager window (small play button arrow):



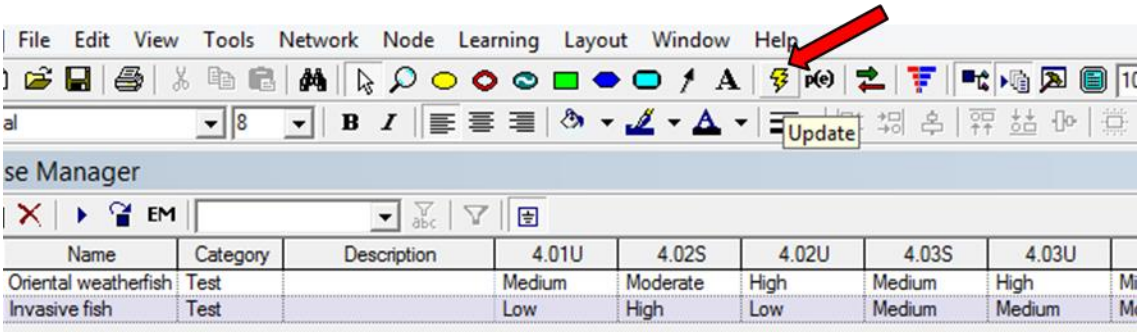
- Next click Update applied case with network evidence icon that is no longer greyed out:



- The following window will pop up. Select yes



- Next, click Update icon (lightning bolt) from top icon tool bar:

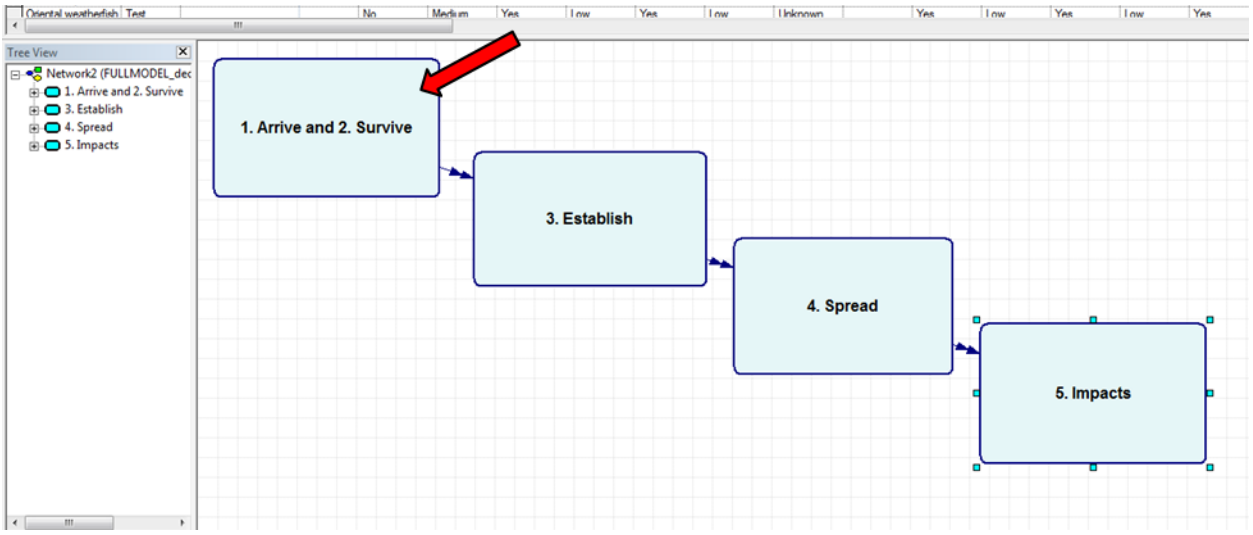


- The model is now updated with the input for your species, and all calculations for conditional probabilities have automatically been performed

- You can now view the model output

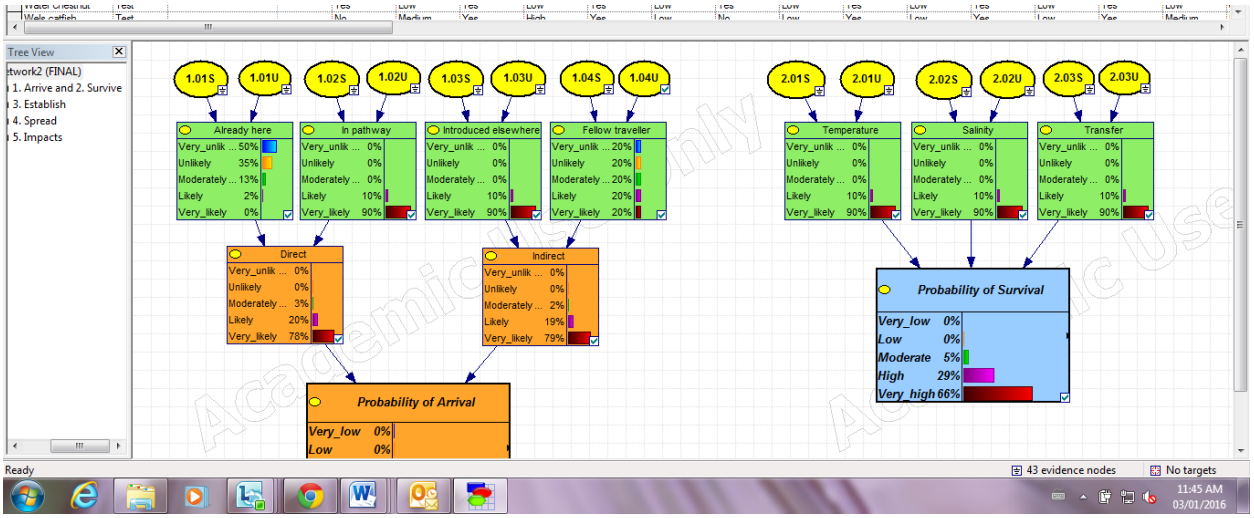
Viewing and saving model output

- Double click on the 1. Arrive and 2.Survive submodel box in the main window:



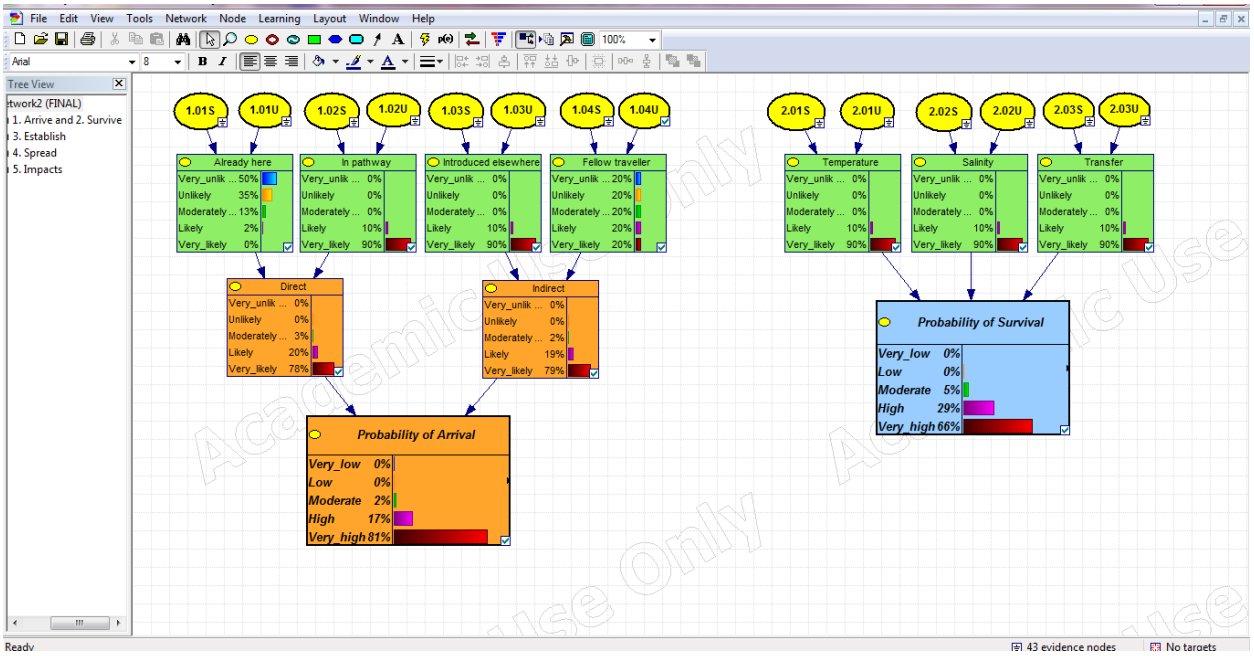
- You will see the components and probability distributions for Arrival and Survival submodels:

- NOTE: Do not click inside coloured boxes

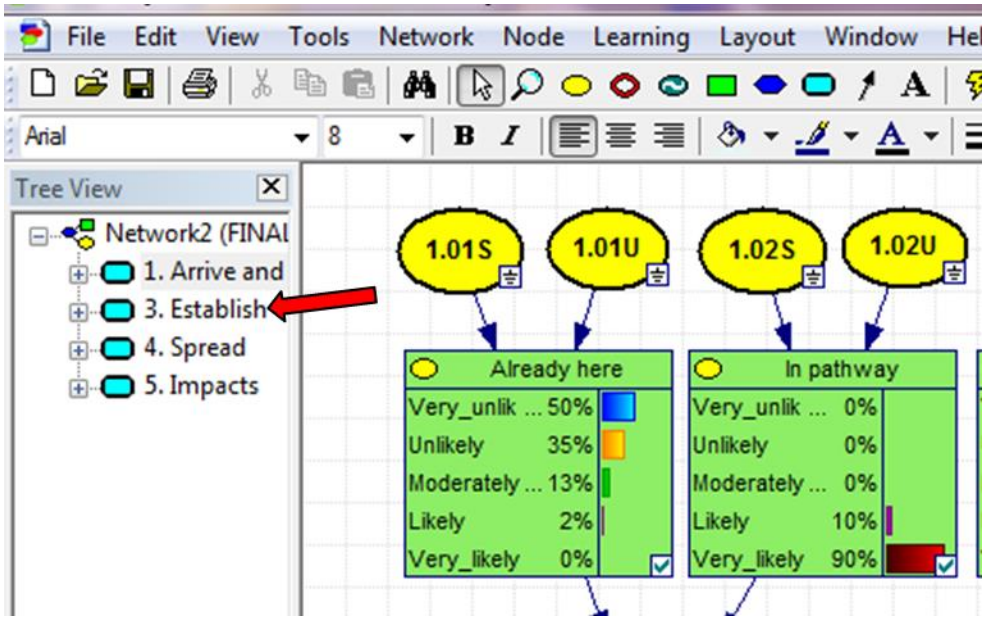


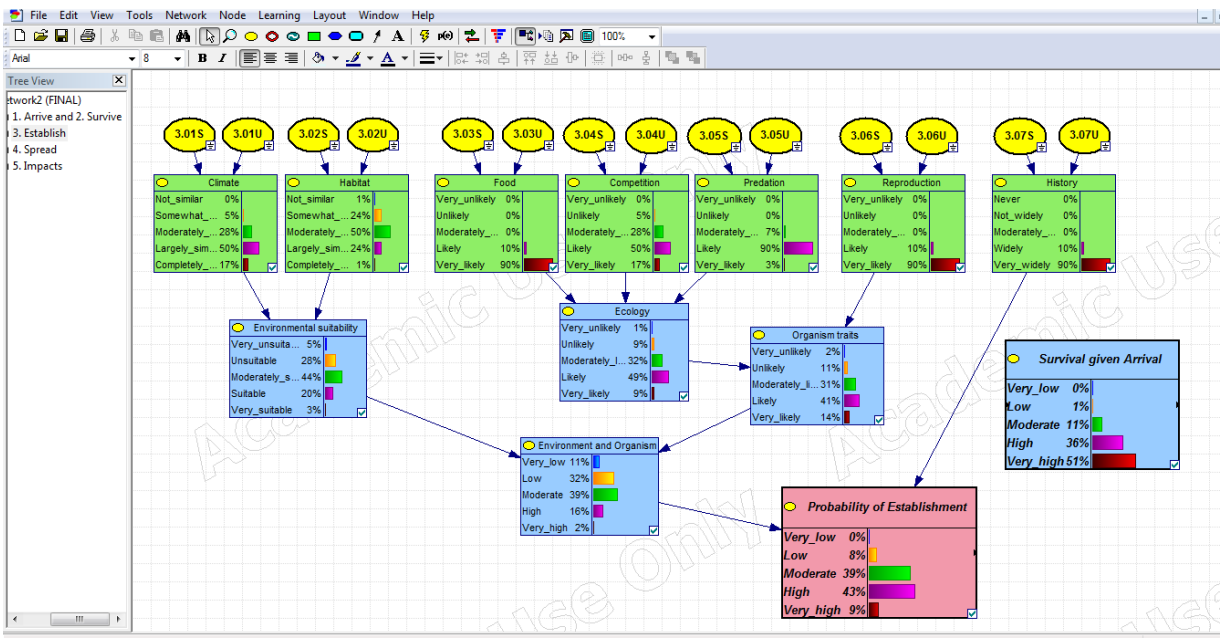
- To see a full page view of the output close Case Manager window (click on small box with X in upper right hand corner of the case manager window or deselect this window from the View menu in the main toolbar)

- You should now be able to view the full screen (e.g.):

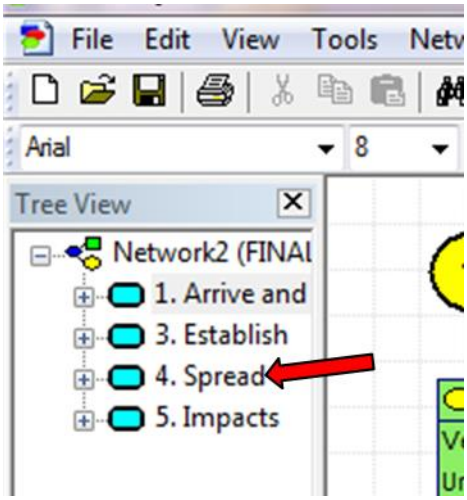


- Take a screen capture of this page (hold Function (fn button on keyboard) + Print Screen (home/prt sc key) and then Paste into a word document for future reference and inclusion in the Risk Assessment report
- You can also print this page by selecting Print from the main File menu
- Next, view the Establish submodel output
- Double click on 3.Establish in left hand menu (Tree View)
- You will see the following (Note: distributions will vary from those shown depending on input)

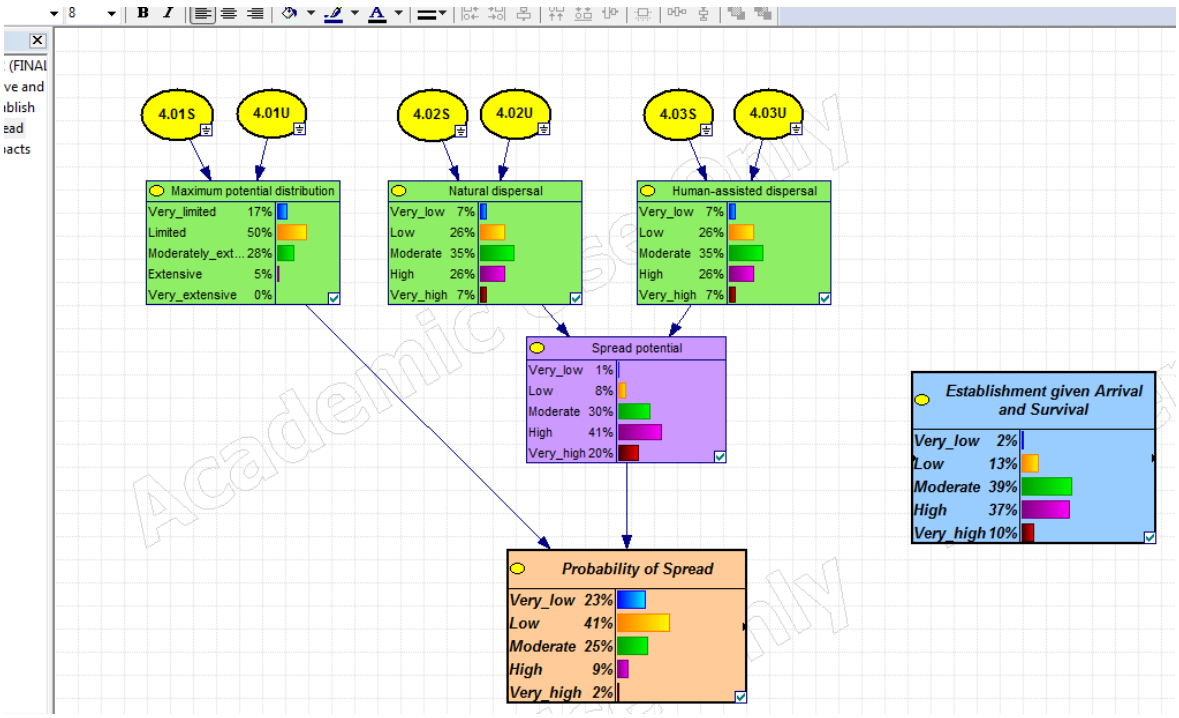




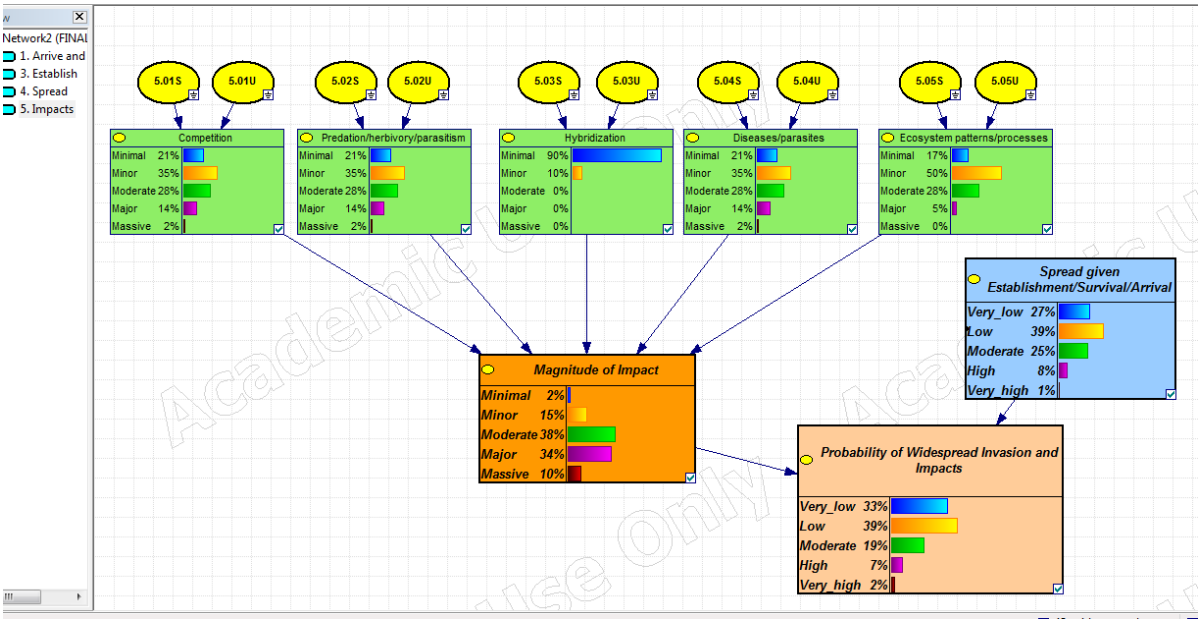
- Again, save a screen capture and paste into appropriate word file (and/or print this screen)
- Repeat the steps noted above for Spread (double click on 4. Spread submodel name) as well as for Impacts. Examples are shown below:



- Spread submodel view:



- Impacts submodel view:

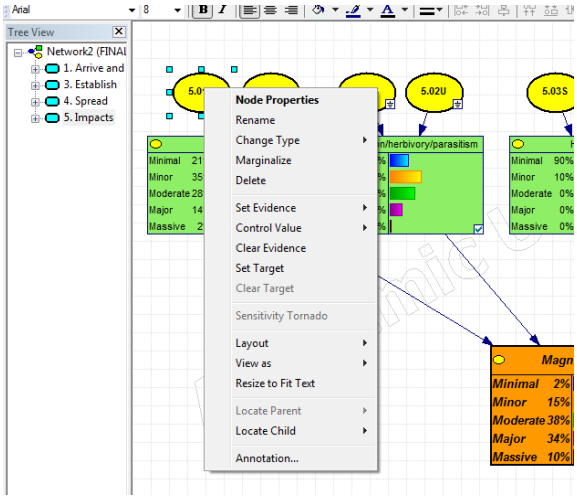


- Ensure that you copy and paste screen captures for all submodels for inclusion in risk assessment document

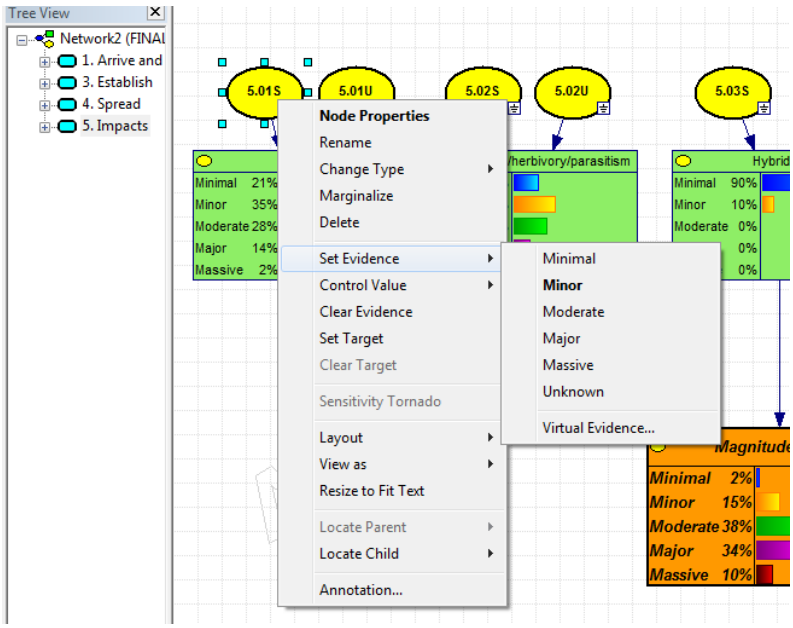
Confirming model input values

- Confirm that the answer distributions reflect your selection of answers/uncertainty levels from the questionnaire. This can be done in one of two ways:

- Hover mouse over individual yellow boxes within a submodel (which comprise the answers and uncertainty levels selected for each question) and right click:

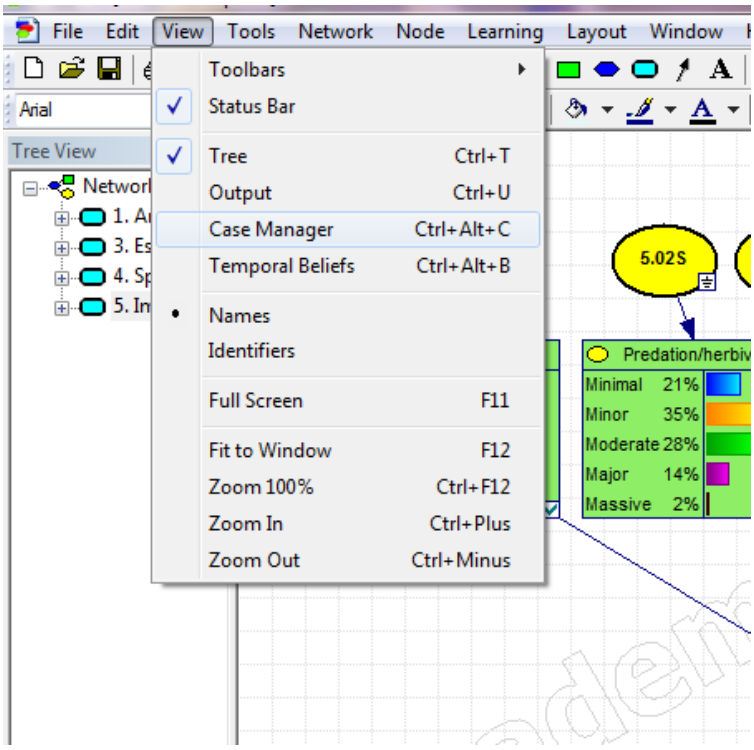


- Hover mouse over Set Evidence to see the answer that was selected (it will be in bold)



- Click anywhere on blank background to get out of drop down menu

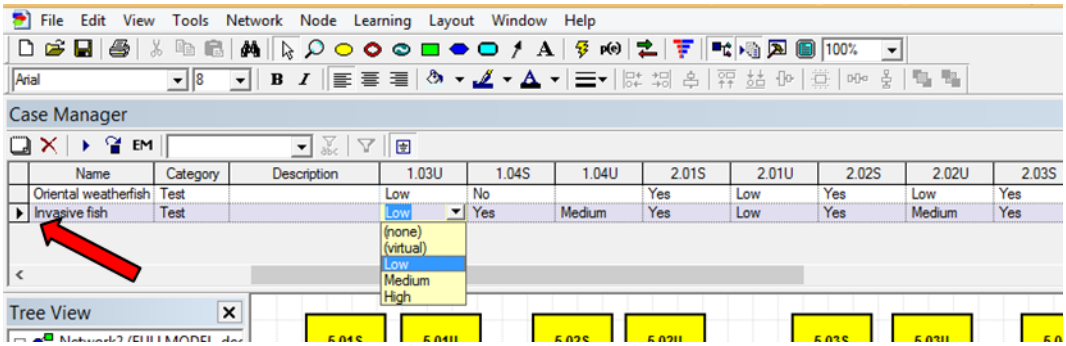
- Re-open original Case Manager window (select from View menu in main tool bar)



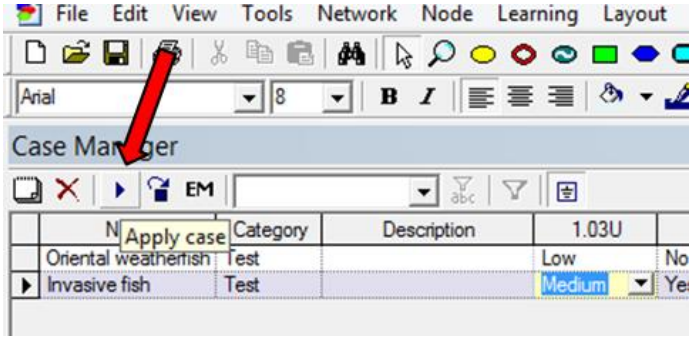
- Double check and confirm answers selected for each question in Case Manager window

Changing or updating input

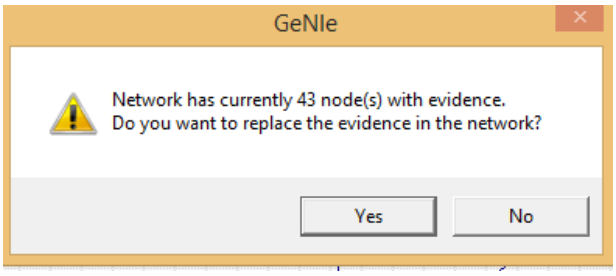
- If you need to change an answer, do so from the Case Manager window.
- As when originally entering input, click in the cell that you want to change and select answer/uncertainty rating from drop down menu
- **NOTE**: confirm that your species is the case in question (working case file will be highlighted in grey, and will be indicated by the small black play button arrow)



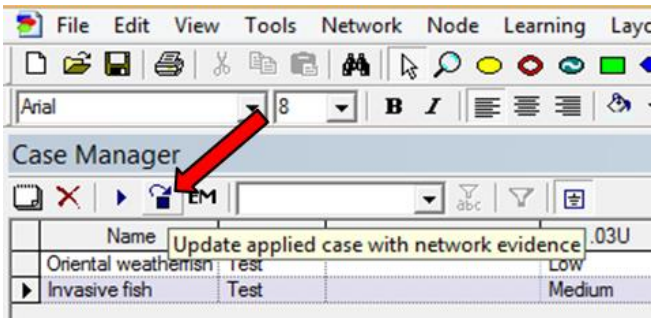
- If you change an answer(s)/uncertainty rating(s) you will have to re-update the model
- Click Apply case icon in Case Manager window (small arrow/play button)



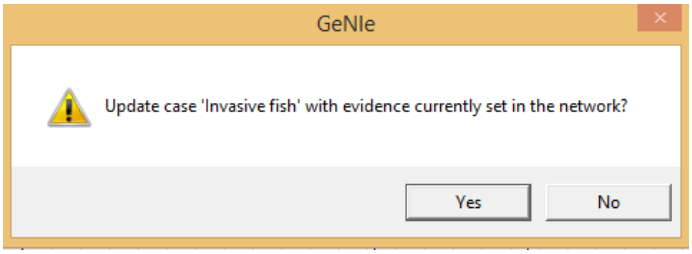
- A pop up menu will appear. Select yes.



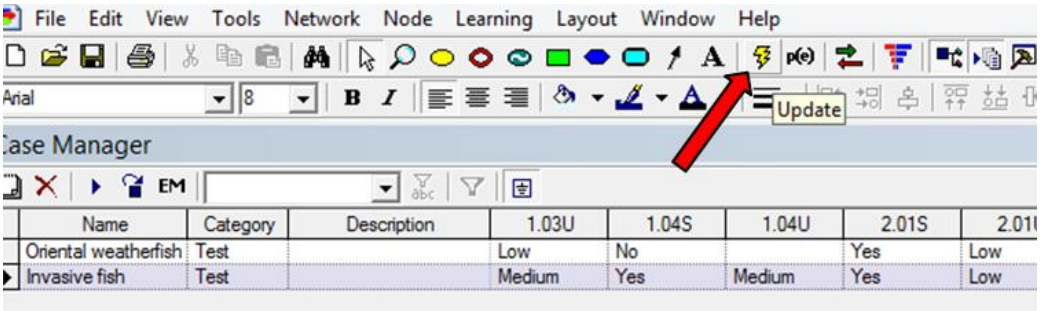
- Next click Update applied case with network evidence icon in Case Manager (square with circular arrow)



- Another pop up menu will appear. Again, select yes



- Finally, click Update icon in top icon tool bar (lightning bolt)

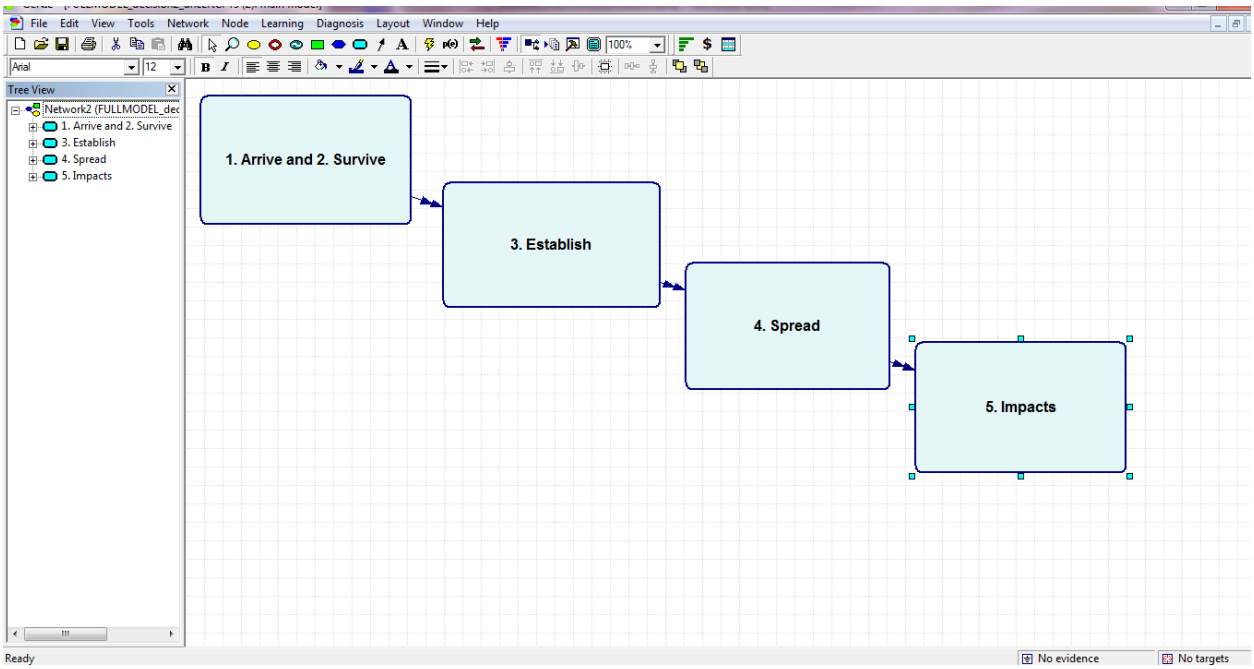


- Take new screen captures (and copy into word file) to reflect change in model outcomes, as described above (i.e., close Case Manager and Output windows to view full screen)

- Save updated model , close all GeNIe windows to end session

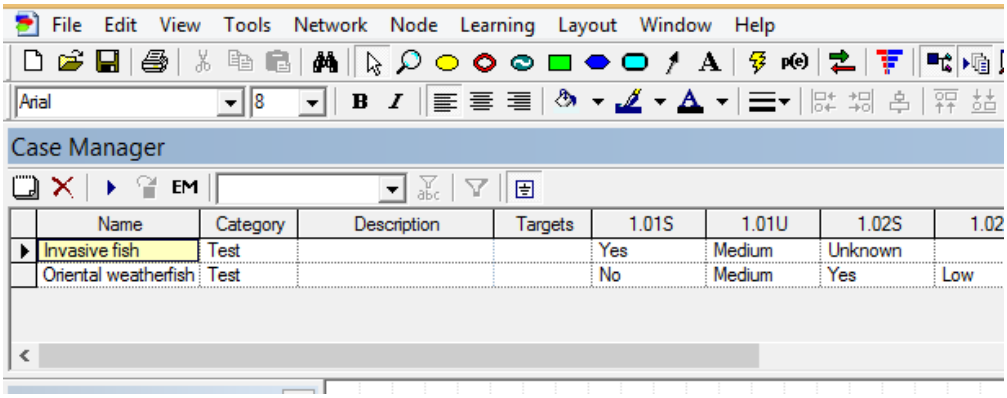
Re-opening model

- If you have previously saved and closed your file, and then re-open it you will view the original screen of the overall model:



- Select Case Manager in the View menu from the main tool bar to find and select the case for your species

- NOTE: The case for which the model will run is indicated with a small black arrow; if you want to change the species, click on the name of the desired species in the name box and the arrow should move to the newly selected species



- Change input if necessary, or run model with existing input

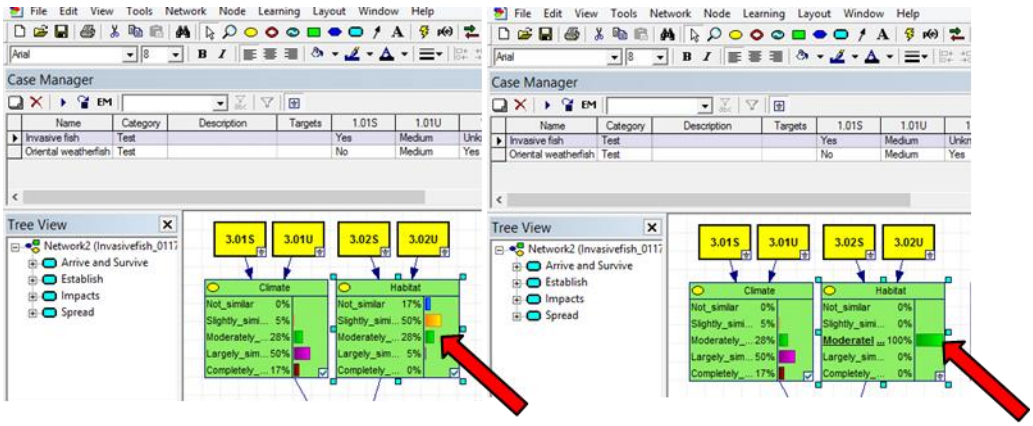
- NOTE: Each time the program is closed and re-opened the sampling algorithm reverts to the default Clustering algorithm. Therefore to run a saved case again, you must first change the algorithm back to Likelihood sampling (i.e., from the Network menu from the main task bar select Algorithm, and then Likelihood sampling)

- Click Apply case (play arrow), then Update applied case with network evidence (select yes to any popup menus), and then the Update icon (see instructions above), view and copy submodel output as instructed above

Troubleshooting

- If you accidentally change values by clicking in coloured box:

- (this would require first highlighting (clicking on) a box, and then double clicking inside of it)



- There is no undo button in GeNIe.

- Either close program without saving and reopen it, or go back to Case Manager and reapply set evidence for your species (play button, yes to popup menus, update with evidence, update button)

References

Berger, S.T., M.D. Netherland and G.E. MacDonald. 2015. Laboratory documentation of multiple-herbicide tolerance to Fluridone, Norflurazon, and Topramazone in a hybrid watermilfoil (*Myriophyllum spicatum* × *M. sibiricum*) population. Weed Science 63(1):235-241.

Blackburn, T.M., F. Essl, T. Evans, P.E. Hulme, J.M. Jeschke, I. Kuhn, S. Kumschick, Z. Markova, A. Mrugała, W. Nentwig, J. Pergl, P. Pysek, W. Rabitsch, A. Ricciardi, D.M. Richardson, A. Sendek, M. Vila, J.R.U. Wilson, M. Winter, P. Genovesi and S. Bacher. 2014. A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12(5):e1001850.

Blackburn, T.M., J.L. Lockwood and P. Cassey. 2015. The influence of numbers on invasion success. Molecular Ecology: 1942–1953.

Bolduan, B.R., G.C. Van Eeckhout, H.W. Quade and J.E. Gannon. 1994. *Potamogeton crispus* – The other invader. Lake and Reservoir Management 10(2): 113-125.

Bomford, M., S.C. Barry and E. Lawrence. 2010. Predicting establishment success for introduced freshwater fishes: A role for climate matching. Biological Invasions 12: 2559–2571.

Borgstrøm, R., J.E. Brittain, K. Hasle, S. Skjølas and J.G. Dokk. 1996. Reduced recruitment in brown trout *Salmo trutta*, the role of interactions with the minnow *Phoxinus phoxinus*. Nordic Journal of Freshwater Research 72: 30–38.

Bradie, J. and B. Leung. 2015. Pathway-level models to predict non-indigenous species establishment using propagule pressure, environmental tolerance and trait data. Journal of Applied Ecology 52: 100–109.

Britton, J.R., J. Cucherousset, G.D. Davies, M.J. Godard and G.H. Copp. 2010. Non-native fishes and climate change: Predicting species responses to warming temperatures in a temperate region. Freshwater Biology 55(5): 1130–1141.

Caiola, N. and A. Sostoa. 2005. Possible reasons for the decline of two native toothcarps in the Iberian Peninsula: evidence of competition with the introduced Eastern mosquitofish. Journal of Applied Ichthyology 21: 358–363.

Carlson, M.L., I.V. Lapina, M. Shephard, J.S. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley and J. Nielsen. 2008. Invasiveness ranking system for non-native plants of Alaska. Alaska Region, Forest Service, U.S. Department of Agriculture. R10-TP-143. 218 p.

Carol, J., L. Zamora and E. García-Berthou. 2007. Preliminary telemetry data on the patterns and habitat use of European catfish (*Silurus glanis*) in a reservoir of the River Ebro, Spain. Ecology of Freshwater Fish 16: 450–456.

Catling, P.M. and I. Dobson. 1985. The biology of Canadian weeds. 69. *Potamogeton crispus* L. Canadian Journal of Plant Science 65: 655-668.

Chagas, G.G., M.N. Fonseca and M.S. Suzuki. 2008. Primary production of *Egeria densa* Planch. (Hydrocharitaceae) in a coastal lagoon with high biogenic turbidity. Acta Limnologica Brasiliensia 20(4): 353-358.

Chan, F.T., J.E. Bronnenhuber, J.N. Bradie, K.L. Howland, N. Simard and S.A. Bailey. 2011. Risk assessment for ship-mediated introductions of aquatic nonindigenous species to the Canadian Arctic. DFO Canadian Science Advisory Secretariat Research Document 2011/105. vi + 91 p.

Copp, G.H., R. Garthwaite and R.E. Gozlan. 2005. Risk identification and assessment of non-native freshwater fishes: concepts and perspectives on protocols for the UK. Science Series Technical Report, Cefas Lowestoft, 129. 32p.

D'hondt, B., S. Vanderhoeven, S. Roelandt, F. Mayer, V. Versteirt, E. Ducheyne, G. San Martin, J.-C. Grégoire, I. Stiers, S. Quoilin and E. Branquart. 2014. *Harmonia*$^{+}$ and *Pandora*$^{+}$: risk screening tools for potentially invasive organisms. Belgian Biodiversity Platform, Brussels. 63 p.

Ding, J. and B. Blossey. 2005. Invertebrate predation on the water lily beetle, *Galerucella nymphaeae* (Coleoptera: Chrysomelidae), and its implications for potential biological control of Water Chestnut, *Trapa natans*. Biological Control 35: 17–26.

Gaertner, M., A. Den Breeyen, C. Hui and D.M. Richardson. 2009. Impacts of alien plant invasions on species richness in Mediterranean type ecosystems: a meta-analysis. Progress in Physical Geography 33(3): 319–338.

García-Berthou, E. 2007. The characteristics of invasive fishes: What has been learned so far? Journal of Fish Biology 71: 33–55.

Gordon, D.R., D.A. Onderdonk, A.M. Fox, R.K. Stocker and C. Gantz. 2008. Predicting invasive plants in Florida using the Australian weed risk assessment. Invasive Plant Science and Management 1(2): 178–195.

Government of Alberta. 2008. Alberta Invasive Alien Species Risk Assessment Tool Version 3. I-IAS Working Group. 64 p.

Great Lakes Aquatic Nonindigenous Species Information System. 2015. *Pseudorasbora parva* Fact Sheet.

Hayes, K.R. and S.C. Barry. 2008. Are there any consistent predictors of invasion success? Biological Invasions 10(4): 483–506.

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

Heffernan, K. E., P.P. Coulling, J.F. Townsend and C.J. Hutto.2001. Ranking invasive exotic plant species in Virginia. Natural Heritage Technical Report 01-13. Richmond, VA. Virginia Department of Conservation and Recreation, Division of Natural Heritage.144 p.

Houghton, C.J. 2015. Round Goby-induced changes in young-of-year Yellow Perch diet and habitat selection. University of Wisconsin-Milwaukee, Milwaukee, WI. Ph.D. Thesis. 94 p.

Howeth, J.G., C.A. Gantz, P.L. Angermeier, E.A. Frimpong, M.H. Hoff, R.P. Keller, N.E. Mandrak, M.P. Marchetti, J.D. Olden, C.M. Romagosa and D.M. Lodge. 2015. Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes. Diversity and Distributions 22(2):148–160.

Hummel, M. and S. Findlay. 2006. Effects of Water Chestnut (*Trapa natans*) beds on water chemistry in the tidal freshwater Hudson River. Hydrobiologia 559: 169–181.

Jacobs, D.L. 1946. Shoot segmentation in *Anacharis densa*. American Midland Naturalist 35(1): 283–286.

Janssen, J. and D.J. Jude. 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in Calumet Harbor, southern Lake Michigan, induced by the newly introduced round goby *Neogobius melanostomus.* Journal of Great Lakes Research 27: 319–328.

Jerde, C.L. and M.A. Lewis. 2007. Waiting for invasions: A framework for the arrival of nonindigenous species. The American Naturalist 170: 1–9.

Jeschke, J.M., S. Bacher, T.M. Blackburn, J.T.A. Dick, F. Essl, T. Evans, M. Gaertner, P.E. Hulme, I. Kuhn, A. Mrugala, J. Pergl, P. Pysek, W. Rabitsch, A. Ricciardi, D.M. Richardson, A. Sendek, M. Vila, M. Winter and S. Kumschick. 2014. Defining the impact of non-native species. Conservation Biology 28: 1188–1194.

Jeschke, J.M. and D.L. Strayer. 2006. Determinants of vertebrate invasion success in Europe and North America. Global Change Biology 12(9): 1608–1619.

Jordan, M.J., G. Moore and T.W. Weldy. 2008. New York State ranking system for evaluating non-native plant species for invasiveness. New York Invasive Species Council. 131 p.

Jules, E.S., M.J. Kauffman, W.D. Ritts and A.L. Carroll. 2002. Spread of an invasive pathogen over a variable landscape: A nonnative root rot on Port Orford cedar. Ecology 83(11): 3167–3181.

Kadono, Y. 2004. Alien aquatic plants naturalized in Japan: History and present status. Global Environmental Research 8(2): 163–169.

Keller, R.P., J.M. Drake and D.M. Lodge. 2007. Fecundity as a basis for risk assessment of nonindigenous freshwater molluscs. Conservation Biology 21(1): 191–200.

Kiviat, E. 1993. Under the spreading water-chestnut. Hudsonia 9: 1–7.

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

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

Koop, A.L., L. Fowler, L.P. Newton and B.P. Caton. 2012. Development and validation of a weed screening tool for the United States. Biological Invasions 14: 273-294.

Kottek, M., J. Grieser, C. Beck, B. Rudolf and F. Rubel. 2006. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15(3): 259–263.

Kulhanek, S.A., A. Ricciardi and B. Leung. 2011. Is invasion history a useful tool for predicting impacts of the world's worst aquatic invasive species? Ecological Applications 21: 189-202.

Kumschick, S., S. Bacher, W. Dawson, J. Heikkilä, A. Sendek, T. Pluess, T.B. Robinson and I. Kühn. 2012. A conceptual framework for prioritization of invasive alien species for management according to their impact. NeoBiota 15: 69–100.

Kumschick, S., M. Gaertner, M. Vila, F. Essl, J.M. Jeschke, P. Pysek, A. Ricciardi, S. Bacher, T.M. Blackburn,J.T.A. Dick, T. Evans, P.E. Hulme, I. Kuhn, A. Mrugala, J. Pergl, W. Rabitsch, D.M. Richardson, A. Sendek and M. Winter. 2014. Ecological impacts of alien species: Quantification, scope, caveats, and recommendations. BioScience 65: 55–63.

LaRue, E.A., D. Grimm and R.A. Thum. 2013a. Laboratory crosses and genetic analysis of natural populations demonstrate sexual viability of invasive hybrid watermilfoils (*Myriophyllum spicatum* × *M. sibiricum*). Aquatic Botany 109: 49-53.

LaRue, E.A., M.P. Zuellig, M.D Netherland, M.A. Heilman and R.A. Thum. 2013b. Hybrid watermilfoil lineages are more invasive and less sensitive to a commonly used herbicide than their exotic parent (Eurasian watermilfoil). Evolutionary Applications 6(3): 462–471.

Leewis, R., L. Duistermaat, A. Gittenberger, T. van der Have, M. Soes and J. Valkenburg. 2013. Veldgids exoten. KNNV publishing, Netherlands.

Leuven, R.S.E.W., G. van der Velde, I. Baijens, J. Snijders, C. van der Zwart, H.J.R. Lenders and A. bij de Vaate. 2009. The River Rhine: A global highway for dispersal of aquatic invasive species. Biological Invasions 11: 1989-2008.

Lockwood, J.L., P. Cassey and T.M. Blackburn. 2009. The more you introduce the more you get: The role of colonization pressure and propagule pressure in invasion ecology. Diversity and Distributions 15: 904–910.

MacLeod, A. 2011. Table to provide guidance regarding the use of the uncertainty rating within the EPPO PRA DSS. CAPRA, EPPO, European Union 7th Framework Programme project PRATIQUE (Grant Agreement No. 212459).

Magarey, R.D., D.M. Borchert and J.W. Schlegel. 2008. Global plant hardiness zones for phytosanitary risk analysis. Scientia Agricola 65: 54–59.

Mandrak, N.E., C. Gantz, L.A. Jones, D. Marson and B. Cudmore. 2013. Evaluation of five freshwater fish screening-level risk assessment protocols and application to non-indigenous organisms in trade in Canada. DFO Canadian Science Advisory Secretariat Research Document 2013/122. v + 125 p.

Marvier, M., P. Kareiva and M.G. Neubert. 2004. Habitat destruction, fragmentation, and disturbance promote invasion by habitat generalists in a multispecies metapopulation. Risk Analysis 24: 869–878.

McAlpine, K.G. and L.K. Jesson. 2007. Linking seed dispersal, germination and recruitment in the invasive species *Berberis darwinii* (Darwin's barberry). Plant Ecology 197: 119–129.

McKenney, D.W., M.F. Hutchinson, J.L. Kesteven and L.A. Venier. 2001. Canada's plant hardiness zones revisited using modern climate interpolation techniques. Canadian Journal of Plant Sciences 81: 129–143.

Miller, S.A. and F.D. Provenza. 2007. Mechanisms of resistance of freshwater macrophytes to herbivory by invasive juvenile common carp. Freshwater Biology 52: 39–49.

Moody, M.L. and D.H. Les. 2007. Geographic distribution and genotypic composition of invasive hybrid watermilfoil (*Myriophyllum spicatum* x *M. sibiricum*) populations in North America. Biological Invasions 9: 559–570.

Moyle, P.B. and M.P. Marchetti. 2006. Predicting invasion success: Freshwater fishes in California as a model. BioScience 56(6): 515–524.

Museth, J., T. Hesthagen, O.T. Sandlund, E.B. Thorstad and O. Ugedal. 2007. The history of the minnow *Phoxinus phoxinus* (L.) in Norway: From harmless species to pest. Journal of Fish Biology 71(Suppl D): 184–195.

Næstad, F. and J.E. Brittain. 2010. Long-term changes in the littoral benthos of a Norwegian subalpine lake following the introduction of the European minnow (*Phoxinus phoxinus*). Hydrobiologia 642: 71–79.

Nentwig, W., E. Kuhnel and S. Bacher. 2010. A generic impact-scoring system applied to alien mammals in Europe. Conservation Biology 24: 302–311.

Nienhuis, S., T.J. Haxton and T.C. Dunkley. 2014. An empirical analysis of the consequences of zebra mussel invasions on fisheries in inland, freshwater lakes in Southern Ontario. Management of Biological Invasions 5: 287–302.

Nienhuis, S. 2015. A risk assessment for European water chestnut (*Trapa natans*) in Ontario- DRAFT. Prepared for the Natural Heritage Section, Natural Resources Conservation Policy Branch, Ontario Ministry of Natural Resources and Forestry. Peterborough, ON. 46 p.

Pettitt-Wade, H., K.W. Wellband, D.D. Heath and A.T. Fisk. 2015. Niche plasticity in invasive fishes in the Great Lakes. Biological Invasions 17:2565–2580.

Pheloung, P.C., P.A. Williams and S.R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57: 239–251.

Pokorny, M.L., R.L. Sheley, C.A. Zabinski, R.E. Engel, T.J. Svejcar and J.J. Borkowski. 2005. Plant functional group diversity as a mechanism for invasion resistance. Restoration Ecology 13(3): 448-459.

Rhymer, J.M. and D. Simberloff. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics 27: 83-109.

Ricciardi, A. 2001.Facilitative interactions among aquatic invaders: Is an "invasional meltdown" occurring in the Great Lakes? Canadian Journal of Fisheries and Aquatic Sciences 58: 2513–2525.

Ricciardi, A. and S.K. Atkinson. 2004. Distinctiveness magnifies the impact of biological invaders in aquatic ecosystems. Ecology Letters 7: 781–784.

Ricciardi, A. and R. Kipp. 2008. Predicting the number of ecologically harmful exotic species in an aquatic system. Diversity and Distributions 14: 374-380.

Ricciardi, A., M.F. Hoopes, M.P. Marchetti and J.L. Lockwood. 2013. Progress toward understanding the ecological impacts of nonnative species. Ecological Monographs 83(3): 263–282.

Ricketts, T.H., E. Dinerstein, D.M. Olson, C.J. Loucks, W. Eichbaum, D. DellaSala, K. Kavanagh, P. Hedao, P.T. Hurley, K.M. Carney, R. Abell and S. Walters. 1999. Terrestrial ecoregions of North America: A conservation assessment. Island Press. Washington, DC. 485 pp.

Rixon, C.A.M., I.C. Duggan, N.M.N. Bergeron, A. Ricciardi and H. J. MacIsaac. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity and Conservation 14: 1365–1381.

Ruesink, J.L., I.M. Parker, M.J. Groom and P.M. Kareiva. 1995. Reducing the risks of nonindigenous species introductions: Guilty until proven innocent. Bioscience 45(7): 475–477.

Sakai, A.K., F.W. Allendorf, J.S. Holt, D.M. Lodge, J. Molofsky, K.A. With, S. Baughman, R.J. Cabin, J.E. Cohen, N.C. Ellstrand, D.E. McCauley, P. O'Neil, I.M. Parker, J.N. Thompson and S.G. Weller. 2001. The population biology of invasive species. Annual Review of Ecology and Systematics 32: 305-332.

Strauss, S.Y., C.O. Webb and N. Salamin. 2006. Exotic taxa less related to native species are more invasive. Proceedings of the National Academy of Sciences of the USA 103: 5841–5845.

Symondson, W.O.C., K.D. Sunderland and M.H. Greenstone. 2002. Can generalist predators be effective biocontrol agents? Annual Review of Entomology 47: 561–594.

Therriault, T.W., A.M. Weise, G.E. Gillespie and T.J. Morris. 2010. Risk assessment for New Zealand mud snail (*Potamopyrgus antipodarum*) in Canada. DFO Canadian Science Advisory Secretariat Research Document 2010/108.

University of Michigan. 2011. Invasive mussels causing massive ecological changes in Great Lake. ScienceDaily. ScienceDaily, 17 April 2011.

van der Veer, G. and W. Nentwig. 2015. Environmental and economic impact assessment of alien and invasive fish species in Europe using the generic impact scoring system. Ecology of Freshwater Fish 24(4): 646–656.

Vélez-Espino, L.A., M.A. Koops and S. Balshine. 2010. Invasion dynamics of round goby (*Neogobius melanostomus*) in Hamilton Harbour, Lake Ontario. Biological Invasions 12: 3861–3875.

Von Holle, B. 2005. Biotic resistance to invader establishment of a southern Appalachian plant community is determined by environmental conditions. Journal of Ecology 93: 16–26.

Wittmann, M.E., C.L. Jerde, J.G. Howeth, S.P. Maher, A.M. Deines, J.A. Jenkins, G.W. Whitledge, S.R. Burbank, W.L. Chadderton, A.R. Mahon, J.T. Tyson, C.A. Gantz, R.P. Keller, J.M. Drake and D.M. Lodge. 2014. Grass carp in the Great Lakes region: Establishment potential, expert perceptions, and re-evaluation of experimental evidence of ecological impact. Canadian Journal of Fisheries and Aquatic Sciences 71(7): 992–999.

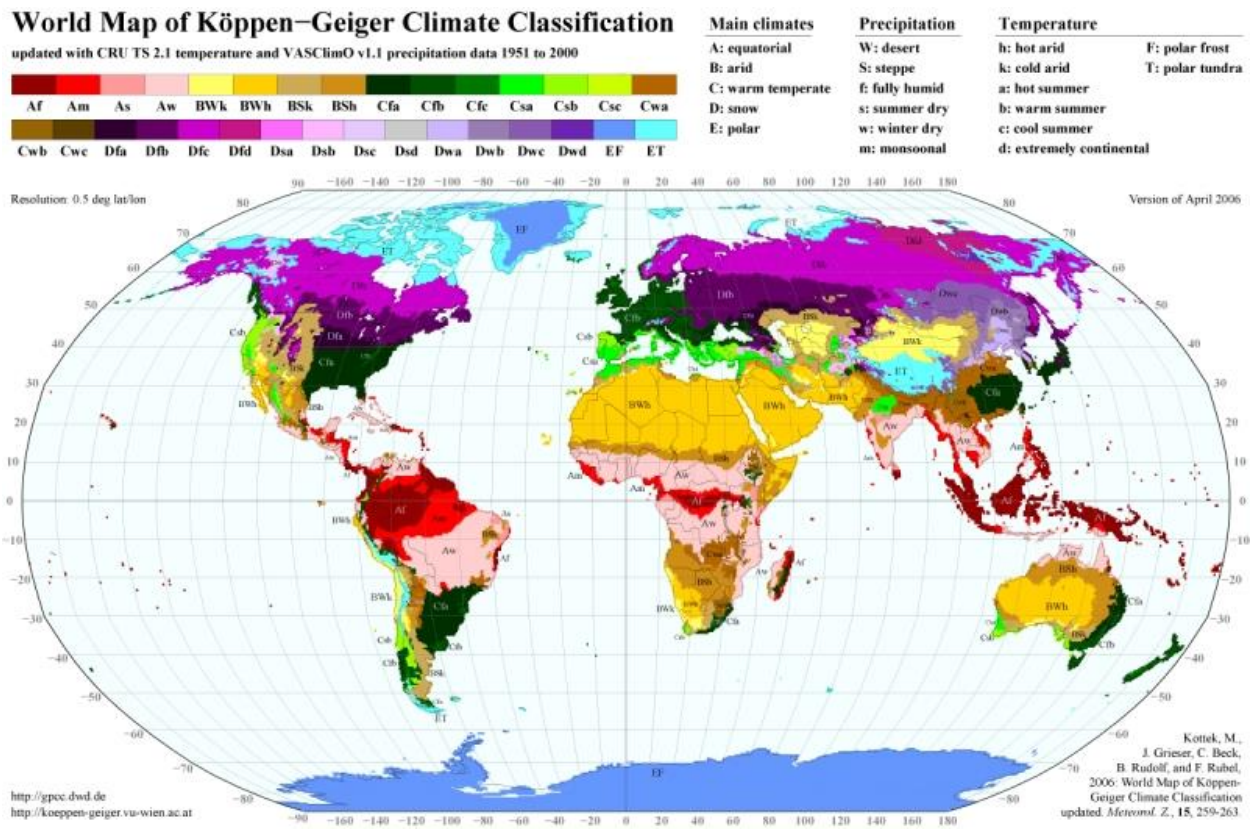
Yarrow, M., V.H. Marín, M. Finlayson, A. Tironi, L.E. Delgado and F. Fischer. 2009. The ecology of *Egeria densa* Planchon (Liliopsida: Alismatales): A wetland ecosystem engineer? Revista Chilena de Historia Natural 82: 299-313.

Appendix 1. Options for conducting climate comparisons.

Visual comparison of climate zone maps

Examples:

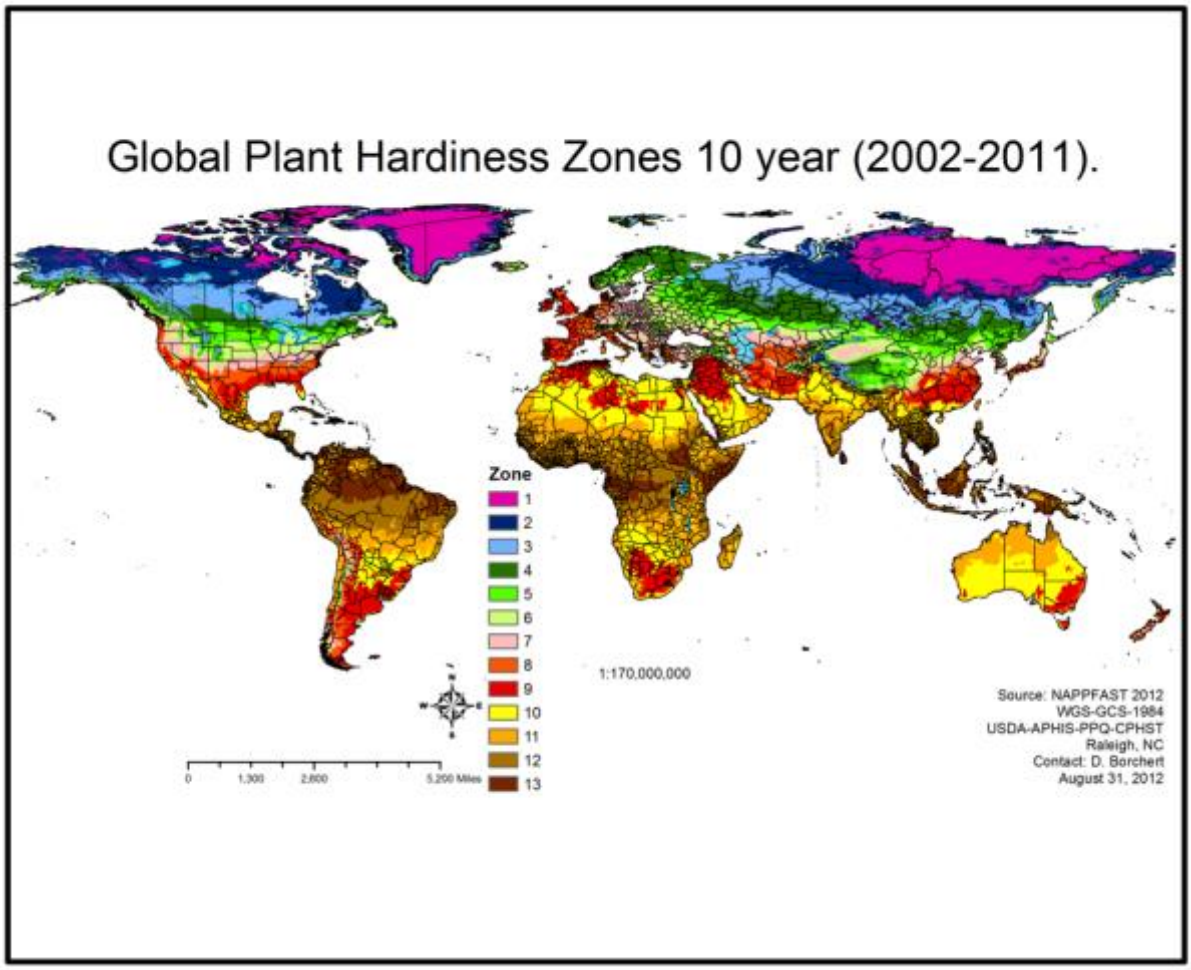
Map of **Köppen-Geiger Climate Zones** available from: koeppen-geiger.vu-wien.ac.at/present.htm



- The global Köppen-Geiger climate zones (Kottek et al. 2006) take into account average minimum winter temperatures and summer maxima (as well as rainfall amount and pattern)
- The climate classification scheme divides climates into five main groups (A, B, C, D, E), each having several types and subtypes. Each particular climate type is represented by a two- to four-letter symbol (with subsequent letters indicating precipitation patterns, and degree of summer heat/winter cold)

- Ontario has three different climate zones (Dfa, Dfb, and Dfc) and is dominated by Dfb.

Map of **Global Plant Hardiness Zones** based on average annual extreme minimum temperatures (Magarey et al. 2008)



- Hardiness zones, which range from 1–13, represent geographically defined areas in which a species is capable of growing, as characterized by long-term climatic conditions including the ability to withstand minimum temperatures within the zone (McKenney et al. 2001).
- Long-term climatic conditions refer to both aquatic and terrestrial environments.
- Climate data used to generate the map span a ten-year period.
- Hardiness zones are variable within a latitudinal zone and reflect a more accurate description of longterm climatic conditions.
- Hardiness zones in Ontario range from 2 (coldest) to 6 (warmest).

Quantitative comparison of climate data using climate-matching software

Examples:

Climatch climate matching software, available from:data.daff.gov.au:8080/Climatch/climatch.jsp or agriculture.gov.au/abares/data (click on Climatch link)

- *Climatch* is a climate-matching algorithm interface that provides regional climatic scores from a global climate database comprising data from weather stations around the world.
- Software tool determines climatic similarity between a Source region (e.g., current global distribution of organism) and Target region (e.g., Ontario).
- User manual available: Crombie, J., Brown, L., Lizzio, J. and Hood, G. (2008). Climatch user manual. Australian Bureau of Rural Sciences.
- Climate match scores range from 0 (poorest match) to 10 (highest level match).
- Scores can be analyzed by calculating Climate 6 ratio (Bomford et al. 2008). Climate 6 = (sum of counts for Climate Scores 6-10)/(Sum of all Climate Scores).

GARP (Genetic Algorithm for Rule Set Production), available from: nhm.ku.edu/desktopgarp/UsersManual.html

Stockwell, D. R. B. 1999. Genetic algorithms II. Pages 123–144 in A. H. Fielding, editor. Machine learning methods for ecological applications. Kluwer Academic Publishers, Boston

Stockwell, D. R. B., and D. G. Peters. 1999. The GARP modelling system: Problems and solutions to automated spatial prediction. International Journal of Geographic Information Systems 13:143–158

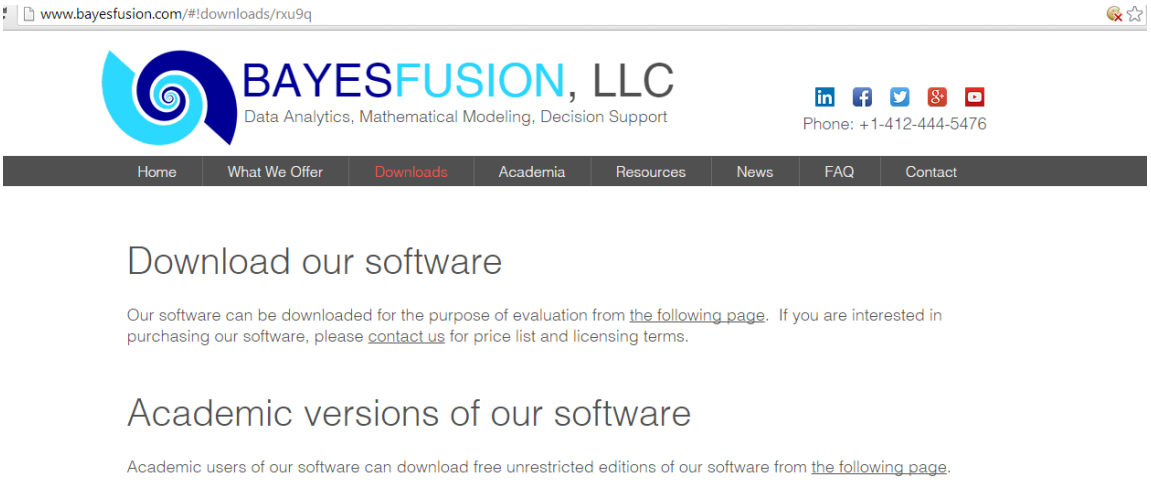
- A computer program based on genetic algorithm that creates ecological niche models for species.
- The generated models describe environmental conditions (precipitation, temperatures, elevation, etc.) under which the species should be able to maintain populations. As input, local observations of species and related environmental parameters are used which describe potential limits of the species' capabilities to survive.

Appendix 2. Guidance on installation of GeNIe software tool

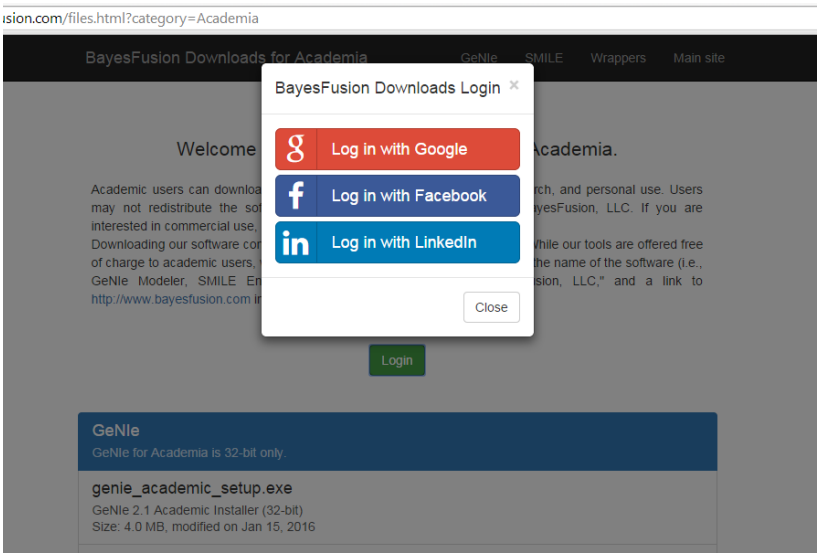
NOTE: For MNRF computers, Administrative Privileges will first be required in order to download and install this software.

The tool is available as a free download from: bayesfusion.com

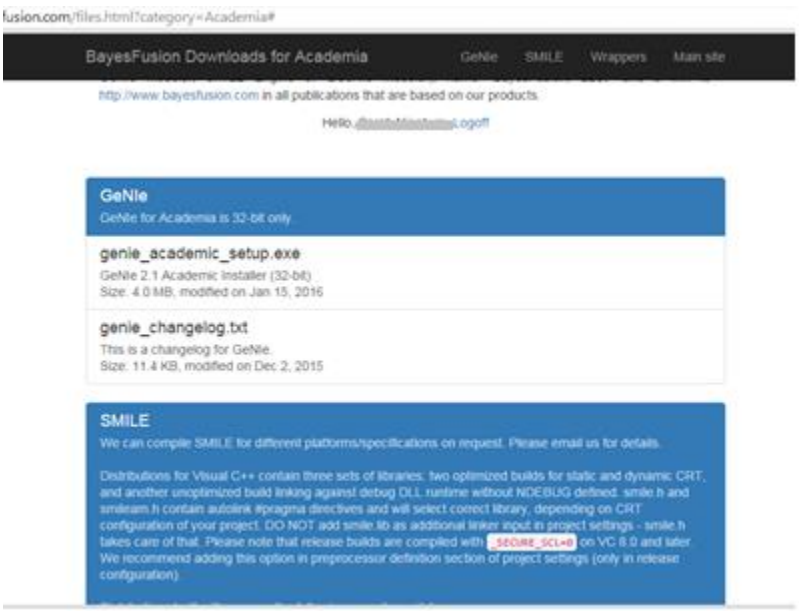
- From the BayesFusion webpage select Downloads
- Under the heading Academic versions of our software click the link to “the following page”



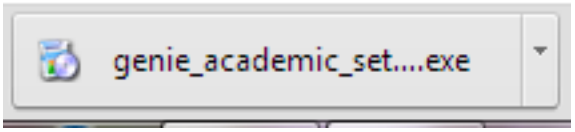
- Select “Login”
- Login using one of the options (e.g., Log in with Google)



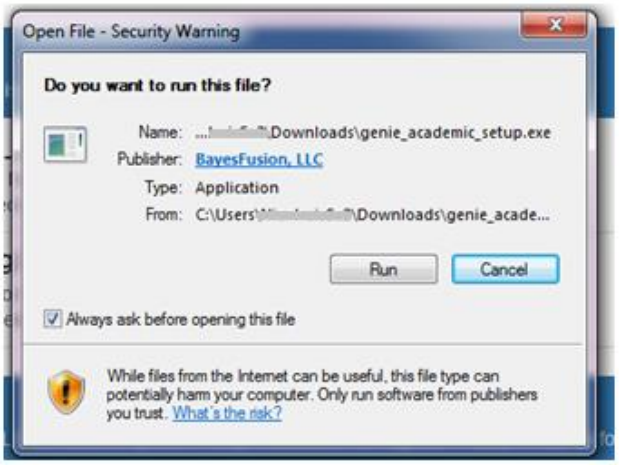
- When prompted, select Allow
- You will be re-directed to the main downloads screen:



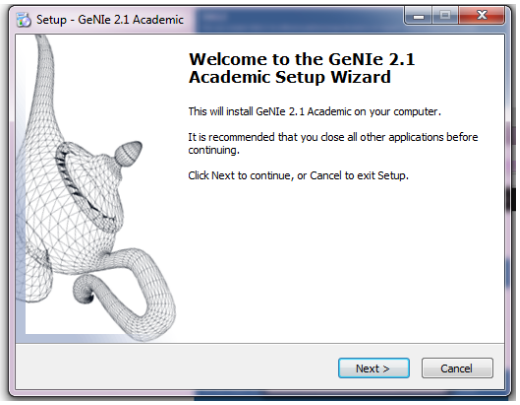
- Select “genie_academic_setup.exe”
- The file download is an executable file
- Once downloaded click the icon shown below to initiate setup



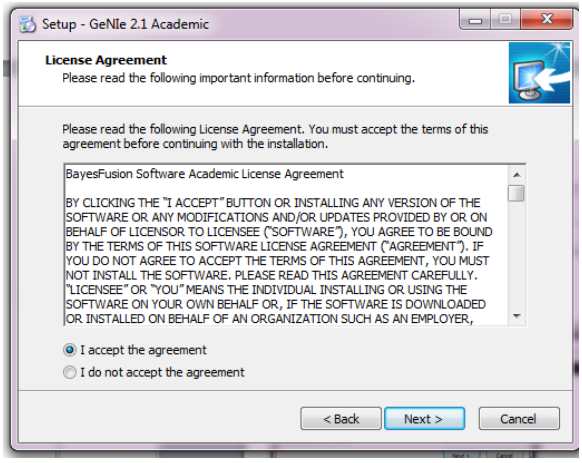
- If prompted with the following pop-up screen to run the file, select Run



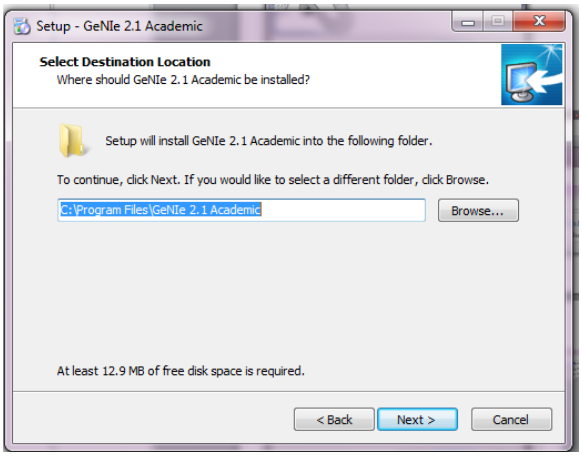
- In the Setup Wizard, select Next



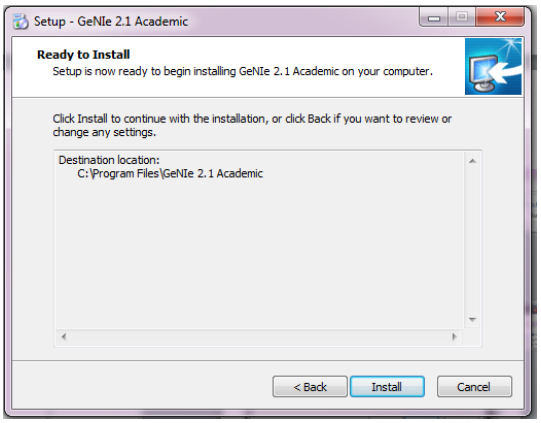
- To finalize installation select I accept the agreement and Next



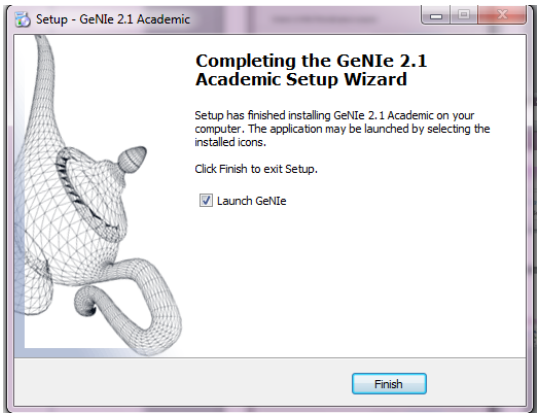
- You will be prompted to select destination location.
- Use folder identified or select a different folder.
- Note location of destination folder for future reference.
- Select Next



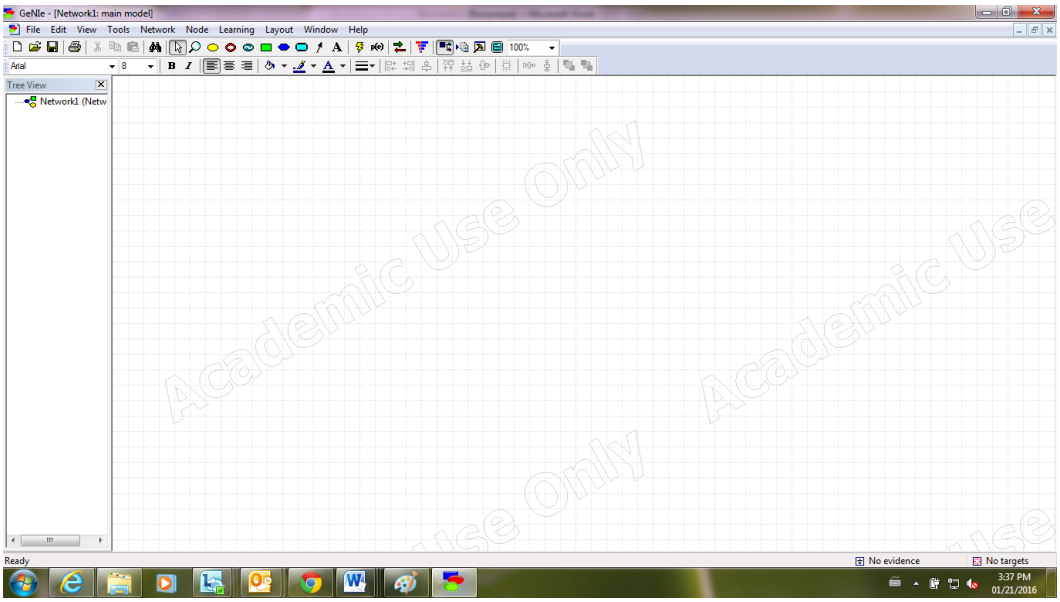
- Select Install



- Select Finish



- GeNIe will open automatically and you will see the following:



- Close GeNIe.
- It is now installed and you can open and use the Risk Modelling Tool.

ISBN 978-1-4606-8858-8 (PDF)