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Application of a Freshwater Mollusc Risk Assessment to Non-indigenous Organisms in Trade in Canada

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

Aquatic invasive species (AIS) threaten global biodiversity and represent the second leading cause of decline among Canadian freshwater species at risk. Establishment of AIS can degrade aquatic habitat, increase competition for resources, and significantly impact long-term sustainability of native species. Fisheries and Oceans Canada (DFO) is mandated to manage and protect Canada's aquatic ecosystems, the health of which can be negatively influenced following the introduction of AIS. Formalized biological risk assessments are able to generate science advice for informed decision making, but are both time and resource intensive. In contrast, screening-level risk assessments (SLRA) are used to assess and prioritize species in a shorter timeframe using information that is readily available. SLRA have been applied across multiple taxonomic groupings (freshwater fishes, molluscs, and plants) to provide a protocol to identify high risk aquatic AIS to (and within) Canada and provide a national ranking of aquatic AIS based on the biological risk they pose to Canadian aquatic ecosystems. This research document evaluates the application of a SLRA protocol for screening of freshwater molluscs in trade within Canada.

A total of 73 freshwater mollusc species were identified as being available in the live trade pathway and capable of becoming established in Canadian fresh waters including 15 potential species that demonstrate the biological attributes to be considered a nuisance species, species which cause environmental and/or economic damages. Of the 27 mollusc species already introduced to Canada, 14 are considered nuisance species, such as Zebra Mussel and New Zealand Mud Snail, known to have negative impacts on native species.

Mise en application d’une évaluation des risques des mollusques d'eau douce aux organismes non indigènes apparaissant dans le commerce au Canada

RÉSUMÉ

Les espèces aquatiques envahissantes (EAE) constituent une menace pour la biodiversité mondiale et représentent la deuxième cause du déclin des espèces d'eau douce en péril au Canada. L'établissement des EAE peut contribuer à la dégradation de l'habitat aquatique, à l'augmentation de la compétition pour les ressources, et avoir des répercussions considérables sur la viabilité à long terme des espèces indigènes. Pêches et Océans Canada (MPO) a la responsabilité de gérer et de protéger les écosystèmes aquatiques du Canada dont la santé peut être détériorée par l'introduction d'EAE. Les évaluations formalisés du risque biologique permettent la production d'avis scientifiques à l’appui de la prise de décisions éclairées, mais exigent tous deux qu'on y consacre beaucoup de temps et de ressources. En revanche, des évaluations préalables des risques (EPR) sont utilisées pour évaluer et prioriser les espèces dans un délai plus court en utilisant de l'information facilement accessible. Les EPR ont été appliquées à divers regroupements taxonomiques (poissons, mollusques et plantes d'eau douce) afin d'établir un protocole permettant d'identifier les EAE posant un risque élevé pour le Canada et un classement national des EAE fondée sur le risque biologique qu'elles posent pour les écosystèmes aquatiques canadiens. Ce document de recherche évalue l'application d'un protocole d'EPR pour l'examen préalable des mollusques d'eau douce apparaissant dans le commerce au Canada.

Au total, 73 espèces de mollusques d'eau douce ont été identifiées comme étant disponibles dans le commerce des espèces vivantes et ayant la capacité de s'établir dans les eaux douces canadiennes, dont 15 espèces potentielles qui présentent les caractéristiques biologiques des espèces considérées comme nuisibles. Parmi les 27 espèces de mollusques déjà introduites au Canada, 14 sont considérées comme des espèces nuisibles, notamment la moule zébrée et la nasse de Nouvelle-Zélande, dont les répercussions négatives sur les espèces indigènes sont connues.

INTRODUCTION

Aquatic invasive species (AIS) threaten global biodiversity (Sala et al. 2000) and are the second leading cause for decline of Canadian freshwater species at risk (Dextrase and Mandrak 2006). The establishment of AIS can reduce the abundance or productivity of sport, commercial, or culturally important species and can cause habitat alteration (Rahel 2002). Therefore, preventing the arrival, establishment, and spread of AIS is an important step to protecting aquatic environments (Kolar 2004).

Fisheries and Oceans Canada (DFO) is mandated to manage and protect Canada's aquatic ecosystems, the health of which are currently jeopardized by the arrival of AIS that can cause ecosystem harm. To aid in the development of DFO regulation, legislation, and management plans to protect Canadian aquatic environments from the impacts of AIS, DFO's Centre of Expertise for Aquatic Risk Assessment (CEARA) is tasked with identifying, assessing, and prioritizing the threats of current and potential aquatic non-indigenous species (NIS). Biological risk assessment protocols provide an appropriate approach to meet this need, as they generate science advice for informed decision making to prevent potential, or deal with ongoing, invasions by predicting the identity, range, and/or impact of potential invaders (Kolar 2004).

CEARA is developing a three-stage biological risk assessment process for aquatic NIS (Chapman et al. 2006, 2009, Mandrak et al. 2012). The three stages include: a) rapid assessment process (RAP) to assess a species within a few days using minimal information; (b) screening-level risk assessment (SLRA) to assess and prioritize a species in about a week using additional information that is readily available; and, (c) detailed-level risk assessment (DLRA) to assess a species within several months using detailed information (Mandrak et al. 2012). Depending on the goal of the risk assessment, increasingly more detailed risk assessments can then be undertaken with the DLRA providing the strongest defensible advice with the least amount of uncertainty.

AIS are introduced into Canadian fresh waters through various vectors and pathways, some of which are associated with the live trade pathway. Freshwater molluscs are primarily found in the ballast water, live food, aquarium, and water garden pathways (Cowie and Robinson 2003). In the United States, the number of households with water gardens quadrupled between 1998 and 2003, reaching an estimated value of US$1.56 billion (Gordon et al. 2012) and the global trade in species for aquaria and water gardens is growing by 14% per year (Padilla and Williams 2004). These trades pose a potential risk of introducing into, and/or spreading non-indigenous molluscs within, Canadian freshwater ecosystems though accidental or deliberate unauthorized release. A recent survey found that snails were the most common animal added to water gardens and that about 3% of water garden owners released animals into the wild (Marson et al. 2009a). Another recent survey of aquarium owners found that 15% added snails to their aquaria and that 1% released animals into the wild (Marson et al. 2009b). Eight of the 22 species of mollusc introduced to North America have been attributed to the ornamental trade, either by intentional release of unwanted specimens or by unintentional introduction from aquaria or water garden supply (Mackie 2000).

The Canadian Food and Inspection Agency (CFIA) and DFO regulate the import and export of aquatic animal species susceptible to reportable (i.e., diseases of significant importance to aquatic animal health or the Canadian economy) and immediately notifiable (i.e., diseases that do not exist in Canada) diseases through the National Aquatic Animal Health Program, consistent with the international standards set by the World Organization for Animal Health (OIE). However, there is currently no national regulation of live mollusc species imported to Canada related to invasiveness. There are also no guidelines for assessment and prioritization as to which mollusc species in trade are of highest risk should they be accidentally or intentionally introduced into Canadian fresh waters.

BACKGROUND

In 2010, DFO's Aquatic Invasive Species program was tasked by both the Office of the Auditor General and an internal evaluation to establish a protocol to provide a scientifically defensible and relatively quick way of screening and prioritizing aquatic NIS. The national ranking of aquatic NIS, based on the biological risk they pose to Canadian aquatic ecosystems, is necessary to screen species for inclusion in AIS regulatory proposals and to better prioritize national and regional NIS program activities and resource allocation. DFO's Legislative and Regulatory Affairs, also a client in this process, requested science advice to support the development of a national regulatory proposal for addressing aquatic NIS. Specifically, it had requested: 1) a protocol to prioritize aquatic NIS; and, 2) a list of high risk aquatic NIS including those NIS already present in some regions of Canada whose transport into other areas in Canada where not present should be limited. This protocol would allow the ranking of aquatic NIS for national priorities and would be used as a biological screening tool for aquatic NIS to determine (in a short time frame) if a detailed-level risk assessment or a risk management evaluation was required based on existing information.

Screening-level risk assessment was identified as the appropriate level to support the development of these regulations by DFO. A suitable SLRA protocol is applicable in a variety of risk assessment contexts and is a means to quickly assess species known to occur in Canada, as well as species proposed for, or currently found in, trade and other pathways that have intermediate or end points within Canada. Prioritization of aquatic NIS can also be determined using the estimated level of risk posed by the species and associated uncertainty, as quantified by the SLRA (Mandrak et al. 2012). Furthermore, with the establishment of appropriate threshold criteria or parameters, the SLRA can supply a risk-based biological screening of aquatic NIS, providing a priority species list for managers and decision makers that requires either a detailed-level risk assessment or a risk management evaluation (Locke et al. 2011). A SLRA protocol would provide DFO with a scientifically defensible and relatively quick means of screening and prioritizing aquatic NIS based on the biological risk they pose to Canadian aquatic ecosystems.

In 2011, a national Canadian Science Advisory Secretariat (CSAS) science peer review process was initiated to provide science advice on the SLRA protocol for aquatic NIS. This process was to consist of at least two peer-review meetings attended by experts from DFO Science, Legislative and Regulatory Affairs, and other sectors of the Department, as well as invited external participants (e.g., other governmental departments, provincial governments, and academics) who could meaningfully contribute to the science review. Part 1 was held in Montreal, Quebec on November 22-24, 2011 (DFO 2012). At that meeting, participants examined the criteria and methodology used to evaluate the various risk assessment protocols (Snyder et al. 2013) and developed a framework for a SLRA protocol for aquatic NIS. Based on this peer review, it was identified that different SLRA protocols may be required for different aquatic NIS taxa and, hence, prioritization using a single protocol may not be possible. Part 2 was held in Burlington, Ontario on March 19-21, 2013. Participants evaluated SLRA protocols for freshwater NIS currently in trade within Canada and lists of potentially invasive species generated from the application of a subset of the protocols. SLRA protocols were evaluated and applied to freshwater fishes, molluscs, and plants currently in trade within Canada. DFO Legislative and Regulatory Affairs confirmed that screening species not yet in Canada was the priority; therefore, NIS already present in some regions of Canada were not included. Additional meetings, not yet scheduled, will be required in the future to evaluate SLRA protocols for marine

NIS, to assess the ability to prioritize all NIS using the chosen SLRA protocols, and to screen NIS already present in some regions of Canada.

PURPOSE

This research document evaluates the application of a SLRA protocol (Keller et al. 2007) for screening of freshwater molluscs in trade within Canada. Comprehensive data are not available on the introduction, establishment, and invasiveness status of freshwater mollusc NIS in Canada; therefore, a Canada-specific SLRA protocol cannot be created. Therefore, the Keller et al. (2007) mollusc NIS SLRA protocol was applied to a list of freshwater mollusc species, known in North American or Canadian trade, screened in after climate matching.

METHODS

A number of biological attributes have been identified as characteristic of species that have become successful invaders including high reproductive capacity, a broad range of environmental tolerances, rapid growth, and ease of dispersal (Baker 1974, Kolar and Lodge 2001; Sakai et al. 2001; Karatayev et al. 2009). Keller et al. (2007) developed a SLRA tool to predict invasiveness for freshwater molluscs using logistic regression as well as categorical and regression tree (CART) analyses based on eight natural history traits of 27 freshwater mollusc NIS in the United States. Based on these analyses, fecundity, the total number of offspring produced by an individual on an annual basis, was shown to be the best predictor of invasive freshwater mollusc species should they become established outside of their native range (Keller et al. 2007). Conversely, characteristics often associated with AIS, including history of invasion and latitudinal range, were not good predictors (Keller et al. 2007). Nuisance species are those for which credible evidence of environmental and/or economic harm has been documented; whereas, those species for which no discernible impacts have been identified are classified as benign (Keller et al 2007). The CART analysis identified the fecundity threshold between benign and nuisance freshwater molluscs to be 162 (Figure 1). Nuisance species had fecundities of >162 offspring/female/year and benign species had fecundities of <162 (Keller et al. 2007). False negatives were relatively low as 17% (1/6) of species were incorrectly screened as nuisance for the Great Lakes and 27% (3/11) of species were incorrectly screened as nuisance for the United States. There were no false positives (i.e., nuisance species incorrectly screened as benign). The estimated overall misclassification rate was 1 in 15 (7%). Jackknife analysis gave a misclassification rate of 20%, with the splitting point of fecundity ranging from 119.5 to 190. This range of possible thresholds represents the range of uncertainty. Identifying an acceptable level of uncertainty is a risk management decision; therefore, screening results will be provided for a range of thresholds. Risk managers will need to decide which threshold best represents their level of risk tolerance.

Based on the logistic regression analysis, fecundity was the only natural history trait used that significantly predicted the nuisance status for the Great Lakes ($p=0.002$, $c=0.960$; Figure 2) (Keller et al. 2007). Similarly, fecundity significantly predicted nuisance status for the contiguous 48 states ($p <0.001$, $c = 0.923$) (Keller et al. 2007).

The evaluation and refinement of a similar tool specific to Canada is not currently possible as comprehensive data are not available on the introduction, establishment, and invasiveness status of freshwater mollusc NIS in Canada. Therefore, the Keller et al. (2007) tool was used to screen freshwater mollusc NIS known, or potentially in, Canadian trade in the following manner: 1) develop a freshwater mollusc species in trade list; 2) screen in species whose native and established introduced range is a climate match to Canada; and, 3) screen the remaining species for invasiveness using the Keller et al. (2007) SLRA protocol.

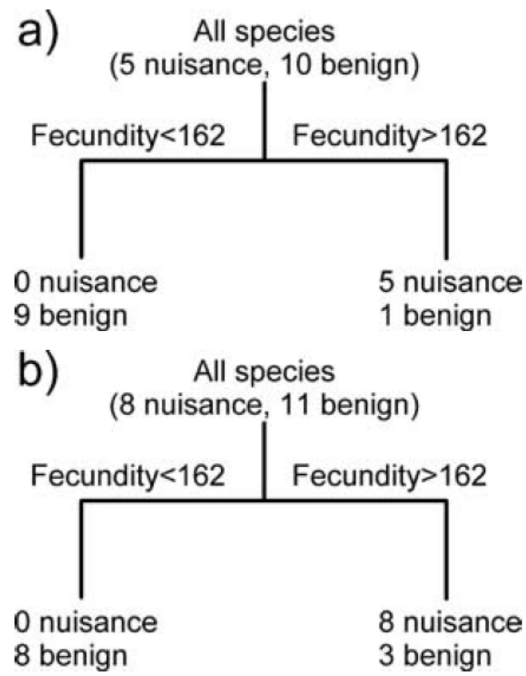

Figure 1. Decision trees for determining whether a freshwater mollusc species will be a nuisance or benign, produced using CART analysis, for: a) the Laurentian Great Lakes basin and, b) the 48 contiguous states of the United States. For the Great Lakes analysis, fecundity was one of eight predictor variables but the only one chosen by the model. For the United States analysis, fecundity was the only predictor used. From Keller et al. 2007.

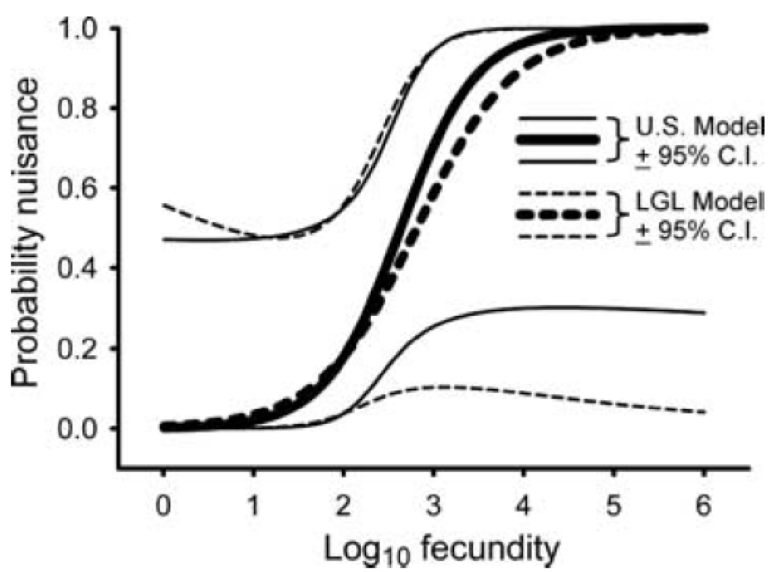

Figure 2. Logistic curves (±95% CI) showing the relationship between fecundity and probability of becoming a nuisance (i.e., causing economic and/or environmental harm) for molluscs in the Laurentian Great Lakes (LGL) and 48 contiguous states of the United States (US). For the Great Lakes analysis, fecundity was one of eight predictor variables but the only one chosen by the model. For the United States analysis, fecundity was the only predictor used. From Keller et al. 2007.

FRESHWATER MOLLUSC SPECIES IN TRADE LIST

Freshwater molluscs currently in trade in North America were identified through a series of literature searches, online searches of aquarist, water garden, biological supply, and live bait websites. This list was supplemented by aquarium and water garden wholesaler and retailer surveys undertaken in the Toronto area (OMNR, Aurora District, unpubl. data) and similar survey data from Wisconsin (S. Van Egeren, WI Dept. Natural Resources, unpubl. data). Native species from regions (Florida, California, Maine, Missouri; Stephens et al., in press) that actively export plants or other aquatic media to Canada were also included as potential hitch-hikers in trade. Only species that are exclusively freshwater taxa were included. A total of 87 freshwater mollusc species were identified (Appendix 1).

SCREENING FRESHWATER MOLLUSC SPECIES BASED ON CLIMATE TOLERANCE FOR CANADA

As detailed distribution maps of the native and established ranges are not readily available for most of the species, climate matching methods that measure the climatic similarity between a Source region (e.g., plant species distribution) and a Target region (e.g., Canada), such as *Climatch*, (Bureau of Rural Sciences 2008), could not be used. As an alternative, USDA hardiness zones, which range 1-13, were used (Figure 3). Hardiness zones 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 of the zone (McKenney et al. 2001). These long-term climatic conditions refer to both aquatic and terrestrial environments and plant hardiness zones are widely used to infer climatic trends in regions such as Canada (McKenney et al. 2001). Hardiness zones are variable within a latitudinal zone and reflect a more accurate description of longterm climatic conditions. This may be used to more effectively match source and target habitat similarity and guide predictions of establishment success by nuisance species. Latitude was not shown to effectively predict invasiveness in earlier studies (Keller et al. 2007).The Global Plant Hardiness Zones (Figure 3), as identified by NCSU/APHIS Plant Pest Forecast (NAPPFAST), were used. The NAPPFAST System is an internet tool for plant pest modeling using georeferenced climatological weather data and represents a joint venture between the Animal and Plant Health Inspection Service (APHIS), North Carolina State University (NCSU), and the information technology company ZedX, Inc. The NAPPFAST System is designed to support the predictive pest mapping needs of the Cooperative Agricultural Pest Survey (CAPS) program and the risk assessment activities of the Pest Epidemiology Risk Assessment Laboratory (PERAL). Climate data for a ten-year span (2002-2011) were used.

Hardiness zones in Canada range from 1 (coldest) to 10 (warmest) out of a possible 13 hardiness zones. Therefore, only freshwater mollusc species with native ranges in hardiness zones of 10 or less were screened in for final invasiveness screening using Keller et al. (2007). Hardiness zones for each freshwater mollusc species were identified through computer-based searches of peer-reviewed sources, online hobbyist websites, IUCN Red List of Threatened Species, USGS online database of aquatic invasive species, and other references provided in Appendix 2. Where a species spanned multiple hardiness zones, the most conservative estimate of hardiness was selected (lowest thermal regime identified was retained).

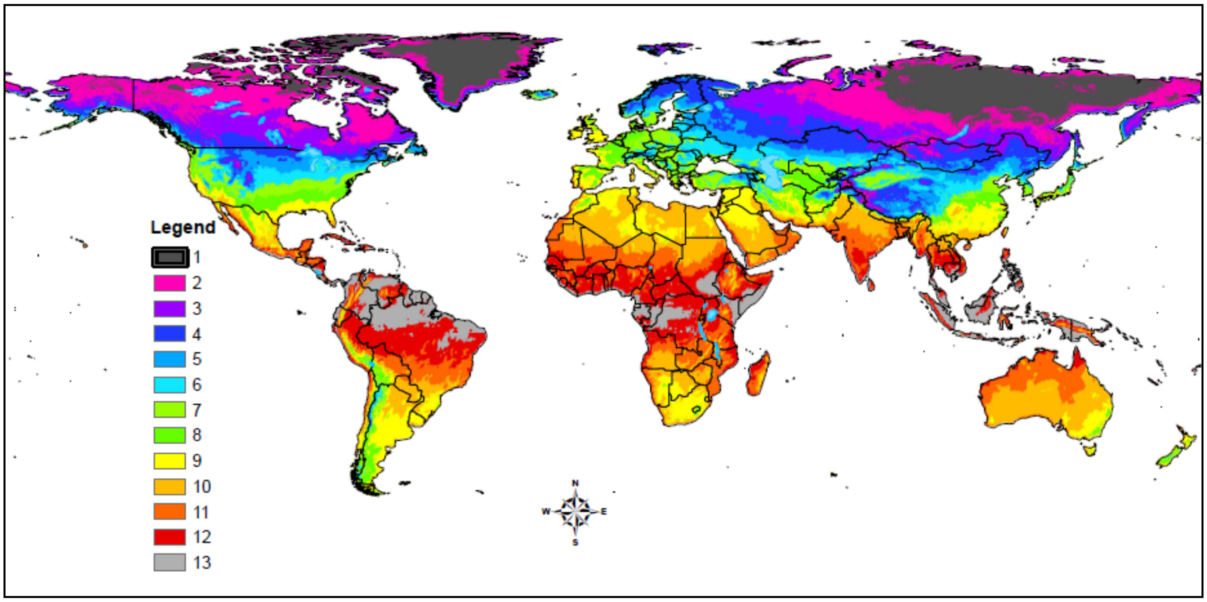

Figure 3. USDA Global Plant Hardiness Zones based on 2002-2011 climate data

SCREENING FRESHWATER MOLLUSC SPECIES FOR INVASIVENESS IN CANADA

The species identified to have suitable climate tolerances for Canada were subsequently screened for invasiveness using Keller et al. (2007). Although only fecundity is required for the Keller et al. (2007) protocol, additional data, potentially beneficial for more detailed management needs (e.g., Therriault et al. 2013), were compiled including history of invasion, parasite or pathogen burden, alkalinity, environmental calcium, and temperature thresholds. Information on biological attributes was obtained through computer-based searches of peer-reviewed sources, online hobbyist websites, IUCN Red List of Threatened Species, USGS online database of aquatic invasive species, and other references provided in Appendix 2. There was significant variation in the amount of information available on a number of species included for screening. In general, natural history information for molluscs is limited (Keller et al. 2007). Although fecundity was identified as being the most important predictive attribute for identifying potential invaders, this parameter was not available for 31 species; therefore, these species could not be assessed. Fecundity data were recorded as the highest possible annual fecundity per species. Where multiple spawning events were estimated on an annual basis, per-event fecundity was multiplied by the number of annual spawning efforts and the highest value estimated was retained.

RESULTS AND DISCUSSION

Of the 87 freshwater mollusc species identified in North American or Canadian trade (Appendix A), 73 had climate tolerances to hardiness zones 1-10, including 32 species that had climate tolerances to hardiness zones 8-10, found only on southern Vancouver Island. Information on hardiness zones could not be found for three species. Of those species not already established in Canada, 15 species had fecundities greater than 162, including 11 tolerant only of hardiness zones 8-10 (Tables 1, 2); these species would be screened in as nuisance species. The results would not change at thresholds of 119 and 189. Information on the fecundity of 31 of the 87 species could not be found.

Of the 27 freshwater mollusc NIS established in Canada, 14 have fecundities greater than 162 (Table 3). Of those 14 species, three have undergone detailed-level risk assessment. Quagga Mussel and Zebra Mussel were assessed as high risk (Therriault et al. 2013), and New Zealand Mudsnail was assessed as moderate risk, to Canadian aquatic ecosystems (Therriault et al. 2011). Although Asian Clam has not been formally assessed, it is known to be an invasive species (Ricciardi 1998; Magara et al. 2001; Cataldo et al. 2012). The European Ear Snail and European Stream Valvata have negatively impacted native gastropods, and the Faucet Snail is thought to be benign (Harman 2000; Haynes et al. 2005). Therefore, six of the 14 species have been assessed, or are thought to be, invasive. The impacts of the 13 species with fecundities less than 119 are largely unknown although the Chinese Mysterysnail is considered benign, Japanese Mysterysnail a net fouler, and the European Fingernail Clam a parasite host (Mackie 1976; Mackie 2000). These observations largely support the fecundity thresholds of 119-189 to differentiate nuisance from benign species.

Table 1. Number of molluscs, not established in Canada, screened in as nuisance species at three annual fecundity thresholds by hardiness zone tolerance.

	Annual Fecundity >		
Hardiness Zone	119	161	189
1	0	0	0
2	0	0	0
3	0	0	0
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	4	4	4
9	7	7	7
10	0	0	0

Table 2. Mollusc species, not known to be established in Canada, screened in as nuisance species at an annual fecundity threshold of 162. References found in Appendix A.

Scientific Name	Common Name	Established in Canada	Hardiness Zone	Annual Fecundity
Biomphalaria alexandrina		Unknown	9	2439
Biomphalaria glabrata	Bloodfluke Planorb	Unknown	8	356
Biomphalaria pfeifferi		No	8	11902
Biomphalaria straminea		No	9	1730
Bulinus truncatus		Unknown	8	1455
Elimia livescens	Liver Elimia	Unknown	5	399
Indoplanorbis exustus		No	9	6132
Lymnaea palustris (Stagnicola palustris)		Unknown	4	310
Lymnaea peregra		Unknown	6	1400
Melanoides tuberculata	Malaysian Trumpet Snail, Red-rimmed Melania	No	9	365
Pomacea bridgesi	Apple Snail, Spiketop Apple Snail, Golden Mystery Snail	No	7	600
Pomacea canaliculata	Golden/Channelled Apple Snail	No	9	4355
Pomacea haustrum	Titan Apple Snail	No	9	236
Pomacea insularum	Island Apple Snail	No	9	700
Tarebia granifera (Thiara granifera)	Quilted Melania	No	8	213

Table 3. Freshwater mollusc NIS known to be established in Canada. Note that there were no species with annual fecundities between 119 and 162. References found in Appendix A.

Scientific Name	Common Name	Established in Canada	Annual Fecundity	Hardiness Zone
Dreissena bugensis	Quagga Mussel	Yes	960000	6
Dreissena polymorpha	Zebra Mussel	Yes	960000	6
Fusconia flava	Wabash Pigtoe	Yes	200000	4
Corbicula fluminea	Asian Clam	Yes	68678	3
Lymnaea natalensis (=Radix natalensis)		Yes	7148	9
Lymnaea peregra		Yes	1400	6
Radix auricularia	European Ear Snail, Big-eared Radix	Yes	1300	2
Valvata piscinalis	European Stream Valvata	Yes	450	2
Bithynia tentaculata	Faucet Snail	Yes	347	3
Helisoma anceps	Two-ridge Rams Horn	Yes	336	2
Lymnaea palustris (=Stagnicola palustris)		Yes	310	4
Lymnaea stagnalis		Yes	240	2
Potamopyrgus antipodarum	New Zealand Mudsnail	Yes	230	7
Physa fontinalis	Common Bladder Snail	Yes	174	2
Bellamya chinensis	Chinese Mysterysnail	Yes	65	2
Bellamya japonica (=Cipangopaludina japonica)	Japanese Mysterysnail	Yes	65	7
Pisidium corneum (=Sphaerium corneum)	European Fingernail Clam	Yes	62	5
Physella acuta	European Physa	Yes	50	5
Musculium partumeium	Swamp Fingernail Clam	Yes	45	2
Musculium lacustre	Lake Fingernail Clam	Yes	35	4
Helisoma trivolvis (=Planorella trivolvis)		Yes	30	2
Pisidium henslowanum	Henslow Peaclam	Yes	25	4
Pisidium moitesserianum	Pygmy Peaclam	Yes	20	2
Pisidium supinuum	Humpbacked Peaclam	Yes	12	5
Pisidium amnicum	Greater European Peaclam	Yes	10	2
Capeloma decisum	Pointed Campeloma	Yes		5

SUMMARY

- Of the 87 freshwater mollusc species identified in North American or Canadian trade:
    - 73 had climate tolerances to hardiness zones 1-10, including 32 species with climate tolerances to hardiness zones 8-10, found only on southern Vancouver Island.
    - Information on hardiness zones could not be found for three species.
- Of those species not already established in Canada:
    - 15 species had fecundities greater than 162, including 11 tolerant only of hardiness zones 8-10; these species would be screened in as nuisance species.
    - Results would not change at thresholds of 119 and 189.
    - Information on the fecundity of 31 of the 87 species could not be found.
- Of the 27 freshwater mollusc NIS established in Canada:
    - 14 have fecundities greater than 162 (Table 3).
    - Of those 14 species, Quagga Mussel and Zebra Mussel have been assessed as high risk, and New Zealand Mud Snail was assessed as moderate risk based on detailed-level risk assessments.
    - Asian Clam has not been formally assessed, but is known to be an invasive species
    - Of the remaining 10 of 14 species, European Ear Snail and European Stream Valvata have negatively impacted native gastropods, and the Faucet Snail is benign.
    - Therefore, six of the 14 species have been previously assessed, or are thought to be, invasive.
    - Impacts of the 13 species with fecundities less than 119 are largely unknown although the Chinese Mystery Snail is considered benign, Japanese Mystery Snail a net fouler, and the European Fingernail Clam a parasite host.
    - These observations largely support the fecundity thresholds of 119-189 to differentiate nuisance from benign species.
- Limitations of the Keller et al., (2007) model are as expected when biological data, notably estimates of annual fecundity, are not available.

REFERENCES CITED

Baker, H.G. 1974. The evolution of weeds. Annu. Rev. Ecol. Syst. 5:1-24.

Cataldo, D., Farrell, I.O., Paolucci, E., Sylvester, F., and Boltovskoy, D. 2012. Impact of the invasive golden mussel (*Limnoperna fortunei*) on phytoplankton and nutrient cycling. Aquatic Invasions 7: 91-100.

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

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

Cowie, R.H., and Robinson, D.G. 2003. Pathways of introduction of nonindigenous land and freshwater snails and slugs. *In* Invasive species: vectors and management strategies. Edited by G. Ruiz and J.T. Carlton. Island Press. Washington, D.C. p. 93-122.

Dextrase, A.J., and Mandrak, N.E. 2006. Impacts of alien invasive species on freshwater fauna at risk in Canada. Biol. Invasions 8: 13-24.

DFO. 2012. Proceedings of the Meeting on Screening-Level Risk Assessment Prioritization Protocol for Aquatic Non-Indigenous Species; November 22-24, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/068.

Gordon, D.R., Gantz, C.A., Jerde, C.L., Chadderton, W.L., Keller, R.P., and Champion, P.D. 2012. Weed risk assessment for aquatic plants: modification of a New Zealand system for the United States. PLoS ONE 7: e40031.

Harman, W.N. 2000. Diminishing species richness of mollusks in Oneida Lake, New York State, USA. Nautilus 114: 120-126.

Haynes, J.M., Trisch, N.A., Mayer, C.M., and Rhyne, R.S. 2005. Benthic macroinvertebrate communities in southwestern Lake Ontario following invasion of Dreissena and Echinogammarus: 1983-2000. J. N. A. Benth. Soc. 24: 148-167.

Karatayev, A.Y., Burlakova, L.E., Padilla, D.K., Mastitsky, S.E., and Olenin, S. 2009. Invaders are not a random selection of species. Biol. Invasions 11: 2009-2019

Keller, R.P., Drake, J.M., and Lodge, D.M. 2007. Fecundity as a basis for risk assessment of nonindigenous freshwater molluscs. Conserv. Biol 21: 191-200.

Kolar, C.S. 2004. Risk assessment and screening for potentially invasive species. New Zeal. J. Mar. Fresh. 38: 391-397.

Kolar, C.S., and Lodge, D.M. 2001. Progress in invasion biology: predicting invaders. Trends Ecol. Evol. 16:199-204.

Locke, A., Mandrak, N. E., and Therriault, T.W. 2011. A Canadian rapid response framework for aquatic invasive species. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/114. vi + 30 p.

Mackie, G.L. 1976. Trematode parasitism in the Sphaeriidae clams, and the effects in three Ottawa River species. Nautilus 90: 36-41.

Mackie, G. L. 2000. Ballast water introductions of mollusca. *In* Nonindigenous freshwater organisms: vectors, biology and impacts. Edited by R. Claudi and J.H. Leach. Lewis Publishers, Boca Raton, Florida. p. 219-254.

Magara, Y., Matsui, Y., Goto, Y., and Yuasa, A. 2001. Invasion of the non-indigenous nuisance mussel, Limnoperna fortune, into water supply facilities in Japan. J. Water Supply Res T. 50: 113-124.

Marson, D., Cudmore, B., Drake, D.A.R., and Mandrak, N.E. 2009a. Summary of a survey of water garden owners in Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2906: v + 23 p.

Marson, D., Cudmore, B., Drake, D.A.R., and Mandrak, N.E. 2009b. Summary of a survey of aquarium owners in Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2905: iv + 20 p.

Mandrak, N.E., Cudmore, B., and Chapman, P.M. 2012. National Detailed-Level Risk Assessment Guidelines: Assessing the Biological Risk of Aquatic Invasive Species in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/092. vi + 15 p.

McKenney, D.E.W., Hutchinson, M.F., Kesteven, J.L., and Venier, L.A. 2001. Canada's plant hardiness zones revisited using modern climate interpolation techniques. Can. J. Plant Sci. 81: 129-143.

Padilla, D.K., and Williams, S.L. 2004. Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. Front. Ecol. Environ. 2:131-138.

Rahel, F.J. 2002. Homogenization of freshwater faunas. Annu. Rev. Ecol. Syst. 33: 291-315.

Ricciardi, A. 1998. Global range expansion of the Asian mussel *Limnoperna fortunei* (Mytilidae): another fouling threat to freshwater systems. Biofouling 13: 97-106.

Sakai, A.K., Allendorf, F.W., Holt, J.S., Lodge, D.M., Molofsky, J., With, K.A., Baughman, S., Cabin, R.J., Cohen, J.E., Elstrand, N.C., McCauley, D.E., O'Neil, P., Marker, I.M., Thompson, J.N., and Weller, S.G. 2001. The population biology of invasive species. Annu. Rev. Ecol. Syst. 32: 305-332.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., and Wall, D.H. 2000. Global Biodiversity Scenarios for the Year 2100. Science 287: 1770-1774.

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

Stephens, H., Cudmore, B., and Gerson, H. in press. Summary of live fish imports into Canada. Can. Tech. Rep. of Fish. Aquat. Sci. 2955: v + 76 p.

Therriault, T.W., Weise, A.M., Gillespie, G.E., and Morris, T.J. 2011. Risk assessment for New Zealand mud snail (*Potamopyrgus antipodarum*) in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/108. vi + 93 p.

Therriault, T.W., Weise, A.M., Higgins S.N., Guo, S., and Duhaime, J. 2013. Risk Assessment for Three Dreissenid Mussels (*Dreissena polymorpha, Dreissena rostriformis bugensis,* and *Mytilopsis leucophaeata*) in Canadian Freshwater Ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/174. v + 88 p.

APPENDIX A. FRESHWATER MOLLUSCS AVAILABLE IN CANADA VIA LIVE TRADE PATHWAYS AND SCREENED USING THE KELLER ET AL. (2007) MODEL

Scientific Name	Common Name	Established in Canada	Hardiness Zone (ref)	Annual Fecundity (ref)	Additional Information References
Ancylus fluviatilis	River Limpet	No	3(e)	80 (a)	b, m, n
Anodonta cygnea	Swan mussel	No	2 (135)		
Bellamya chinensis (=Cipangopaludina chinensis) and *C. chinensis maleata*	Chinese Mystery Snail	Yes	2 (o)	65 (a)	b, d, g, h, i, j k, l
Bellamya japonica (=Cipangopaludina japonica)	Japanese Mystery Snail	Yes	7 (p)	65 (a)	b
Biomphalaria alexandrina		Unknown	9 (q)	2439 (a)	b, f, t
Biomphalaria glabrata	Bloodfluke Planorb (r)	Unknown	8 (s)	356 (a)	b, f, q, t
Biomphalaria havanensis	Ghost Rams-horn		12 (136)		t, 137
Biomphalaria pfeifferi		No	8 (u)	11902 (a)	b, t, v
Biomphalaria straminea		No	9 (w)	1730 (a)	b, t, x
Bithynia tentaculata	Faucet Snail	Yes	3 (gg)	347 (a)	b, ff, hh, ii
Bulinus abyssinicus			11 (z)	3572 (a)	b, y
Bulinus globosus			11 (bb)	1736 (a)	b, aa
Bulinus tropicus			11 (cc)	12812 (a)	b
Bulinus truncatus		Unknown	8 (ee)	1455 (a)	b
Campeloma decisum	Pointed Campeloma	Yes	3 (138)	2.6-10 (161)	
Clea Helena	Assassin Snail	Unknown	9 (jj)		b, c
Clithon corona	Horned Nerite Snail	Unknown	8 (ll)		b, c, kk
Corbicula fluminea	Asian Clam	Yes	3 (pp)	68678 (a)	b, c, d, oo,

Scientific Name	Common Name	Established in Canada	Hardiness Zone (ref)	Annual Fecundity (ref)	Additional Information References
					mm, nn
Dreissena bugensis	Quagga Mussel	Yes	6 (rr)	960000 (a)	b
Dreissena polymorpha	Zebra Mussel	Yes	6 (rr)	960000 (a)	b, oo, ss, tt
Drepanotrema aeruginosus	Rusty Rams-horn		unknown		b
Drepanotrema cimex	Ridged Rams-horn		11 (uu)		b
Drepanotrema kermatoides	Crested Rams-horn		unknown		b, qq
Elimia livescens (formerly *Goniobasis*)	Liver Elimia	Yes	5 (139)	399 (162)	
Elimia virginica	Piedmont Elimia	Unknown	5 (vv)		b, hh
Eupera cubensis (Pisidium singleyi)	Mottled Fingernail Clam	No	5 (140)	64 max, function of adult size (163)	141, a
Fossaria viridis	Green Pond Snail		unknown		142
Fusconaia flava	Wabash Pigtoe	Yes	4 (xx)	Fecundity >200,000 (G. Mackie, pers. comm) Natality ~0.00001% of fecundity	ww
Gillia altilis	Buffalo Pebblesnail	No	5 (yy)		b, ff, hh
Helisoma anceps	Two-ridge Rams-horn	Yes	2 (56)	13.75 ± 2.91/wk, or 280-336/yr (164)	
Helisoma sp.	Black Rams-horn	No	unknown		a
Helisoma trivolvis (Planorella trivolvis)		Yes	2 (zz)	30 (zz)	58

Scientific Name	Common Name	Established in Canada	Hardiness Zone (ref)	Annual Fecundity (ref)	Additional Information References
Indoplanorbis exustus		No	9 (59)	6132 (a)	b, 59, 60, 61, 62
Lasmigona subviridis	Green Floater	No	5 (63)		b, 64
Limnoperna fortunei	Golden Mussel	No	3 (144)		145, 146
Lymnaea natalensis (Radix natalensis)		Unknown	9 (65)	7148 (a)	b, 66
Lymnaea palustris (Stagnicola palustris)		Yes	4 (67)	310 (a)	b, dd, 68
Lymnaea peregra (= *Radix peregra*)		Yes	6 (71)	1400 (a)	B, dd, 143
Lymnaea stagnalis		Yes	2 (69)	240 (165)	70
Marisa cornuarietis	Giant Rams-horn		12 (72)	1711 (a)	B, 73, 75
Melanoides tuberculata	Malaysian Trumpet Snail, Red-rimmed Melania	No	9 (74, 76)	365 (a)	b, c
Melanoides turriculus	Fawn Melania		12 (78)		b, 77
Musculium lacustre	Lake Fingernail Clam	Yes	4 (148)	4-35 (163)	147
Musculium partumeium	Swamp Fingernail Clam	Yes		45 (166)	
Neothauma tanganyicense			12 (149)	2 (149)	
Nerita natalensis sp. *"Tracked"*	Tracked Nerite Snail	Unknown	9 (80)		c, 79, 81
Nerita sp.	Nerita Snail, Tiger Blood	Unknown	9 (80)		c, 82
Nerita sp.	Nerita Snail, Zebra	Unknown	9 (80)		c, 82
Nerita sp.	O Ring Snail	Unknown	9 (80)		c, 82
Nerita sp.	Ornate Crown Snail	Unknown	9 (80)		c, 82
Nerita sp.	Zorro Snail	Unknown	9 (80)		c

Scientific Name	Common Name	Established in Canada	Hardiness Zone (ref)	Annual Fecundity (ref)	Additional Information References
Neritina reclivata	Olive Nerite	Unknown	9 (80)		c, 83
Physa fontinalis	Common Bladder Snail	Yes	2 (84)	174 (a)	b, 85, 87
Physella acuta	European Physa	Yes	5 (86)	50 (86)	88, 89
Pila conica			10 (150)		
Pisidium amnicum	Greater European Peaclam	Yes	2 (90)	5-10 (163)	a, b, 91
Pisidium corneum (Sphaerium corneum)	European Fingernail Clam	Yes	4 (96)	3-62 (163)	a, b, 97
Pisidium henslowanum	Henslow Peaclam	Yes	2 (92)	5.8-25 (163)	a, b
Pisidium hibernicum	Once a synonym of *P. ferrugineum* but now a distinct species in Europe only	No	2 (98)	22 (a)	b
Pisidium moitesserianum	Pygmy Peaclam	Yes	2 (93)	2.5-3.1X2 broods/yr (165, 167)	a, b, 92
Pisidium punctiferum	Striate Peaclam	No	6 (94)		
Pisidium supinuum	Humpbacked Peaclam	Yes	5 (95)	12 (a)	b
Planorbella duryi	Seminole Rams-horn	No	9 (152)		151
Planorbis contortus (Bathyomphalus contortus)	Twisted Rams-horn	Unknown	2(99)	34 (a)	b, 57, 100
Pomacea bridgesi	Applesnail, Spiketop Applesnail, Golden Mystery Snail	No	7 (101)	600 (102)	a, b, c, 60, 111
Pomacea canaliculata	Golden/Channelled Applesnail	No	9 (104)	4355 (a)	b, d, 103, 106

Scientific Name	Common Name	Established in Canada	Hardiness Zone (ref)	Annual Fecundity (ref)	Additional Information References
Pomacea cumingii		No	9 (154)		153
Pomacea haustrum	Titan Applesnail	No	9 (107)	236 (105)	b, 108, 111
Pomacea insularum	Island Applesnail	No	9 (109)	700 (109)	110, 111
Potamilus alatus	Pink Heelsplitter	No	5 (155)		110, 111
Potamopyrgus antipodarum	New Zealand Mudsnail	Yes	7 (112)	230 (a)	b, 113, 114, 115
Radix auricularia	Europear Ear Snail, Big-eared Radix	Yes	2 (117)	1300 (a)	b, dd, 116, 118
Sinanodonta woodiana	Chinese Pond Mussel	No	3 (156)		157, 158
Stenophysa marmorata	Marbled Aplexa	No	9 (119)		b, 120
Stenophysa maugeriae	Tawny Aplexa		12 (121)		b
Tarebia granifera (Thiara granifera)	Quilted Melania	No	8 (122)	213 (a)	b, 123, 124
Tylomelania cf. gemmifera	Gold Rabbit Snail		10 (125)	3 (126)	c
Tylomelania gemmifera X zeamais	Sulawesi Snail		10 (125)	3 (126)	c
Tylomelania gemmifers	Sulawesi Snail		10 (125)	3 (126)	c
Tylomelania kruimeli	Sulawesi Snail		10 (127)	14 (127)	c
Tylomelania patrichalis	Sulawesi Snail		10 (125)	3 (126)	c
Tylomelania spec	Sulawesi Snail		10 (125)	3 (126)	c
Tylomelania towutica	Sulawesi Snail		10 (125)	3 (126)	c
Tylomelania zeamais	Sulawesi Snail		10 (125)	3 (126)	c
Valvata piscinalis	European Stream Valvata	Yes	2 (128)	450 (a)	b, 129

Scientific Name	**Common Name**	**Established in Canada**	**Hardiness Zone (ref)**	**Annual Fecundity (ref)**	**Additional Information References**
Viviparus georgianus	Banded Mystery Snail	Yes	4 (130)	11 (130)	d, 131
Viviparus malleatus is a synonym of *Bellamya chinensis*	Chinese Mystery Snail	See *Bellamya chinensis*	6 (132)		a, b, c, 133, 134
Viviparus subpurpureus	Olive Mystery Snail	No	6 (160)		159
Lymnae sp.	Melantho snails		unknown		

APPENDIX B. REFERENCES FOR APPENDIX A

In text	Full reference
a	Keller R.P., and Lodge, D.M. 2007a. Species invasions from commerce in live aquatic organisms: problems and possible solutions. BioScience 57: 428-436.
b	Keller R.P., Drake, J.M., and Lodge, D.M. 2007b. Fecundity as a basis for risk assessment of nonindigenous freshwater molluscs. Conserv. Biol. 21: 191-200.
c	File sent by Scott Van Egeren. It was put together by a contact of his called Kevin Cohen from liveaquaria.com. It is a list of available invertrebrates in trade.
d	Results of sampling in Toronto, led by Nick Mandrak
e	ICUN Red List for *Ancylus fluviatilis* (River Limpet)
f	Dejong, R.J., Morgan, J.A., Paraense, W.L., Pointier, J.P., Amarista, M., Ayeh-Kumi, P.F., Babiker, A., Barbosa, C.S. et al., 2001. Evolutionary relationships and biogeography of Biomphalaria (Gastropoda: Planorbidae) with implications regarding its role as host of the human bloodfluke, *Schistosoma mansoni*. Mol. Biol. Evol. 18 (12): 2225-2239.
g	USGS Nonindigenous Aquatic Species Factsheet for *Cipangopaludina chinensis malleata* (Chinese mysterysnail)
h	Kipp and Benson (2008) in Karatayev et al., 2009
i	Jokinen 1982; Jokinen 1992 in Kipp and Benson 2011
j	Global Invasive Species Database for *Bellamya chinensis* (mollusc)
k	Oecologia (2009) 159: 161–170
l	Biol Invasions (2010) 12:1591–1605
m	AnimalBase Species Summary for *Ancylus fluviatilis*
n	Encyclopedia of Life on *Ancylus fluviatilis* (River Limpet)
o	USGS Nonindigenous Aquatic Species Factsheet for *Cipangopaludina chinensis* (Chinese Mysterysnail)
p	USGS Nonindigenous Aquatic Species Factsheet for *Cipangopaludina japonica* (Japanese Mysterysnail)
q	ICUN Red List for *Biomphalaria alexandrina*
r	Catalogue of Life for *Biomphalaria glabrata*
s	Distribution of the snail *Biomphalaria glabrata*, intermediate host of *Schistosoma mansoni*, within a St Lucian field habitat by R.F. Sturrock
t	Cowie, R.H., Dillon, R.T., Robinson, D.G., and Smith, J.W. 2009. Alien non-marine snails and slugs of priority quarantine importance in the United States: A preliminary risk assessment. Am. Malacol. Bull. 27: 113-132.
u	IUCN Red List for *Biomphalaria pfeifferi*

In text	Full reference
v	Bull World Health Organ. 1963; 29(4): 531–537.
w	Pointier, J.P., Pointier, J.P., David, P., and Jarne, P. 2005. Biological invasions: The case of planorbid snails. J. Helminthol. 79 (3): 249-256.
x	Meier-Brook, C. 1974. A snail intermediate host of *Schistosoma mansoni* introduced into Hong Kong. Bull. World Health Organ.51(6): 661.
y	Brown, D.S. 1994. Freshwater Snails of Africa and their Medical Importance. Taylor and Francis. ISBN 0-7484-0026-5. p. 225-226, 333-334.
z	IUCN Red List for *Bulinus abyssinicus*
aa	Natural History Museum on *Bulinus globosusl*
bb	IUCN Red List for *Bulinus globosus*
cc	IUCN Red List for *Bulinus tropicus*
dd	Correa C. A., Escobar J. S., Durand P., Renaud F., David P., Jarne P., Pointier J.-P. & Hurtrez-Boussès S. (2010). "Bridging gaps in the molecular phylogeny of the Lymnaeidae (Gastropoda: Pulmonata), vectors of Fascioliasis". *BMC Evolutionary Biology*
ee	IUCN Red List for *Bulinus truncatus*
ff	Jokinen, E. 1992. The Freshwater Snails (Mollusca: Gastropoda) of New York State. The University of the State of New York, The State Education Department, The New York State Museum, Albany, New York 12230. 112 p.
gg	USGS Nonindigenous Aquatic Species Factsheet for *Bithynia tentaculata* (mud bithynia, faucet snail)
hh	Mills, E.L., J.H. Leach, J.T. Carlton and C.L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19(1): 1-54.
ii	Nalepa, T.F., Fanslow, D.L., Lansing, M.B., Lang, G.A., Ford, M., Gostenik, G., and Hartson, D.J. 2002. Abundance, Biomass, and Species Composition of Benthic Macroinvertebrates Populations in Saginaw Bay, Lake Huron, 1987-1996. NOAA Great Lakes Environmental Research Laboratory and Cooperative Institute for Limnology and Ecosystem Research, Michigan, Ann Arbor. 32 p.
jj	Invasive Species Compendium Datasheet for *Clea helena* (assassin snail)
kk	Freshwater and Marine Aquarium Hobby Online Resources search for Horned Nerite Snail (*Clithon corona*)
ll	IUCN Red List for *Clithon corona*
mm	USGS (2001): Nonindigenous species information bulletin: Asian clam, *Corbicula fluminea* (Müller, 1774) (Mollusca: Corbiculidae).
nn	USGS Nonindigenous Aquatic Species Factsheet for *Corbicula fluminea* (Asian clam)
oo	Evolutionary and physiological adaptations of aquatic invasive animals: r selection versus resistance by Robert F. McMahon

In text	Full reference
pp	Global Invasive Species Database for *Corbicula fluminea* (mollusc)
qq	USGS Nonindigenous Aquatic Species Factsheet for *Drepanotrema kermatoides* (crested rams-horn)
rr	USGS Nonindigenous Aquatic Species Factsheet for *Dreissena rostriformis bugensis* (quagga mussel)
ss	DFO 2013. Risk Assessment for Dreissenid mussels in Canada (Therriault et al., 2013)
tt	Global Invasive Species Database for *Dreissena polymorpha* (mollusc)
uu	IUCN Red List for *Drepanotrema cimex* (Ridged Rams-horn)
vv	USGS Nonindigenous Aquatic Species Factsheet for *Elimia virginica* (Piedmont elimia)
ww	USGS Nonindigenous Aquatic Species Factsheet for *Fusconaia flava* (Wabash pigtoe)
xx	IUCN Red List for *Fusconaia flava* (Wabash Pigtoe)
yy	USGS Nonindigenous Aquatic Species factsheet for *Gillia altilis* (buffalo pebblesnail)
zz	Freshwater Gastropods of North America for *Helisoma* (*Planorbella*) *trivolvis*
56	AnimalBase Species Summary for *Helisoma anceps*
57	Bogan A. E. (1996). *Planorbella magnifica*. 2006 IUCN Red List of Threatened Species. Downloaded on 7 August 2007
58	Fried, B., Nanni, T.J., Reddy, A., and Fujino, T. 1996. Maintenance of the life cycle of *Echinostoma trivolvis* (Trematoda) in dexamethasone- treated ICR mice and laboratory-raised *Helisoma trivolvis* (Gastropoda). Parasitol. Res. 83: 16-19.
59	IUCN Red List for *Indoplanorbis exustus*
60	Cowie, R.H., Dillon, R.T., Robinson, D.G., and Smith, J.W. 2009. Alien Non-Marine Snails and Slugs of Priority Quarantine Importance in the United States: A Preliminary Risk Assessment. Am. Malacol. Bull. 27: 113.
61	Budha, P.B., et al. 2012. *Indoplanorbis exustus*. In: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.1.
62	Influence of Temperature on Survival, Growth and Fecundity of the Freshwater Snail *Indoplanorbis exustus* (Deshayas)
63	IUCN Red List for *Lasmigona subviridis* (Green Floater)
64	USGS Nonindigenous Aquatic Species Factsheet for *Lasmigona subviridis* (green floater)
65	IUCN Red List for *Lymnaea natalensis*
66	Appleton C., Ghamizi M., Jørgensen A., Kristensen T. K., Stensgaard A-S., Van Damme D. (2009). "*Lymnaea natalensis*". *IUCN Red List of Threatened Species* (2010.4 ed.).
67	IUCN Red List for *Stagnicola palustris*
68	AnimalBase Species Summary for *Stagnicola palustris*
69	IUCN Red List for *Lymnaea stagnalis* (Great Pond Snail)

In text	Full reference
70	Soldánová, M., Selbach, C., Sures, B., Kostadinova, A., and Pérez-del-Olmo, A. 2010. Larval trematode communities in *Radix auricularia* and *Lymnaea stagnalis* in a reservoir system of the Ruhr River. Parasites & Vectors 3:56.
71	Encyclopedia of Life on *Lymnaea peregra*
72	USGS Nonindigenous Aquatic Species Factsheet for *Marisa cornuarietis* (giant rams-horn snail)
73	IUCN Red List for *Marisa cornuarietis*
74	IUCN Red List for *Melanoides tuberculata*
75	The Apple Snail Website
76	USGS Nonindigenous Aquatic Species Factsheet for *Melanoides tuberculata* (red-rim melania)
77	USGS Nonindigenous Aquatic Species Factsheet for *Melanoides turriculus* (fawn melania)
78	Encyclopedia of Life on *Melanoides turriculus* (Fawn Melania)
79	The Aquarium Wiki on Zebra Nerite Snail (*Nerita natalensis*)
80	IUCN Red List for *Neritina natalensis*
81	Appleton, C., Kristensen, T.K., Lange, C.N., Stensgaard, A-S. & Van Damme, D. (2010). "*Neritina natalensis*". *IUCN Red List of Threatened Species. Version 3.1*. International Union for Conservation of Nature.
82	Live Aquarium for Nerita Snail (*Nerita sp.*)
83	The Aquarium Wiki on Olive Nerite Snail (*Neritina reclivata*)
84	IUCN Red List for *Physa fontinalis* (Common Bladder Snail)
85	Encyclopedia of Life on *Physa fontinalis (*Common Bladder Snail)
86	AnimalBase Species Summary for *Physa acuta*
87	AnimalBase Species Summary for *Physa fontinalis*
88	Encyclopedia of Life on *Physella acuta* (Acute Bladder Snail)
89	Semenchenko, A., Laenko, T., and Razlutskij, V. 2008. A new record of the North American gastropod *Physella acuta* (Draparnaud, 1805) from the Neman River Basin, Belarus. Aquatic Invasions 3: 359-360.
90	Encyclopedia of Life on *Pisidium amnicum* (Giant Pea Mussel)
91	USGS Nonindigenous Aquatic Species Factsheet for *Pisidium amnicum* (greater European peaclam)
92	USGS Nonindigenous Aquatic Species Factsheet for *Pisidium henslowanum* (Henslow peaclam)
93	USGS Nonindigenous Aquatic Species Factsheet for *Pisidium moitessierianum* (pygmy peaclam)
94	Encyclopedia for Life on *Pisidium punctiferum* (Striate Peaclam)

In text	Full reference
95	Encyclopedia for Life on *Pisidium supinum* (Humpbacked Peaclam)
96	Encyclopedia for Life on *Sphaerium corneum* (Horny Orb Mussel)
97	USGS Nonindigenous Aquatic Species Factsheet for *Sphaerium corneum* (European fingernail clam)
98	Encyclopedia of Life for *Pisidium hibernicum* (Globular Pea Mussel)
99	IUCN Red List for *Bathyomphalus contortus* (Twisted Ram's-horn)
100	AnimalBase Species Summary for *Bathyomphalus contortus*
101	USGS Nonindigenous Aquatic Species Factsheet for *Pomacea bridgesi* (spiketop applesnail)
102	IUCN Red List for *Pomacea bridgesii* (Common Apple Snail, Golden Mystery Snail)
103	The Apple Snail Website
104	IUCN Red List for *Pomacea canaliculata* (Channeled applesnail)
105	Terrestrial mollusc tool *Pomacea spp.* factsheet
106	Lv et al., 2009. PLoS Negl Trop Dis. 2009 September; 3(9): e520. Human Angiostrongyliasis Outbreak in Dali, China
107	The Apple Snail Website
108	USGS Nonindigenous Aquatic Species Factsheet on *Pomacea haustrum* (titan applesnail)
109	The Apple Snail Website
110	Benson A. J. (2008). "*Pomacea insularum*". USGS Nonindigenous Aquatic Species Database, Gainesville, FL
111	Global Invasive Species Database on *Pomacea insularum* (mollusc)
112	USGS Nonindigenous Aquatic Species Factsheet on *Potamopyrgus antipodarum* (New Zealand mudsnail)
113	Therriault, T.W., Weise, A.M., Gillespie, G.E., and Morris, T.J. 2010. Risk assessment for New Zealand mud snail (*Potamopyrgus antipodarum*) in Canada. DFO Can.Sci. Advis. Sec. Res. Doc. 2010/108.
114	Life Cycle of the parasite *Microphallus sp. (Trematoda)*
115	Levri, E.P. 1999. Parasite-induced change in host behavior of a freshwater snail: parasitic manipulation or byproduct of infection? Behav. Ecol. 10: 234-241.
116	USGS Nonindigenous Aquatic Species Factsheet on *Radix auricularia* (European ear snail)
117	IUCN Red List on *Radix auricularia*
118	Mackie, G. L., D. S. White and T. W. Zdeba. 1980. *A guide to freshwater mollusks of the Laurentian Great Lakes with special emphasis on the genus Pisidium*. Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Duluth, Minnesota 55804. 144 p.
119	Global Biodiversity Information Facility Dataset on *Stenophysa marmorata*

In text	Full reference
120	Discovery Life on *Stenophysa marmorata*
121	Encyclopedia of Life for *Stenophysa maugeriae*
122	Texas Invasives Database on *Tarebia granifera* (Quilted Melania)
123	Miranda, N.A.F., Perissinotto, R., and Appleton, C.C. 2010. Salinity and temperature tolerance of the invasive freshwater gastropod *Tarebia granifera*. S. Afr. J. Sci. 2010;106(3/4), Art. #156, 7 p.
124	Appleton C. C., Forbes A. T.& Demetriades N. T. (2009). "The occurrence, bionomics and potential impacts of the invasive freshwater snail *Tarebia granifera* (Lamarck, 1822) (Gastropoda: Thiaridae) in South Africa". *Zoologische Mededelingen* 83.
125	von Rintelen T. & Glaubrecht M. (2005). "Anatomy of an adaptive radiation: a unique reproductive strategy in the endemic freshwater gastropod *Tylomelania* (Cerithioidea: Pachychilidae) on Sulawesi, Indonesia and its biogeographical implications." *Biological Journal of the Linnean Society* 85: 513–542. doi:10.1111/j.1095-8312.2005.00515.x
126	Live Aquaria for Gold Rabbit Snail (*Tylomelania gemmifera*)
127	Köhler F. & Rintelen T. (2011). "*Tylomelania kruimeli*". In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2.
128	USGS Nonindigenous Aquatic Species Factsheet on *Valvata piscinalis* (European stream valvata)
129	2006 IUCN Red List of Threatened Species.
130	USGS Nonindigenous Aquatic Species Factsheet for *Viviparus georgianus* (banded mysterysnail)
131	Freshwater Gastropods of North America Blog
132	Walker, B. 1918. A synopsis of the classification of the fresh-water Mollusca of North America, north of Mexico, and a catalogue of the more recently described species. Ann Arbor: The University of Michigan
133	Global Invasive Species Database on *Bellamya chinensis* (mollusc)
134	Global Biodiversity Information Facility Dataset on *Viviparus malleatus Reeve*
135	IUCN Red List on *Anodonta cygnea* (Swan Mussel)
136	Dejong, R. J.; Morgan, J. A.; Paraense, W. L.; Pointier, J. P.; Amarista, M.; Ayeh-Kumi, P. F.; Babiker, A.; Barbosa, C. S.; Brémond, P.; Pedro Canese, A.; De Souza, C. P.; Dominguez, C.; File, S.; Gutierrez, A.; Incani, R. N.; Kawano, T.; Kazibwe, F.; Kpikpi, J.; Lwambo, N. J.; Mimpfoundi, R.; Njiokou, F.; Noël Poda, J.; Sene, M.; Velásquez, L. E.; Yong, M.; Adema, C. M.; Hofkin, B. V.; Mkoji, G. M.; Loker, E. S. (2001). "Evolutionary relationships and biogeography of Biomphalaria (Gastropoda: Planorbidae) with implications regarding its role as host of the human bloodfluke, Schistosoma mansoni". *Molecular biology and evolution* 18 (12): 2225–2239
137	USGS Nonindigenous Aquatic Species Factsheet on *Biomphalaria havanensis* (ghost rams-horn)
138	Freshwater Gastropods of North America for *Campeloma decisum*
139	USGS Nonindigenous Aquatic Species Factsheet on *Elimia livescens* (liver elimia)
140	USGS Nonindigenous Aquatic Species Factsheet for *Eupera cubensis* (mottled fingernailclam)

In text	Full reference
141	IUCN Red List for *Eupera cubensis*
142	USGS Nonindigenous Aquatic Species Factsheet for *Fossaria viridis*
143	USGS Nonindigenous Aquatic Species Factsheet for Leptodea fragilis (fragile papershell)
144	Global Invasive Species Database on *Limnoperna fortunei* (mollusc)
145	Karatayev, A.Y., Burlakova, L.E., Karatayev, V.A., and Boltovskoy, D. 2010. *Limnoperna fortunei* versus *Dreissena polymorpha*: population densities and benthic community impacts of two invasive freshwater bivalves. J. Shellfish Res. 29: 975–984
146	Golden Mussel - *Limnoperna fortunei*
147	USGS Nonindigenous Aquatic Species Factsheet for *Musculium sp* (fingernail clam)
148	Kuiper, J.G.J., Økland, K.A., Knudsen, J., Koli, L., von Proschwitz, T., and Valovirta, I. 1989. Geographical distribution of the small mussels (Sphaeriidae) in North Europe (Denmark, Faroes, Finland, Iceland, Norway and Sweden). Ann. Zool. Fennici. 26: 73-101.
149	IUCN Red List for *Neothauma tanganyicense*
150	The Apple Snail Website
151	USGS Nonindigenous Aquatic Species Factsheet for *Planorbella duryi* (Seminole rams-horn)
152	AnimalBase Species Summary for *Helisoma duryi*
153	USGS Nonindigenous Aquatic Species Factsheet for *Pomacea cumingii* (an applesnail)
154	The Apple Snail Website
155	USGS Nonindigenous Aquatic Species Factsheet for *Potamilus alatus* (pink heelsplitter)
156	USGS Nonindigenous Aquatic Species Factsheet for *Sinanodonta woodiana* (Chinese pond mussel)
157	IUCN Red List for *Sinanodonta woodiana* (Chinese Pond Mussel)
158	Pavljuchenko, O.V. 2005. The first record of the helminth *Aspidogaster conchicola* (Aspidogastrea) in *Sinanodonta woodiana* (Mollusca, Bivalvia) from Ukraine. Vestnik Zoologii 39: 50.
159	USGS Nonindigenous Aquatic Species Factsheet for *Viviparus subpurpureus* (olive mysterysnail)
160	Encyclopedia of Life for *Viviparus subpurpureus* (Olive Mysterysnail)
161	Welsh, P.G. 1991. Relationships between environmental variables and demographic parameters of nine populations of *Campeloma decisum* (Say) (Gastropoda: Viviparidae) in South-central Ontario. Thesis (M.Sc.) University of Guelph, Guelph, ON 105 p.
162	Dazo, B.C. 1965. The morphology and natural history of *Pleurocera acuta* and *Goniobasis livescens* (Gastropoda: Cerithiacea: Pleuroceridae. Malacologia 2:1-80. (Copied March 15, 2012 from malacologia archive)
163	Mackie, G. L. 2007. Biology of freshwater corbiculid and sphaeriid clams of North America. Ohio Biological Survey, Columbus, OH. 438 + ix p. ISBN13 978-0-86727-158-4

In text	Full reference
164	Crews, A.E. and Esch, G.W. 1986. Seasonal dynamics of *Halipegus occidualis* (trematoda: Hemiuridae) in *Helisoma anceps* and its impact on fecundity of the snail host. J. Parasitol. 72(5): 646-651.
165	Hoffer J.N, Ellers, J., and Koene, J.M. 2010. Costs of receipt and donation of ejaculates in a simultaneous hermaphrodite. BMC Evol. Biol. 363:1-8.
166	Hornbach, D.J., Way, C.M., and Burky, A.J. 1980. Reproductive strategies in the freshwater sphaeriid clam, *Musculium partumeium* (Say), from a permanent and a temporary pond. Oecologia, 44(2): 164-170.
167	Grigorovich, I.A., Korniushin, A.V., and MacIsaac, H.J. 2000. Moitessier's pea clam *Pisidium moitessierianum* (Bivalvia, Sphaeriidae): a cryptogenic mollusc in the Great Lakes. Hydrobiologia 435: 153-165.