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# The Risk of Introducing Live Organisms by the Aquarium, Water Garden, and Seafood Trades in Canada 

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## 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.

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#### Abstract

The aquarium, water garden, and live seafood trades are major pathways for the introduction of aquatic species into Canada. If released, some imported species may become invasive, with negative consequences for Canadian ecosystems. This research document describes the movement of live aquatic (freshwater, brackish, and marine) organisms including fishes, invertebrates, and plants in trade into and within Canada, identifies aquatic species previously or presently in trade, describes end user participation and the release of aquatic organisms to the wild, develops spatially explicit estimates of propagule pressure, and identifies possible critical control points. A total of $4,296,188$ aquarium organisms, representing 844 taxa, were imported into Canada from 40 source countries during a four-month period in 2018. The top three ports of entry, by trade volume, were Windsor, ON; Mirabel, QC; and, Calgary, AB. Imported aquarium organisms were distributed within Canada via major distribution hubs in Innisfil, ON; LaSalle, QC; and, Calgary, AB. Aquarium retailers tended to aggregate around major urban centers. A baseline scenario assuming a 10.6\% participation rate and a 3.9\% release rate estimated that 57,799 households released 347,650 aquarium organisms per year. During the same four-month timeframe, $3,758,224$ water garden organisms, representing 199 taxa, were imported into Canada from 19 source countries. Major ports of entry and distribution hubs for water garden organisms were the same as the aquarium pathway. Water garden retailers were also found around major cities. An estimated 50,769 households released 305,367 water garden organisms per year, based on an assumed $9.2 \%$ participation rate and $3.9 \%$ release rate. About $82,434,924$ live seafood organisms, representing 84 taxa, were imported into Canada from 20 source countries during the same four-month period. Major ports of entry for live seafood organisms included Ottawa, ON; Richmond, BC; St-Stephen, NB; and, Toronto, ON. Montebello, QC; Chilliwack, BC; and, Cap-Pelé, NB were major distribution hubs for live seafood organisms. Similar to the other pathways, live seafood retailers clustered around major cities. An estimated 47,964 users released 288,502 live seafood organisms per year, based on an assumed $3.5 \%$ participation rate and $3.9 \%$ release rate. Critical control points that allow the greatest volume of organisms in trade to be encountered were identified. For all three pathways, these included the major ports of entry, key distribution hubs, and urban centres where aggregations of retailers, end users, and releasers occur. Results of sensitivity analyses suggested that all parameters considered had an equal effect on the propagule pressure estimates for all pathways, though they had a disproportionate effect on the spatial distribution of end users and releasers. Despite uncertainty around model parameters, statistically significant hot spots of introduction risk were identified. Maintaining detailed import records and characterizing the human dimensions of the aquarium, water garden, and live seafood trades would reduce uncertainty and refine spatially explicit estimates of propagule pressure associated with each pathway.


## INTRODUCTION

Live aquatic (freshwater, brackish water, and marine) organisms including fishes, invertebrates, and plants are imported into Canada each year through the aquarium, water garden, and seafood trades (Mandrak et al. 2014, Schroeder et al. 2014, Azan et al. 2015). The legal import of live ornamental fishes was worth almost $\$ 10$ million CAD in 2018 (Government of Canada 2020). The trade of live aquatic species provides economic opportunities, has raised public awareness on biodiversity and conservation issues (Maceda-Veiga et al. 2016), and also promotes human health through stress reduction (aquarium and water garden hobbies) (Helfman 2007) and provision of food. While most organisms in trade remain in captivity or are consumed, there is increasing evidence that the aquarium, water garden, and live seafood trades are major pathways for the introduction and spread of aquatic invasive species (AIS) (Chapman et al. 2003, Padilla and Williams 2004, Keller and Lodge 2007). The accidental escape of cultivated species from aquaculture farms (e.g., via pond drainages and overflow during flood/spate events) is not uncommon (Courtenay and Stauffer 1990, Naylor et al. 2001, Helfman 2007) and intentional release of unwanted organisms by breeders and fish farmers can occur due to undesirable qualities or overproduction (Helfman 2007). Ornamental and pet species can also be deliberately released by their owners as a perceived "humane" disposal method (Courtenay 1999, Copp et al. 2005, Gertzen et al. 2008), such as when species outgrow or overpopulate aquariums or water gardens.

The invasion of organisms in trade follows the typical stage-based invasion process (i.e. transport, introduction, establishment, and spread) with barriers (i.e. geography; domestication, cultivation, or captivity; survival and reproduction; and dispersal and environmental factors) that may prevent organisms from passing to the next stage (modified from Chan et al. 2020, Figure 1). There are opportunities at each point in the trade supply chain (i.e. culture facilities, distributors, retailers, and end users) for organisms to transition from domestication, cultivation, or captivity to the recipient environment via accidental or intentional introductions. Indeed, a number of organisms in trade have been observed in Canadian ecosystems, some of which have caused significant negative ecological impacts (Crossman and Cudmore 1999a,b, Mandrak and Cudmore 2010). Notable examples include the Eurasian Tench (Tinca tinca), Goldfish (Carassius auratus), Common Carp/Koi (Cyprinus carpio), Asian Clam (Corbicula fluminea), Banded Mystery Snail (Viviparus georgianus), Eurasian Frog-bit (Hydrocharis morsus-ranae), and Fanwort (Cabomba caroliniana) (Kerr et al. 2005, Funnell et al. 2009, Avlijaš et al. 2018, Castañeda et al. 2018).
Through the federal-provincial-territorial Canadian Council of Fisheries and Aquaculture Ministers' National Aquatic Invasive Species Committee (NAISC), provincial and territorial governments and DFO's Aquatic Ecosystems management sector have requested scientific advice about the risk of introducing live organisms through the aquarium, water garden, and live seafood pathways in Canada. Previous Canadian Science Advisory Secretariat (CSAS) processes have evaluated the screening-level risk posed by species imported to Canada through live trades based on species import volume and estimates of species survival and establishment (Gantz et al. 2014, Mandrak et al. 2014, Schroeder et al. 2014). However, significant uncertainties remain about: 1) the scope and scale of these pathways (i.e. species supply chains) in Canada, including key ports of entry, distribution hubs, retailers, and end users; 2) the movement and release behaviour of end users; and, 3) the composition of species associated with each pathway. Addressing these uncertainties would allow spatially explicit estimates of species introduction effort (propagule pressure) to be developed for each pathway, which would help to refine current estimates of invasion risk. Characterizing these components will help to inform management and policy by developing a better understanding of key control
points, informing research priorities and monitoring programs, and guiding communication strategies for high-risk components (e.g., education and outreach campaigns).

The overarching objective of this research document is to assess the pathway-level risk of introducing live organisms by the aquarium, water garden, and seafood pathways in Canada. Specific objectives are to:

1. Characterize the movement of aquatic organisms in trade into and within Canada, including components such as the number and spatial distribution of species entry points, distributor hubs, retailers, and end users (i.e. aquarium and water garden owners; live seafood consumers);
2. Describe Canadian participation and release rates of end users, per pathway;
3. Based on available data, identify aquatic organisms documented in trade in Canada;
4. Develop spatially explicit estimates of propagule pressure, per pathway, including a description of key uncertainties; and
5. Identify critical control points.

This study defines propagule pressure as the total number of individuals of all species released via each of the aquarium, water garden, and live seafood pathways (i.e. introduction stage of Figure 1) in Canada. Thus, introduction risk is evaluated based on the total propagule pressure associated with each pathway (i.e. the probability of introducing $n$ organisms per pathway per year; see Drake et al. 2015a). The diversity of imported species (i.e. colonization pressure) also contributes to invasion risk by affecting the probability of species establishment, but it is beyond the scope of this pathway-level analysis. The online sale (e-commerce) of aquarium, water garden, and live seafood organisms is a large, growing, and complex pathway that warrants a separate analysis (e.g., Derraik and Phillips 2010, Mazza et al. 2015) and is not examined here. However, all live organisms that were imported into Canada, either for online or in-store sale during the study period (see Methods), are considered. Species that are bred, cultivated, or farmed in Canada (i.e. the domestic production and distribution of aquarium, water garden, and live seafood organisms) are also excluded from the study.

## METHODS

## DATA ANALYSIS FRAMEWORK

An analytical framework was developed to follow the typical supply chain of organisms in trade, and was applied to each pathway (Figure 2). The framework expanded on the simplified supply chain outlined by Chan et al. (2020) to include source countries, Canadian ports of entry, distributors, retailers, end users, and releasers (numbered nodes in Figure 2). Species import records allowed tracking the movement of imported live aquatic organisms from source countries to ports of entry and distributors (solid lines connecting nodes 1 to 3 ), thereby addressing objectives 1 and 3 . Retailer information (node 4) was collected by conducting web searches of retail outlets selling aquarium, water garden, or live seafood organisms. A literature review was conducted to quantify the proportion of Canadians owning aquaria or water gardens, or purchasing live seafood (i.e. participation rate), and the proportion of aquarium or garden owners, or live seafood consumers, who released organisms into the environment (i.e. release rate) (objective 2). The participation and release rates were then applied to census data to estimate the number and spatial distribution of end users and releasers (nodes 5 and 6, and objective 4). Data for tracking the movement of organisms from distributors to releasers were not available (dotted lines in Figure 2). Finally, critical control points, defined as nodes along the
supply chain (e.g., import and distribution hubs) that could allow the greatest number of organisms to be encountered for management (e.g., for species screening, education, or enforcement), were identified by examining the movement of aquatic organisms in trade into and within Canada and the spatially explicit estimates of propagule pressure separately for each pathway (objective 5).

## SPECIES IMPORT RECORDS

Species import records were obtained from the Canada Border Services Agency (CBSA) and the Canadian Food Inspection Agency (CFIA). The datasets varied in the duration of records, taxonomic resolution of imported species, and supply chain details. The CBSA dataset, obtained via the Single Window Initiative, Pathfinder project, contained information on 19,094 transactions, or 112,134 records, of goods imported into Canada from June 15 ${ }^{\text {th }}, 2018$ to October $15^{\text {th }}, 2018$. An import transaction can include multiple records if more than one type of good (or species) is being imported into the country during a single event. The dataset included the Harmonized System (HS) code and other government department (OGD) extension of the imported goods, a description of the goods (species and intended use, when provided), quantity, release date, release office (port of entry into Canada), country of origin (may or may not reflect the species' native range), as well as broker, vendor, importer, and/or distributor details (name, address, and contact information). In contrast, the CFIA data, compiled by the Automated Import Reference System (AIRS), contained information on the HS code and OGD extension of the imported goods, HS description (not the same as description of the goods), quantity, calendar year, country of origin, the province or territory of the port of entry, and the destination province or territory of goods imported into Canada from 2008 to 2018. While the CFIA data had better temporal coverage than the CBSA dataset, the CBSA dataset provided higher resolution details needed for quantifying the number of organisms imported into Canada via the aquarium, water garden, and live seafood trades, as well as characterizing their subsequent movement within the country. Therefore, the analysis was conducted using the CBSA data as the primary source, but results were ground truthed using CFIA data. Groundtruthing was performed using import records of aquarium fishes only from both datasets as they were the most complete owing to their designated codes in the HS system (see below), thus allowing a more complete comparison between data sources. The CBSA and CFIA data used for the analysis can be found in an associated data report (Brinklow et al. 2021).
HS codes were used to identify records that were relevant to the aquarium, water garden, and live seafood trades (Appendix A). The HS code system is an international nomenclature for the classification of products established by the World Customs Organization (CBSA 2018). The six-digit HS code (e.g., 03.01.11) can be broken down into three parts: the first two digits identify the chapter the goods are classified in (e.g., $03=$ fishes, crustaceans, molluscs, and other aquatic invertebrates), the next two digits denote groupings within that chapter (e.g., $03.01=$ live fishes), and the final two digits provide more information regarding the goods (e.g., 03.01.11 = live, freshwater ornamental fishes). In Canada, additional digits provide further details about the imported goods in some cases. For example, live, fresh, or chilled specimens are aggregated under a six-digit HS code for most crustaceans. The additional digits, 03.06.32.0010, differentiate live Homarus spp. (lobster) from other (e.g., chilled) Homarus spp., 03.06.32.0090. Extra information on some imported goods may be provided via OGD extensions. For instance, unrooted cuttings and slips of live plants are grouped under the sixdigit code 06.02.10. To identify unrooted aquatic plants for aquaria under this code, the OGD extension 1204 was used. A total of 9,432 records over the four-month period were relevant to the aquarium, water garden, and live seafood trades. The dataset was further refined to 8,192 records using the criteria below for estimating the movement of organisms in trade into and within Canada.

About $50 \%$ of the import transactions for ornamental and live food fishes between June and October of 2018 were paper-based and import details were not recorded by CBSA's Pathfinder project (H. Gerson, CBSA, pers. comm.). The proportion of the transactions with missing import details is likely greater for invertebrates and plants than for fishes. However, the exact proportions were difficult to estimate because these species do not have designated HS codes (H. Gerson, CBSA, pers. comm.). One thousand two hundred and twenty-three records with missing import details ( $\sim 13 \%$ of the 9,432 records) were excluded from further analysis. There were 599 records with inconsistencies between the HS code description and the description of goods. For example, there were marine species imported under the HS code for live freshwater ornamental fishes, and vice versa. In addition, there were food fishes and invertebrates imported under the ornamental fish HS codes and ornamental fishes imported under HS codes not designated for ornamental fishes. These records were corrected and were included in the analysis. Only live aquatic organisms were considered. For HS codes that did not differentiate live specimens from fresh or chilled (i.e. dead) ones, which applied to invertebrates, only records ( $\sim 52 \%$ of 8,603 live, fresh, chilled invertebrate records) in which the description of goods clearly indicated that the specimens were alive or potentially alive at time of import to Canada were included.

Records were assigned to pathways using HS codes, description of goods (when available), and vendor, importer, and/or distributor information (e.g., ornamental fish vs. seafood wholesaler). All live ornamental fishes imported under the HS codes 03.01.11 (freshwater ornamental fishes) and 03.01.19 (other ornamental fishes) were assumed to be associated with the aquarium pathway. A subset of the ornamental fishes imported under the HS code 03.01.11 were assigned to the water garden pathway by consulting DFO's records of aquatic organisms in trade from October 2004 to September 2005 (Bradie et al. 2013 citing B. Cudmore and N. Mandrak, unpublished data), in which the reason for import was determined based on the species' temperature tolerance and known association with water gardens (B. Cudmore, DFO, pers. comm.). All freshwater aquatic plants imported under the HS code 06.02.90 (live rooted greenhouse aquatic plants) with the OGD extension 2494 or with "aquarium plant" in the description of goods were assigned to the aquarium pathway. All of these plants, except for the Moss Ball (Aegagropila linnaei) and aquascape species (e.g., Dwarf Hairgrass Eleocharis parvula), were assigned to the water garden pathway as well. Terrestrial plants (e.g., Ti plant Cordyline terminalis and Mondo Grass Ophiopogon japonicas) that were imported as aquatic or aquarium plants were also considered for the water garden pathway. Therefore, a single record of freshwater ornamental fish or aquatic plant could be attributed to both the aquarium and water garden pathways (i.e. double-counted). No marine species were considered for the water garden pathway, as there was little evidence of saline water gardens in Canada (D. Holland and M. Majer, CAOAC, pers. comm.). Organisms imported for public aquariums and zoos, scientific research, as well as environmental testing were excluded from the analysis ( $n=17$ ) due to the very low chance that these organisms would be released to the environment. All remaining live fishes and invertebrates were assigned to the seafood pathway. There was no evidence of live aquatic plants or seaweeds imported for food, though processed seaweed products were observed.

Import quantity was used to estimate the number of aquatic organisms associated with each pathway. Over $53 \%$ of the refined records documented import quantity in abundance (i.e. count or number of specimens), but 3,809 of them involving 88 taxa were listed by weight. These records were converted from weight to number using species-specific density or biomass estimates based on records with both quantity and weight ( 1 species, see Bradie et al. 2013), literature values ( 1 species), typical market weights advertised by online seafood retail outlets (59 species), and the length-weight relationships available from FishBase when only the typical market size (in length) was available (17 species, Froese and Pauly 2019). Species-specific
density or biomass could not be calculated for 10 taxa due to missing species-level details in the records. Instead, quantity was estimated using the average density across species belonging to that taxonomic group.
A list of aquarium, water garden, and live seafood organisms observed in the Pathfinder dataset was compiled (these species may be native or nonindigenous to Canada). Taxonomic nomenclature is consistent with the FishBase, SeaLifeBase, AlgaeBase, Global Biodiversity Information Facility, and Encyclopedia of Life. No attempt was made to evaluate the accuracy of import records in terms of species identity or to confirm that organisms were live at time of import. The species list may be used to inform future research (e.g., species-specific risk assessment) and management (e.g., decisions about regulated AIS). Fishes listed in the Pathfinder data were compared with those reported by previous studies of fishes in trade in Canada (Rixon et al. 2005, Gertzen et al. 2008, Mandrak et al. 2014) to highlight those that have not been documented in previous studies.

## TRADE DISTRIBUTION NETWORKS

Country of origin, CBSA release office, and destination information in the Pathfinder dataset were used to identify the source countries, ports of entry, and distributors, respectively, associated with each pathway (nodes 1, 2, and 3 in Figure 2). Because retailer information was not available from the dataset, a list of retailers was compiled for each pathway by reviewing published reports and conducting Google web searches of retail outlets that sell live aquatic organisms (node 4 in Figure 2). Retailers were defined as any retail outlet with a physical location that sells live aquatic organisms directly to end users (consumers). Although live organisms may be purchased via online stores or forums, this was beyond the scope of this assessment (see Introduction). To ensure comprehensive geographic coverage, retailers were searched by province and territory and in both urban and rural areas using Google Maps. In addition, retailers that may not have Internet or social media presence, typically smaller independent shops, were targeted by examining reviews on Yelp, a business directory and crowd-sourced review forum. Pet store chains and aquarium specialty stores were searched for the aquarium pathway. For the water garden pathway, pet store chains, aquarium specialty stores, garden centres, nurseries, pond stores, and fish farms/hatcheries were considered. Supermarket chains, independent grocers, ethnic supermarkets, seafood markets, and fish farms/hatcheries were included for the live seafood pathway. Only retailers that sold live aquatic organisms were included. For instance, not all pet stores sell aquatic organisms and only a subset of grocery stores sell live seafood. The geographic location and the taxa (i.e. fishes, invertebrates, and/or plants) sold by these retailers were recorded. When possible, individual retailers were contacted by phone, email, and/or via social media to confirm the information. Retailer data compiled for the analysis can be found in the associated data report (Brinklow et al. 2021). The lists of retailers may not be complete; however, they include major retailers across Canada and should be representative of the general spatial patterns of retailers associated with the aquarium, water garden, and live seafood trades in Canada.

To geocode components (i.e. ports of entry, distribution hubs, and retailers) of the distribution network for spatial analyses, the November 2018 version of the Postal Code ${ }^{\text {OM }}$ Conversion File Plus (PCCF+) was obtained from Statistics Canada. The conversion file provides a link between the six-character postal codes used by Canada Post and the standard 2016 census geographic areas used by Statistics Canada, though there are discrepancies between the postal code and the census geographic boundaries (Statistics Canada 2018). Postal codes were converted to geographic coordinates using the PCCF+ file (SAS 9.4). The geographic coordinates represent the centroid of the six-character postal code boundaries. Components of the distribution network were mapped using a Geographic Information System (ESRI ArcGIS desktop 10.5.1). The
movement of aquatic organisms in trade between components of the distribution networks were characterized using flow maps, which were created using the XY to Line tool in ArcGIS. Flow lines were constructed as rhumb lines in the GCS_WGS_1984 coordinate system, with width of the lines representing the aggregate number of organisms following a given path.

## SPATIALLY EXPLICIT ESTIMATES OF PROPAGULE PRESSURE

## Aquarium pathway

A model was developed to quantify spatially explicit estimates of propagule pressure for the aquarium pathway in Canada. The number and spatial distribution of end users (i.e. aquarium owners) (step 1 below, node 5 in Figure 2) and those who release aquarium organisms into the environment (i.e. releasers) (step 2 below, node 6 in Figure 2) were estimated. Then, the expected number of releasers was combined with the potential number of propagules released by a releaser to estimate the total number of aquarium organisms released per year (step 3). The model was parameterized using literature values. Specifically, past studies were used to determine the proportion of Canadians owning aquaria- $p(A q)$, the proportion of aquarium owners in urban versus rural areas ( $\mathrm{U}: \mathrm{R}$ ), the proportion of aquarium owners releasing organisms- $p(\operatorname{Re\| } \| q)$, and the typical number of aquarium organisms (i.e. propagule size) released per event.

## Step 1. Estimating the number and spatial distribution of aquarium owners

To estimate the number of aquarium owners in Canada, $p(A q)$ was determined following the approach of Gertzen et al. (2008) for quantifying propagule pressure of the freshwater ornamental fish trade in Montréal, QC. The American Pet Products Association (APPA) reported that $10.6 \%$ of households in the United States (US) owned aquaria in a 1994 national survey (cited by Chapman et al. 1997 and Gertzen et al. 2008). More recent surveys by APPA suggest that $p(A q)$ in the US is relatively constant over time, though the absolute number of aquaria owners has increased (Insurance Information Institute 2020). In addition, the behaviour of US and Canadian aquarists were similar in terms of imports per capita and the identity of most frequently traded species (Bradie et al. 2013), supporting the use of US data for this analysis. Therefore, $10.6 \%$ was adopted as the baseline $p(A q)$ because similar data did not exist for Canada. Given the uncertainty around the parameter, the baseline $p(A q)$ was increased or decreased by $50 \%$ in a one-parameter-at-a-time sensitivity analysis to better understand how this value affects the number and distribution of aquarium owners in Canada (Table 1). The high $\mathrm{p}(\mathrm{Aq}), 15.9 \%$, could account for increases in aquarium ownership over time not observed in the US, whereas the low $\mathrm{p}(\mathrm{Aq}), 5.3 \%$, may address the potential difference in ownership rates between the US and Canada. For each sensitivity scenario, $p(A q)$ was applied to the 2016 Canadian dwelling counts obtained from Statistics Canada's 2016 Census of Population Program (Statistics Canada 2019a), the most recent detailed enumeration of Canadian residents. Therefore, the unit for end users was household and multi-person households owning aquaria were considered only once.

To characterize the expected spatial distribution of households owning aquaria in Canada, U:R for aquarium owners was explored. This step was included because recent work by Hunt et al. (2017) suggests that recreational fishing activities, another major pathway of AIS, are influenced by population density (i.e. urban vs rural areas). Forward Sortation Areas (FSAs) were examined following the approach of Hunt et al. $(2017,2019)$ and Buckley et al. 2021. FSAs are the first three characters of the six-character postal codes, in which those with numerals 1-9 and 0 for the second character were treated as urban and rural areas, respectively (Government of Canada 2015). Recognizing that the FSA classification of urban and rural areas may not reflect the current census population for some parts of Canada, the proportion of urban versus rural
areas by province and territory based on the FSA classification was compared with that based on the 2016 Census Program (Statistics Canada 2020). The proportion of urban versus rural areas based on the two classifications were comparable for all provinces and territories, except for New Brunswick (Table 2). For New Brunswick, areas were classified as urban or rural by overlaying areas with population centre data obtained from the 2016 Census of Population Program in ArcGIS.

Data collected via the "Great Canadian Aquarium Survey" provided the only estimate of U:R of aquarium owners in Canada, though $\sim 76 \%$ of these responses were from Ontario (Marson et al. 2009a). It was determined that $85.9 \%$ of surveyed aquarium owners resided in urban areas, whereas only $14.1 \%$ lived in rural areas. The spatial distribution of households owning aquaria was consistent with the background spatial distribution of the population in Ontario (i.e. 86.3\% and $13.7 \%$ in urban and rural areas, respectively), estimated using the dwelling counts data from Statistics Canada (Statistics Canada 2019a). This suggests that the spatial pattern of aquarium ownership, unlike recreational fishing, corresponds tightly with patterns of population density (i.e. a greater number of aquarium owners exist in areas with a greater number of residents). Therefore, no correction was made to $\mathrm{p}(\mathrm{Aq})$ based on whether the households were located in an urban or rural area, assuming that the $U: R$ observed for the Ontario sample applies to the rest of the country. To account for parameter uncertainty owning to the fact that most respondents of the "Great Canadian Aquarium Survey" were from Ontario and thus the estimated U:R may not be representative for other regions, a separate one-parameter-at-a-time sensitivity analysis was conducted by incorporating the baseline $U: R, 86: 14$, and altering it by $\pm 10 \%$ (Table 1). The urban-biased U:R ratio (94:6) represented the case in which there are more aquarium owners in urban areas, likely due to greater access to aquarium retail outlets, whereas the opposite represented a rural-biased $U: R(77: 23)$ scenario. During sensitivity analysis, the proportion of households owning aquaria, $p(A q)$, was corrected based on whether the households were located in an urban or rural area. The corrected values were determined using Bayes' theorem:
(1)

$$
p(A q \mid U)=\frac{p(U \mid A q) \cdot p(A q)}{p(U)}
$$

where $p(A q \mid U)=$ the corrected $p(A q)$ for urban areas, $p(U \mid A q)=$ the proportion of households owning aquaria in urban areas, $p(A q)=$ proportion of households owning aquaria, and $p(U)=$ the proportion of households in urban areas; and

$$
\begin{equation*}
p(A q \mid R)=\frac{p(R \mid A q) \cdot p(A q)}{p(R)} \tag{2}
\end{equation*}
$$

where $p(A q \mid R)=$ the corrected $p(A q)$ for rural areas, $p(R \mid A q)=$ the proportion of households owning aquaria in rural areas, $p(A q)=$ the proportion of households owning aquaria, and $p(R)=$ proportion of households in rural areas. The values for $p(U)$ and $p(R)$ were $86.3 \%$ and $13.7 \%$, respectively.
The FSAs boundary file was acquired from Statistics Canada's 2016 Census of Population Program for mapping the spatial distribution of households owning aquaria in Canada (Statistics Canada 2019b). Because FSAs vary in size, the spatial unit for the analysis was standardized by creating a $50 \mathrm{~km} \times 50 \mathrm{~km}$ gridded map of Canada using the Albers Equal Area Conic projection in ArcGIS ( $n=4,803$ ). To estimate the number of households per grid, the density of households was calculated for each FSA, assuming that households are evenly distributed within a given FSA. While this assumption is unlikely to hold true, data to refine the assumption
were not available. Then, the FSA boundaries were overlaid onto the gridded map. Where the original FSA polygons were split into slivers by the grids, the number of households in each grid was calculated by multiplying the household density, $p(A q \mid U)$ or $p(A q \mid R)$, and the slivered area of the overlapping FSA. When a grid overlapped multiple slivered FSAs, the number of households for that grid was the sum of the product of the household densities, $\mathrm{p}(\mathrm{Aq} \mid \mathrm{U})$ and/or $p(A q \mid R)$, and the slivered areas of the overlapping FSAs. The number of households owning aquaria was also summarized at the watershed level. A watershed boundary file was obtained from the National Hydro Network (NHN, Government of Canada 2016). The NHN sub-drainage areas (secondary watersheds) were overlaid onto the gridded map of Canada and the number of aquarium owners in each watershed was the sum of households owning aquaria in all grids overlapped by the watershed.

## Step 2. Estimating the number and spatial distribution of households releasing aquarium organisms

The number of households releasing aquarium organisms was estimated by applying $p(\operatorname{Rel} \mid A q)$ to the expected number of households owning aquaria in Canada. An interview survey conducted for aquarium owners in Montréal, QC revealed that $6.9 \%$ of respondents had released at least one aquarium fish (Gertzen et al. 2008). In contrast, only $0.8 \%$ and $1.1 \%$ of aquarium owners indicated releasing plants and animals, respectively, in DFO's "Great Canadian Aquarium Survey" (Marson et al. 2009a). The median (i.e. 3.9\%) of the reported proportion of aquarium owners that were releasers was selected as the baseline $p(\operatorname{Re\| } \| \mathrm{Aq})$. To account for parameter uncertainty, the baseline $p(\operatorname{Rel} \mid A q)$ was increased or decreased by $50 \%$, such that high $p(\operatorname{Re} \| A q)=5.9 \%$ and low $p(\operatorname{Rel} \mid A q)=2.0 \%$, in sensitivity analyses (Table 1).

To map the spatial distribution of households releasing aquarium organisms, the expected number of households owning aquaria in each $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid was multiplied by $\mathrm{p}(\mathrm{Rel\mid} \mathrm{Aq})$. The number of households releasing aquarium organisms was also summarized at the watershed level by summing the number releasers in all grids overlapped by the watershed. This approach assumed that releasers do not travel beyond the watershed in which they reside to release organisms into the environment, while recognizing that released organisms may spread to connected waterbodies within a watershed. Further, the Getis-Ord Gi* statistics in ArcGIS were calculated to identify statistically significant areas (i.e. hot spots) where releasers aggregate. It was assumed that the interaction between two areas declines as the distance between them increases (i.e. distance decay, the inverse distance method in ArcGIS). The threshold distance was set to 100 km and measured using Euclidean distance.

## Step 3. Estimating propagule pressure of the pathway

The number of aquarium organisms released per year (i.e. propagule pressure) was estimated by modelling the number of aquarium organisms potentially released per release event (i.e. propagule size) and the expected number of releasers. Gertzen et al. (2008) reported that aquarium owners on average owned five fishes and that releasers on average released $5.1 \%$ of aquarium fishes owned, suggesting that the typical propagule size per event is small. Therefore, it was assumed that the probability distribution of propagule size follows a right-skewed, zerotruncated Poisson distribution where $\lambda=$ the average number of organisms released and $n=$ the potential number of releasers (from step 2). To account for the underreporting of propagule size, six organisms $(\lambda=6)$ was selected as the baseline average propagule size and this value was increased and decreased by $50 \%$ in sensitivity analyses to account for uncertainty (Table 1). The baseline, high, and low $\lambda$ scenarios represented a frequency distribution with a mode (i.e. the most common propagule size) of four, seven, and one, respectively. The selected probability distribution and $\lambda$ were assumed to be constant across the country. A Monte Carlo resampling process was used to calculate the number of aquarium organisms potentially released per year
with $\pm 95 \%$ confidence interval by drawing the number of aquarium owners releasing organisms estimated in step 2 from the zero-truncated Poisson distribution for 1,000 iterations for each scenario.

To obtain a coarse estimate of the proportion of aquarium organisms imported into Canada that can be expected to be released into the environment by aquarium owners, the baseline mean number of aquarium organisms released per year was compared with the reported total number of aquarium organisms imported into Canada scaled to a 12-month period.

## Water garden pathway

As with the aquarium pathway, a model was developed to quantify spatially explicit estimates of the propagule pressure of the water garden pathway in Canada. The number and spatial distribution of end users (i.e. water garden owners) (step 1 below, node 5 in Figure 2) and those who release water garden organisms into the environment (i.e. releasers) (step 2 below, node 6 in Figure 2) were estimated. Then, the expected number of releasers was combined with the potential number of propagules released by a releaser to estimate the total number of water garden organisms released per year (step 3). The model was parameterized using literature values. Specifically, past studies were used to determine the proportion of Canadians owning water gardens- $p(W G)$, the distribution of water garden owners in urban versus rural areas $(U: R)$, the proportion of water garden owners releasing organisms- $p(R e l \mid W G)$, and the typical number of water garden organisms (i.e. propagule size) released per event.

## Step 1. Estimating the number and spatial distribution of water garden owners

Extending the approach of the aquarium pathway, the expected number of water garden owners in Canada, $\mathrm{p}(\mathrm{WG})$, was determined via a literature review. A survey conducted by the National Gardening Association found that the proportion of households owning water gardens increased from $3.9 \%$ in 1998 to $14.4 \%$ in 2003 in the US (Gordon et al. 2012 citing Crosson 2003). Similar statistics were not available for Canada. The median (i.e. $9.2 \%$ ) of the 1998 and 2003 values was adopted as the baseline $p(W G)$ because water garden ownership is likely lower in Canada than in the US owing to the generally colder climates that limit the number of species and shorten the season suitable for water gardening. To account for parameter uncertainty, the baseline $p$ (WG) was increased or decreased by $50 \%$ in a one-parameter-at-a-time sensitivity analysis (Table 3). The high p(WG), 13.7\%, could account for greater than expected water garden ownership in Canada relative to the baseline estimate, whereas the low $p(W G), 4.6 \%$, could account for reduced ownership. For each sensitivity scenario, p(WG) was applied to the 2016 Canadian dwelling counts obtained from Statistics Canada's 2016 Census of Population Program (Statistics Canada 2019a). The unit for end users was household so that multi-person households owning water gardens were considered once only.
Recognizing that water gardening is mostly an outdoor activity and is constrained by climate, the potential geographic extent of water garden ownership was limited to Agriculture and AgriFood Canada's Plant Hardiness Zones (PHZs) 2a to 9a (Government of Canada 2019), following the methods of Buckley et al. 2021. These PHZs included areas where common water garden plants, as recorded by Marson et al. 2009b and Buckley et al. 2021, were reported to survive. Therefore, the gridded map of Canada created for the aquarium pathway was clipped to include only areas overlapping with PHZs 2a to 9a in ArcGIS. Then, to determine the expected spatial distribution of households owning water gardens, U:R for water garden owners was determined. Areas were classified as urban or rural using census population data for New Brunswick and FSAs for the remaining provinces and territories. Data collected via the "Great Canadian Water Garden Survey" provided the basis to estimate U:R, though ~ 95\% of these responses were from Ontario (Marson et al. 2009b). It was determined that $74.4 \%$ and $25.6 \%$ of
surveyed water garden owners resided in urban and rural areas, respectively. A lower U:R for water garden owners (74:26) compared with the background spatial distribution of the population in Ontario (86:14) suggested that water garden owners tended to be slightly biased towards rural areas, relative to overall population density, likely due to more available space for water gardening. It was assumed that the baseline $\mathrm{U}: \mathrm{R}$ was generally constant across regions in the absence of evidence to suggest otherwise. To account for parameter uncertainty owing to the fact that most respondents of the "Great Canadian Water Garden Survey" were from Ontario and thus the estimated U:R may not be representative for other regions, a one-parameter-at-atime sensitivity analysis was conducted by altering the baseline U:R by $\pm 10 \%$ (Table 3). The urban-biased $U: R(82: 18)$ represented the case in which there are greater than expected water garden owners in urban areas, whereas the opposite situation was represented by the ruralbiased U:R (67:33). The proportion of households owning water gardens, $p(W G)$, was corrected based on whether the households were located in an urban or rural area using Bayes' theorem:

$$
\begin{equation*}
p(W G \mid U)=\frac{p(U \mid W G) \cdot p(W G)}{p(U)} \tag{1}
\end{equation*}
$$

where $p(W G \mid U)=$ the corrected $p(W G)$ for urban areas, $p(U \mid W G)=$ the proportion of households owning water gardens in urban areas, $p(W G)=$ proportion of households owning water gardens, and $p(U)=$ proportion of households in urban areas; and
(2)

$$
p(W G \mid R)=\frac{p(R \mid W G) \cdot p(W G)}{p(R)}
$$

where $p(W G \mid R)=$ the corrected $p(W G)$ for rural areas, $p(R \mid W G)=$ the proportion of households owning water gardens in rural areas, $p(W G)=$ proportion of households owning water gardens, and $p(R)=$ proportion of households in rural areas. The values for $p(U)$ and $p(R)$ are $86.6 \%$ and 13.7\%, respectively.

Finally, the number of households in each $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid of the clipped map was calculated by multiplying the household density, $p(W G \mid U)$ and/or $p(W G \mid R)$, and the slivered areas of the overlapping FSA(s). Similar to the aquarium pathway, the number of households owning water gardens was also summarized at the watershed level by summing water garden owners in all grids overlapped by the watershed.

## Step 2. Estimating the number and spatial distribution of households releasing water garden organisms

The approach for estimating the number and spatial distribution of releasers associated with the aquarium pathway was applied to the water garden pathway. The number of households releasing water garden organisms was estimated by applying $p(R e l \mid W G)$ to the expected number of households owning water gardens in Canada. The "Great Canadian Water Garden Survey" reported that $1.3 \%$ and $2.8 \%$ of water garden owners indicated releasing plants and animals, respectively (Marson et al. 2009b). To account for the likely underreporting by survey respondents, the $p(\operatorname{Rel} \| A q)$ values from the aquarium pathway were used to estimate the proportion of water garden owners releasing organisms such that the baseline $\mathrm{p}(\mathrm{Rel\mid WG})=$ $3.9 \%$, high $p($ Rel $\mid W G)=5.9 \%$, and low $p($ Rel $\mid W G)=0.8 \%$ in sensitivity analyses.
To map the spatial distribution of households releasing water garden organisms, the expected number of households owning water gardens in each $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid was multiplied by $p($ Rel|WG). The number of households releasing water garden organisms was also summarized at the watershed level. As with the aquarium pathway, the Getis-Ord Gi* statistics in ArcGIS
were calculated to identify statistically significant areas (i.e. hot spots) where releasers aggregate.

## Step 3: Estimating propagule pressure of the pathway

The number of water garden organisms released per year (i.e. propagule pressure) was estimated by modelling the number of water garden organisms potentially released per release event (i.e. propagule size) and the potential number of releasers. No information regarding the typical propagule size of water garden organisms per event was available. Given the similarity between the aquarium and water garden pathways, particularly the reasons for end users to release ornamental organisms (Courtenay 1999, Gertzen et al. 2008), it was assumed that the average number of water garden organisms released per event is small and comparable with that of the aquarium pathway. Therefore, a right-skewed, zero-truncated Poison frequency distribution may also be suitable for describing the propagule sizes for the water garden pathway. As with the aquarium pathway, six organisms ( $\lambda=6$ ) was selected as the baseline average propagule size and was increased and decreased by $50 \%$ in sensitivity analyses to account for uncertainty (Table 3). Again, the selected probability distribution and $\lambda$ were assumed to be constant across the country. A Monte Carlo resampling process was used to calculate the number of water garden organisms potentially released per year with $\pm 95 \%$ confidence interval by drawing the number of releasers estimated in step 2 from the zerotruncated Poisson distribution for 1,000 iterations for each scenario.

To obtain a coarse estimate of the proportion of imported water garden organisms that can be expected to be released into the environment by water garden owners, the baseline mean number of water garden organisms released per year was compared with the reported total number of water garden organisms imported into Canada scaled to a 12-month period.

## Live seafood pathway

Based on the approach for the aquarium pathway, a model was developed to quantify spatially explicit estimates of propagule pressure of the live seafood pathway in Canada. The number and spatial distribution of end users (i.e. individuals purchasing live seafood including freshwater, brackish, or marine species) (step 1 below, node 5 in Figure 2) and those who release live seafood organisms into the environment (i.e. releasers) (step 2 below, node 6 in Figure 2) were estimated. Then, the expected number of releasers was combined with the potential number of propagules released by a releaser to estimate the total number of live seafood organisms released per year (step 3). The model was parameterized using literature values. Particularly, past studies were used to determine the proportion of Canadians purchasing live seafood (assumed for intended consumption-p(LF)), the distribution of the population purchasing live seafood in urban versus rural areas (U:R), the proportion of the population purchasing live seafood that released organisms-p(Rel|LF), and the typical number of live seafood organisms (i.e. propagule size) released per event.

## Step 1. Estimating the number and spatial distribution of individuals purchasing live seafood

The number and spatial distribution of individuals purchasing live seafood was estimated using an approach similar to the aquarium and water garden pathways. First, a literature review was conducted to determine p(LF). A Canadian survey conducted by Abacus Data revealed that $88.0 \%$ of respondents had consumed seafood in a three-month period (Coletto et al. 2011). It was assumed that $88.0 \%$ of the Canadian population were seafood consumers in the absence of more representative data. To determine the proportion of seafood consumers purchasing live seafood, the proportion of seafood retailers that sell live versus fresh, chilled, and/or frozen (i.e. dead) seafood was estimated using the compiled retailer data. It was assumed that the
proportion of live versus fresh, chilled, and/or frozen seafood available at retail stores was related to the proportion of seafood consumers purchasing live versus fresh, chilled, and/or frozen seafood based on supply and demand. Live seafood comprised $4.0 \%$ of seafood products carried at the retailers identified. Therefore, $4.0 \%$ was applied to the $88.0 \%$ to estimate the baseline $p(L F)$. To account for uncertainty around the parameter (e.g., the percentage of live seafood products at retailers and its relationship with the percentage of seafood consumers purchasing live seafood), the baseline $p(L F), 3.5 \%$, was increased and decreased by $50 \%$ (i.e. high $p(L F)=5.3 \%$ and low $p(L F)=1.8 \%$, respectively) in a one-parameter-at-a-time sensitivity analysis (Table 4). Then, for each sensitivity scenario, p(LF) was applied to the 2016 Canadian population data obtained from Statistics Canada's 2016 Census of Population Program. The end user for live seafood was an individual purchaser, unlike the aquarium and water garden pathways, which used households.

To characterize the expected spatial distribution of individuals purchasing live seafood in Canada, U:R for live seafood consumers in urban versus rural areas was evaluated. Areas were classified as urban or rural using census population data for New Brunswick and FSAs for the remaining provinces and territories. However, the literature review did not reveal any information regarding the distribution of the population purchasing live seafood in urban versus rural areas. Therefore, $\mathrm{U}: \mathrm{R}$ for live seafood consumers was determined based on the location of retailers in Canada that sell live seafood, which assumed an intrinsic spatial relationship between supply and demand. The proportion of retailers selling live seafood in urban and rural areas based on the retailer data is $85.5 \%$ and $14.4 \%$, respectively. The background spatial distribution of the Canadian population is $83.3 \%$ and $16.7 \%$ in urban and rural areas, respectively, estimated using the census population data (Statistics Canada 2019a). A greater U:R ratio for live seafood consumers ( $86: 14$ ) compared with the background spatial distribution of the Canadian population (83:17) suggested that live seafood consumers tended to reside in urban areas slightly more than would be predicted by population density, likely due to greater access to live seafood retail outlets. It was assumed that the baseline $U: R$ ratio was generally constant across regions in the absence of evidence to suggest otherwise. To account for parameter uncertainty, a one-parameter-at-a-time sensitivity analysis was conducted by altering the baseline $\mathrm{U}: \mathrm{R}$ by $\pm 10 \%$ (Table 4). The urban-biased U:R (94:6) represented the case in which there are greater than expected live seafood consumers in urban areas relative to population density, whereas the opposite scenario was rural-biased (U:R 77:23). The proportion of the population purchasing live seafood, $p(L F)$, was corrected based on whether the individuals were located in an urban or rural area. The corrected values were determined using Bayes' theorem:

$$
\begin{equation*}
p(L F \mid U)=\frac{p(U \mid L F) \cdot p(L F)}{p(U)} \tag{1}
\end{equation*}
$$

where $p(L F \mid U)=$ the corrected $p(L F)$ for urban areas, $p(U \mid L F)=$ the proportion of individuals purchasing live seafood residing in urban areas, $p(L F)=$ proportion of individuals purchasing live seafood, and $p(U)=$ proportion of Canadians residing in urban areas; and
(2)

$$
p(L F \mid R)=\frac{p(R \mid L F) \cdot p(L F)}{p(R)}
$$

where $p(L F \mid R)=$ the corrected $p(L F)$ for rural areas, $p(R \mid L F)=$ the proportion of individuals purchasing live seafood residing in rural areas, $p(L F)=$ proportion of individuals purchasing live seafood, and $p(R)=$ proportion of Canadians residing in rural areas. The values for $p(U)$ and $p(R)$ are $83.3 \%$ and $16.7 \%$ respectively.

The number of individuals in each $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid of the gridded Canadian map was calculated by multiplying the population density, $p(L F \mid U)$ or $p(L F \mid R)$, and the slivered area of the overlapping FSA(s). The number of individuals purchasing live seafood was also summarized at the watershed level by summing the live seafood consumers in all grids overlapped by the watershed.

## Step 2. Estimating the potential number and spatial distribution of releasers

The approach for estimating the number and spatial distribution of releasers associated with the aquarium pathway was applied to the live seafood pathway. The number of individuals releasing live seafood organisms was estimated by applying $p(\operatorname{Rel} \mid L F)$ to the expected number of individuals purchasing live seafood in Canada. However, no information regarding the proportion of the population purchasing live seafood who release organisms (i.e. releasers)$p($ Rel |LF) -was available. In the absence of pathway-specific data, the $p(R e l \mid A q)$ values from the aquarium pathway were used to estimate the proportion of the population purchasing live seafood who release organisms such that the baseline p(Re||LF) $=3.9 \%$, high $p(\operatorname{Re|} \mid L F=5.9 \%$, and low p (Rel|LF $=0.8 \%$ ) in sensitivity analyses.

To map the spatial distribution of individuals releasing live seafood organisms, the expected number of individuals purchasing live seafood in each $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid was multiplied by $p($ Rel|LF). The number of individuals releasing live seafood organisms was also summarized at the watershed level. Further, the Getis-Ord Gi* statistics in ArcGIS were calculated to identify statistically significant areas (i.e. hot spots) where releasers aggregate (see step 2 under the aquarium pathway for details).

## Step 3: Estimating propagule pressure of the pathway

The number of live seafood organisms released per year (i.e. propagule pressure) was calculated by modelling the number of live seafood organisms potentially released per event (i.e. propagule size) and the expected number of releasers. While studies examining the propagule size of live seafood organisms per event were not available, the findings of Gertzen et al. (2008) for the release of aquarium organisms are likely applicable to live seafood releases. It is expected that the most common propagule size is small (e.g., one or few unconsumed fishes or invertebrates), though clam or mussel releases may involve a slightly greater number of individuals. Therefore, a right-skewed, zero-truncated Poison frequency distribution was assumed to be suitable for describing the propagule sizes for the live seafood pathway. As with the case of the aquarium pathway, six organisms $(\lambda=6)$ was selected as the baseline average propagule size and was increased and decreased by $50 \%$ in sensitivity analyses to account for uncertainty (Table 4). Again, the selected probability distribution and $\lambda$ were assumed to be constant across the country. A Monte Carlo resampling process was used to calculate the number of live seafood organisms potentially released per year with $\pm 95 \%$ confidence interval by drawing the number of releasers estimated in step 2 from the zero-truncated Poisson distribution 1,000 iterations for each scenario.

To obtain a coarse estimate of the proportion of imported live seafood organisms that are expected to be released into the environment by live seafood consumers, the baseline mean number of live seafood organisms released per year was compared with the reported total number of live seafood organisms imported into Canada scaled to a 12 -month period.

## IDENTIFYING CRITICAL CONTROL POINTS

Critical control points were defined as geographic locations of each component of the supply chain (ports of entry, distribution hubs, retailers, end users, and releasers) that involve the greatest numbers of organisms in trade. In some cases, imported organisms from the greatest
number of source countries were also identified. For each pathway, critical control points were identified by examining the assembled trade distribution network as well as the estimated number and spatial distribution of end users and releasers. The critical control points allow the greatest bulk volume of organisms to be encountered for potential management actions (e.g., species screening, education, enforcement), though the use of each control point will depend on the specific management objective (e.g., optimize surveillance vs. prevent releases).

## RESULTS

## AQUARIUM PATHWAY

## Movement of aquarium organisms into and within Canada

A total of $4,296,188$ aquarium organisms were imported into Canada from 40 source countries during the four-month period in 2018 where high-resolution Pathfinder data were available (Figure 3). A list of aquarium taxa $(\mathrm{n}=844)$ found in the Pathfinder dataset is provided in Appendix B. The US was the leading source country for organisms imported for the aquarium trade, followed by Indonesia and Sri Lanka (Table 5).
The majority of the aquarium organisms were imported into Canada via Windsor, ON (41\% of the total number of imported aquarium organisms); Mirabel, QC (30\%); and Calgary, AB (25\%, Figure 4). Aquarium organisms that entered Canada via Windsor and Mirabel originated from only three and four source countries, respectively. In contrast, Calgary received aquarium organisms originating from 26 countries. A summary of the number of aquarium organisms imported into Canada by port of entry and source country is provided in Table 6.
Innisfil, ON; LaSalle, QC; and, Calgary, AB were the top three distribution hubs receiving the greatest number of imported aquarium organisms (Table 7). The leading distribution hub, Innisfil, ON is located in a rural area, about 80 km north of Toronto, ON, while the remaining distribution hubs are in urban areas. Once imported into Canada, aquarium organisms were occasionally moved beyond the province of the port of entry (Figure 4 and Table 7). For example, aquarium organisms imported via Richmond, BC were transferred to distribution hubs in $A B$ and $M B$, though some remained within the province. There were also inter-provincial movements of aquarium organisms from Toronto, ON to Laval, QC.
There were at least 1,163 retailers selling live aquarium fishes, invertebrates, and plants in Canada (Figure 5). These retailers generally aggregated around major cities such as Richmond, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; Toronto, ON; Montréal, QC; Moncton, NB; and Halifax, NS. This was somewhat expected as businesses generally select their locations based on population density to reach a greater number of potential customers.

The CFIA dataset recorded an annual average of 13,318,572 ( $\pm 8,843,262$ SEM) aquarium fishes imported into Canada between 2008 and 2018. The top five source countries for aquarium fishes based on the CFIA dataset were Indonesia, the US, the Philippines, Singapore, and Thailand, which is fairly consistent with the CBSA Pathfinder dataset. When scaling the Pathfinder records to a 12-month period, they represented approximately $97.0 \%$ of the annual aquarium fish imports in Canada, assuming the CFIA dataset is complete.

## Spatially explicit estimates of propagule pressure

An estimated $1,491,256$ households owned aquaria in Canada, though this number ranged from 745,719 to $2,237,279$ (Figure 6). A $50 \%$ increase or decrease in $p(A q)$ led to a $50 \%$ increase or decrease in the estimated number of households owning aquaria, respectively. In the baseline
scenario, there were households owning aquaria in all provinces and territories (Figure 7). The presence of households owning aquaria in northern communities may be an artifact of the way human population density was estimated from FSAs of varying sizes (see the Methods section for details) as some relatively small FSAs resulted in greater than expected population density. Altering $\mathrm{p}(\mathrm{Aq})$ changed the geographic extent of households owning aquaria (Figure 7). The number of households owning aquaria increased when $p(A q)$ was increased from the baseline, $10.6 \%$, to high $p(A q), 15.9 \%$, with increases in the number of aquarium owners mostly observed in northern YT, AB, and QC. In contrast, there were fewer households owning aquaria when $p(A q)$ decreased from the baseline to low $p(A q), 5.3 \%$, with geographic extent largely restricted to south of $66^{\circ} \mathrm{N}$ plus some parts of YT, NT, and NU. The magnitude of change in the number of grids with aquaria owners relative to baseline ranged from a $3.1 \%$ increase in high $p(A q)$ scenario to a $15.8 \%$ decrease in low $p(A q)$ scenario (Figure 8). In general, households owning aquaria aggregated along the Canada-US border, especially near major cities such as Vancouver, BC; Edmonton, AB; Calgary, AB; Toronto, ON; and Montréal, QC, likely due to the proximity to aquarium retail outlets. This spatial pattern is consistent with population density in Canada. The spatial patterns of households potentially owning aquaria at the watershed level were similar to those at the grid level (Figures 9 and 10).

The number of households releasing aquarium organisms in Canada was estimated at 57,799 and this value ranged between 28,921 and 87,008 (Figure 6). Increasing p(Aq) or p(Rel|Aq) by $50 \%$ resulted in $a \sim 50 \%$ increase in the number of households releasing aquarium organisms. The opposite pattern was observed when decreasing $p(A q)$ or $p(R e l \mid A q)$ by $50 \%$. In the baseline scenario, households releasing aquarium organisms were distributed mainly along the CanadaUS border plus northern $B C$, northern $A B$, some parts of NL, and around Whitehorse, YT , and Yellowknife, NT (Figure 11). Increasing p(Aq) or $p(\mathrm{Rel\mid Aq})$ by $50 \%$ expanded the geographic extent of households releasing aquarium organisms, mainly in northern $B C, A B, S K$, and $Q C$. In contrast, decreasing $p(A q)$ or $p(\operatorname{Rel} \| A q)$ by $50 \%$ constricted the geographic extent of releasers to areas along the US-Canada border, though clusters of releasing households could be found in southwestern Ontario and along the St. Lawrence River. The magnitude of change in the number of grids with releasers relative to baseline ranged from a 11.4\% decrease in low $p(A q)$ and low $p(\operatorname{Re\| } \| q)$ scenarios to a $22.3 \%$ increase in high $p(A q)$ and high $p(\operatorname{Rel|Aq})$ scenarios (Figure 8), signifying that the spatial distribution of end users was less sensitive to input parameters than other model outputs. The spatial patterns of households releasing aquarium organisms at the watershed level were similar to those at the grid level (Figures 10 and 12). Results of the hot spot analysis indicated that major cities including Victoria, BC; cities in the Greater Vancouver Area, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Winnipeg, MB; Windsor, ON; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Barrie, ON; Kingston, ON; Ottawa-Gatineau, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Trois-Rivières, QC; Québec City, QC; Saguenay, QC; Moncton, NB; and, Halifax, NS were statistically significant areas where releasers aggregated (Figure 13). Results of the one-parameter-at-a-time sensitivity analysis scenarios suggested that changes in parameter values did not affect the results of the hot spot analysis.

In scenarios where the proportion of households owning aquaria in urban and rural areas were considered, the estimated number of aquarium owners and releasers of aquarium organisms in Canada were comparable to those generated without correcting $p(A q)$ for urban and rural areas (see above). The number of households owning aquaria was estimated at 1,493,611, but this number ranged between 746,675 and $2,239,950$. The number of households releasing aquarium organisms with $\mathrm{U}: \mathrm{R}$ corrections was estimated at 57,942 , though this number ranged from 28,945 to 87,212 . The geographic extent of households owning aquaria and households releasing aquarium organisms in the baseline $p(A q)$, low $p(A q)$, and high $p(A q)$ scenarios were
similar to those described above for scenarios without U:R corrections (Figures 14-16). However, in the urban-biased $p(A q)$ scenario, the geographic extent of aquarium owners was restricted to areas south of $66^{\circ} \mathrm{N}$ latitude plus some parts of YT, NT, and NU as the proportion of households owning aquaria in urban to rural areas increased from the baseline U:R (86:14) to 94:6 (Figure 14). In contrast, aquarium owners were more evenly distributed across Canada when $\mathrm{U}: \mathrm{R}$ decreased to 77:23 in the rural-biased $p(A q)$ scenario. For households releasing aquarium organisms, the spatial distribution was patchy along the Canada-US border in the urban-biased $p(A q)$ scenario, whereas releasers were more evenly distributed in areas south of $60^{\circ} \mathrm{N}$ latitude plus some parts of YT, NT, QC, and NL in the rural-biased p(Aq) scenario (Figure 15). The spatial patterns of households owning aquaria and releasing aquarium organisms at the watershed level were similar to those at the grid level (Figures 17-19).

The number of aquarium organisms released per year in Canada was estimated at 347,650 ( $95 \%$ confidence interval $346,555-348,776$ ) for $n=57,799$ (baseline number of households releasing aquarium organisms) and $\lambda=6$ (average propagule size) (Figure 20). However, this estimate ranged from 152,196 to 457,882 depending on the sensitivity analysis scenario (Figure 21). $A 50 \%$ increase in $p(A q), p(\operatorname{Re\| } \mid A q)$, or $\lambda$ led to a $\sim 50 \%$ increase in the estimated number of aquarium organisms released per year, whereas the opposite pattern was observed when decreasing $p(A q)$ or $p(\operatorname{Re\| } \| q)$ by $50 \%$ (Figure 21). Decreasing $\lambda$ by $50 \%$ resulted in a decrease in the number of aquarium organisms released per year by $47.5 \%$. A comparison of the baseline mean number of aquarium organisms released per year in Canada with the four-month Pathfinder records scaled to a 12-month period (12,915,414 aquarium organisms) suggested that $2.7 \%$ of aquarium organisms imported into Canada are expected to be released by aquarium owners.

## Critical control points of the pathway

Windsor, ON; Mirabel, QC; and, Calgary, AB were the top three ports of entry receiving the greatest number of imported aquarium organisms. Calgary, $A B$ warrants additional attention as it processed aquarium organisms originating from a wide range of source countries, increasing the likelihood that some imported species could survive if introduced into the environment. Postborder critical control points included major distribution hubs of aquarium organisms including Innisfil, ON; LaSalle, QC; and Calgary, AB. Occasional inter-provincial movements of aquarium species were observed from $B C$ to $A B$ and $M B$, as well as from $O N$ to QC. Retailers that sold live aquarium fishes, invertebrates, and plants tended to aggregate around major cities (e.g., Richmond, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; Toronto, ON; Montréal, QC; Moncton, NB; and Halifax, NS). Spatially explicit estimates of propagule pressure, after accounting for parameter uncertainty, suggested that end users, especially releasers, were typically found in or near major cities (e.g., Victoria, BC; cities in the Greater Vancouver Area, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Winnipeg, MB; Windsor, ON; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Barrie, ON; Kingston, ON; Ottawa-Gatineau, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Trois-Rivières, QC; Québec City, QC; Saguenay, QC; Moncton, NB; and Halifax, NS). This observation is consistent with the known positive relationship between human population and the propagule pressure of ornamental organisms (Copp et al. 2005, 2006, Duggan et al. 2006).

## WATER GARDEN PATHWAY

## Movement of water garden organisms into and within Canada

A total of $3,758,224$ water garden organisms were imported into Canada from 19 source countries during the four-month Pathfinder period in 2018 (Figure 22). A list of water garden taxa ( $n=199$ ) found in the Pathfinder dataset is provided in Appendix B. The US was the leading source country for aquatic organisms imported via the water garden trade, followed by Thailand and Germany (Table 8).

The majority of water garden organisms were imported into Canada via Windsor, ON (47\% of the total number of imported water garden organisms); Mirabel, QC (34\%); and Calgary, AB ( $16 \%$, Figure 23). All water garden organisms that entered Canada via Windsor, ON and Mirabel, QC originated from the US. In contrast, those imported into the country via Calgary originated from seven countries. However, Edmonton, AB processed water garden organisms originating from the greatest number of sources (11 countries) when compared with other ports of entry. A summary of the number of water garden organisms imported into Canada by port of entry and source country is provided in Table 9.
The top three distribution hubs for water garden organisms were Innisfil, ON; LaSalle, QC; and Calgary, $A B$ (Table 10). Not surprisingly, there was overlap in the distribution networks of aquarium and water garden organisms (Figures 4 vs. 23). Inter-provincial movements observed for aquarium organisms were also found for water garden organisms (Figure 23 and Table 10). Again, water garden organisms imported via Richmond, BC were observed being moved to distribution hubs in $A B$ and $M B$, and via Toronto, $O N$ to distributors in QC.
There were at least 1,284 retailers selling live fishes, invertebrates, and plants for water gardens in Canada (Figure 24). As is the case with the aquarium trade, these retailers clustered around major cities such as Richmond, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; Toronto, ON; Montréal, QC; Moncton, NB; and Halifax, NS.

## Spatially explicit estimates of propagule pressure

An estimated 1,301,154 households owned water gardens in Canada, though this number ranged from 650,644 to 1,951,778 (Figure 25). A 50\% increase or decrease in p(WG) led to a $50 \%$ increase or decrease in the estimated number of households owning water gardens, respectively. In the baseline scenario, the geographic extent of households owning water gardens covered areas south of $60^{\circ} \mathrm{N}$ latitude, mainly along the Canada-US border (Figure 26). Not surprisingly, there were no households owning water gardens in the northern regions of Canada including YT, NT, and NU, as well as northern parts of AB, SK, ON, QC, and NL. The lack of northern ownership was due to the plant hardiness zone restrictions, rather than underlying factors related to population density (see Buckley et al. 2021). Altering p(WG) changed the geographic extent of households owning water gardens very slightly, resulting in a $<1 \%$ change in the number of grids with water garden owners relative to the baseline in each sensitivity analysis scenario (Figures 26 and 27). There were more water garden owners around major cities when $p(W G)$ was increased from the baseline, $9.2 \%$, to high $p(W G), 13.7 \%$, compared to when it was decreased from baseline to low $p(W G), 4.6 \%$. An increase in the proportion of households owning water gardens in urban to rural areas from the baseline U:R (74:26) to 82:18 led to increased patchiness in the spatial distribution of water garden owners in the urban-biased $p(W G)$ scenario, whereas a decrease in U:R to 67:33 resulted in households with water gardens more evenly distributed across Canada in the rural-biased p(WG) scenario. Decreasing U:R essentially increased the number of water garden owners in rural areas relative to those in urban neighbourhoods. This may be the case as water gardens typically require
outdoor backyard space that may not be available in high density urban settings (e.g., townhouses, condos, and/or apartments, see Buckley et al. 2021), though there is evidence of small patio and balcony water gardens (e.g., container water gardens) in urban areas (D. Holland, CAOAC, pers. comm.). The spatial patterns of households owning water gardens at the watershed level were similar to those at the grid level (Figures 28 and 29). The observed spatial patterns are consistent with the population distribution of Canada and where common water garden plants are expected to survive.

The number of households releasing water garden organisms in Canada was estimated at 50,769 and ranged between 25,305 and 76,119 (Figure 25). Increasing p(WG) or p(Rel|WG) by $50 \%$ resulted in a $\sim 50 \%$ increase in the number of households releasing water garden organisms. The opposite was observed when decreasing p(WG) or p(Rel|WG) by $\sim 50 \%$. In the baseline scenario, the households releasing water garden organisms were distributed mainly along the Canada-US border, especially in southern BC, southern parts of the Prairie Provinces, southwestern ON, southern QC, the Maritimes, and Newfoundland (Figure 30). Increasing $p(W G)$ or $p($ Rel|WG) by $50 \%$ or applying a rural-biased $p(W G)$ expanded the geographic extent of households releasing water garden organisms in BC, AB, MB, and ON. In contrast, decreasing $p(W G)$ or $p(\operatorname{Rel} \mid W G)$ by $50 \%$ or applying an urban-biased $p(W G)$ constricted the geographic extent of households releasing water garden organisms, with releasers aggregated in southwestern ON, along the St. Lawrence River in QC, and in the Maritimes. However, they were also sparsely located around major cities in southern BC, the Prairies, and Newfoundland. The magnitude of change in the number of grids with releasers relative to baseline ranged from a $3.7 \%$ increase in rural-biased $p(W G)$ scenario to a $11.9 \%$ decrease in low $p(W G)$ and low $p($ Rel|WG) scenarios (Figure 27), signifying that the spatial distribution of end users was less sensitive to input parameters than other model outputs. The spatial patterns of households releasing water garden organisms at the watershed level were similar to those at the grid level (Figures 29 and 31). Results of the hot spot analysis further indicated that major cities including Victoria, BC; Vancouver, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Ottawa, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Québec City, QC; and Halifax, NS were statistically significant areas where households releasing water garden organisms aggregated (Figure 32). There were no hot spots in areas suitable for water gardening in SK, the Maritimes (NB, NS, and PE), and NL. Results of the one-parameter-at-atime sensitivity analysis scenarios suggested that changes in parameter values had no effect on the results of the hot spot analysis.
The number of water garden organisms released per year in Canada was estimated at 305,367 ( $95 \%$ confidence interval $304,307-306,479$ ) for $n=50,769$ (baseline estimate of the number of households releasing water garden organisms) and $\lambda=6$ (average propagule size) (Figure 33). However, this estimate ranged from 152,196 to 457,882 under different sensitivity analysis scenarios (Figure 34). A $50 \%$ increase in p(WG), p(Rel|WG), or $\lambda$ led to a $\sim 50 \%$ increase in the estimated number of water garden organisms released per year, whereas a reverse pattern was observed when decreasing p(WG) or p(Rel|WG) by 50\% (Figure 34). Decreasing $\lambda$ by $50 \%$ resulted in a decrease in the number of water garden organisms released per year by 47.5\%. A comparison of the baseline mean number of water garden organisms released per year in Canada with the four-month Pathfinder records scaled to a 12-month period (11,301,522 water garden organisms) suggested that $2.7 \%$ of water garden organisms imported into Canada are expected to be released by water garden owners.

## Critical control points of the pathway

There was overlap between the critical control points of the water garden pathway and those of the aquarium pathway. Windsor, ON; Mirabel, QC; and Calgary, AB were the top three ports of entry receiving the greatest number of imported water garden organisms. However, Edmonton, AB also warrants attention as it received water garden organisms originating from the greatest number of sources, which may increase the likelihood that some of the imported species could survive if introduced into the environment. As is the case with the aquarium pathway, postborder critical control points included major distribution hubs of water garden organisms including Innisfil, ON; LaSalle, QC; and Calgary, AB. Occasional inter-provincial movements of water garden species were observed from $B C$ to $A B$ and $M B$, as well as from ON to QC. Retailers that sold live fishes, invertebrates, and plants for water gardens aggregated around major cities (e.g., Richmond, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; Toronto, ON; Montréal, QC; Moncton, NB; and Halifax, NS). Spatially explicit estimates of propagule pressure, after accounting for parameter uncertainty, suggested that end users, especially releasers, were typically found in or near major cities (e.g., Victoria, BC; Vancouver, BC; Calgary, AB; Edmonton, AB; Winnipeg, MB; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Ottawa, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Québec City, QC; and Halifax, NS). This observation further supports the positive relationship between human population and the propagule pressure of ornamental organisms (Copp et al. 2005, 2006, Duggan et al. 2006).

## LIVE SEAFOOD PATHWAY

## Movement of live seafood organisms into and within Canada

A total of $82,434,924$ live seafood organisms were imported into Canada from 20 source countries during the four-month period covered by the Pathfinder data in 2018 (Figure 35). The imported organisms included species native to Canada such as the Snow Crab (Chionoecetes opilio) that was harvested in the Atlantic Ocean, off Saint Pierre and Miquelon. A list of live seafood taxa $(\mathrm{n}=84)$ found in the Pathfinder dataset is provided in Appendix B. The US was the leading source country for aquatic organisms imported via the live seafood trade, followed by Ireland and New Zealand (Table 11).

The majority of the live seafood organisms were imported into Canada via Ottawa, ON (60.6\% of the total number of imported live seafood organisms); Richmond, BC (15.1\%); and StStephen, NB (14.0\%; Figure 36). Live seafood organisms entering the country via Ottawa, ON and St-Stephen, NB originated from only one and two source countries, respectively. In contrast, Richmond, BC handled live seafood organisms originating from seven countries. However, Toronto, ON received live seafood organisms from the greatest number of sources (13 countries). A summary of the number of live seafood organisms imported into Canada by port of entry and source country is provided in Table 12.
Montebello, QC; Chilliwack, BC; and Cap-Pelé, NB were the top three distribution hubs receiving the greatest number of imported live seafood organisms (Table 13). The top distribution hub, Montebello, QC, is located in a rural area, about 80 km east of Ottawa. The remaining distributors could be found in both urban and rural areas. There were more distributors in the Maritimes than the rest of the country. There were also greater numbers of distribution hubs for the live seafood trade compared to the aquarium and water garden trades. Once imported into Canada, live seafood organisms were often moved beyond the province of the port of entry (Figure 36 and Table 13). Six of the 20 ports of entry were involved in interprovincial movement of live seafood organisms. For example, live seafood organisms imported via St-Stephen, NB were transferred to distribution hubs in PE, NS, and QC. There was also
movement of live seafood organisms from Belleville, NB to distribution hubs in NS, PE, NL, and QC.

There were at least 2,341 retailers selling live seafood in Canada (Figure 37). These retailers were found mainly along the Canada-US border, where the majority of the Canadian population resided. Similar to the aquarium and water garden trades, the retailers generally aggregated around major cities such as Richmond, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Regina, SK; Winnipeg, MB; London, ON; Hamilton, ON; Toronto, ON; Ottawa, ON; Montréal, QC; Moncton, NB; and Halifax, NS. This observation suggests that there is a positive relationship between human population and the propagule pressure for the live seafood pathway, which was also the case for the aquarium and water garden pathways.

## Spatially explicit estimates of propagule pressure

An estimated 1,237,160 individuals purchased live seafood organisms in Canada each year, but this number ranged from 618,629 to 1,855,969 (Figure 38). A 50\% increase in p(LF) led to a $50 \%$ increase in the estimated number of individuals purchasing live seafood, whereas a reverse pattern was observed when decreasing p(LF) by $50 \%$. In the baseline scenario, there were individuals purchasing live seafood in all provinces and territories (Figure 39). The presence of individuals purchasing live seafood in northern communities may be an artifact of the way human population density was estimated from FSAs of varying sizes (see the Methods for details). Some relatively small FSAs resulted in greater than expected population density. In addition, it is likely that northern communities rely on subsistence fishing and wild harvesting rather than purchasing live seafood from retail outlets, indicating that the analytical framework could benefit from regional modifications, should suitable data become available. Altering p(LF) changed the geographic extent of individuals purchasing live seafood (Figure 39). The number of individuals purchasing live seafood increased when $p(L F)$ was increased from the baseline $3.5 \%$ to $5.3 \%$ in the high $p(L F)$ scenario, with increases in the number of live seafood consumers mostly observed in areas south of $60^{\circ} \mathrm{N}$ latitude. In contrast, there were fewer individuals purchasing live seafood when $p(L F)$ decreased from the baseline to $1.8 \%$ in the low $p(L F)$ scenario, with geographic extent largely restricted south of $66^{\circ} \mathrm{N}$ plus some parts of YT , NT, NU, and QC. The geographic extent of live seafood consumers was restricted to areas south of $60^{\circ} \mathrm{N}$ latitude plus some parts of YT, NT, NU, and QC as the proportion of individuals purchasing live seafood in urban to rural areas increased from the baseline $U: R(86: 14)$ to $94: 6$ in the urban-biased $p(L F)$ scenario. In contrast, live seafood consumers were more evenly distributed across Canada when $\mathrm{U}: \mathrm{R}$ decreased from baseline to 77:23 in the rural-biased scenario, with geographic extent covering almost the entire country. The magnitude of change in the number of grids with live seafood consumers ranged from a $3.7 \%$ increase in the ruralbiased $p(L F)$ scenario to a $29.5 \%$ decrease in the urban-biased $p(L F)$ scenario (Figure 40). In general, a high number of individuals purchasing live seafood were aggregated along the Canada-US border. This spatial pattern is consistent with population density in Canada. The spatial patterns of individuals potentially purchasing live seafood at the watershed level were similar to those at the grid level (Figures 41 and 42).

The number of live seafood consumers releasing live seafood organisms in Canada was estimated at 47,964 and the value ranged between 23,924 and 70,046 (Figure 38). Increasing $p(L F)$ or $p$ (Rel|LF) by $50 \%$ resulted in a $\sim 50 \%$ increase in the number of individuals releasing live seafood organisms. The opposite was observed when decreasing p(LF) or p(Rel|LF) by $50 \%$. In the baseline scenario, individuals releasing live seafood organisms were distributed along the Canada-US border plus northern AB, the Maritimes, some parts of NL, and major northern cities including Whitehorse, YT and Yellowknife, NT (Figure 43). Increasing p(LF) or $p$ (Rel|LF) by $50 \%$ or applying a rural bias $p(L F)$ expanded the geographic extent of individuals
releasing live seafood organisms, mainly in northern SK, and MB. In contrast, decreasing p(LF) or $p$ (Rel|LF) by $50 \%$ or applying an urban bias $p(L F)$ constricted the geographic extent of individuals releasing live seafood organisms, with releasers sparsely distributed along the USCanada border and in the Maritimes. However, high concentrations of releasers were found in Southwestern Ontario and along the St. Lawrence River in QC. The magnitude of change in the number of grids with releasers relative to baseline ranged from a $23.0 \%$ increase in rural-biased p(LF) scenario to a $25.0 \%$ decrease in urban-biased p(LF) scenario (Figure 40), signifying that the spatial distribution of end users was less sensitive to input parameters than other model outputs. The spatial patterns of individuals releasing live seafood organisms at the watershed level were similar to those at the grid level (Figures 42 and 44). Results of the hot spot analysis indicated that major cities such as Victoria, BC; cities in the Greater Vancouver Area, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Winnipeg, MB; Windsor, ON; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Barrie, ON; Ottawa-Gatineau, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Trois-Rivières, QC; Québec City, QC; and Halifax, NS were statistically significant areas where individuals releasing live seafood organisms aggregated (Figure 45). Results of the one-parameter-at-a-time sensitivity analysis scenarios suggested that changes in parameter values had no effect on the results of the hot spot analysis.

The number of live seafood organisms released per year in Canada was 288,502 (95\% confidence interval $287,457-289,563$ ) for $n=47,964$ (baseline estimate of the number of individuals releasing live seafood organisms) and $\lambda=6$ (average propagule size) (Figure 46). However, this estimate ranged from 143,913 to 433,362 under various sensitivity scenarios (Figure 47). A $50 \%$ increase in $p(L F), p($ Rel|LF), or $\lambda$ led to $a \sim 50 \%$ increase in the estimated number of live seafood organisms released per year, whereas the opposite pattern was observed when decreasing p(LF) or p(Rel|LF) by $50 \%$. Decreasing $\lambda$ by $50 \%$ resulted in a decrease in the number of live seafood organisms released per year by $47.5 \%$. A comparison of the baseline mean number of live seafood organisms released per year in Canada with the fourmonth Pathfinder records scaled to a 12 -month period ( $247,304,772$ live seafood organisms) suggested that $0.1 \%$ of the live seafood organisms imported into Canada were expected to be released by live seafood consumers.

## Critical control points of the pathway

Ottawa, ON; Richmond, BC; and St-Stephen, NB were the top three ports of entry receiving the greatest quantity of imported live seafood. Toronto, ON also warrants attention as it received live seafood organisms originating from the greatest number of sources. Post-border critical control points included major distribution hubs of live seafood including Montebello, QC; Chilliwack, BC; and Cap-Pelé, NB. There were frequent inter-provincial movements of live seafood organisms from NB to PE, NS, NL, and QC. Some inter-provincial movements of live seafood organisms were also observed from ON to NB, QC to ON and vice versa, and BC to AB and ON. Retailers that sold live seafood aggregated around major cities (e.g., Richmond, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Regina, SK; Winnipeg, MB; London, ON; Hamilton, ON; Toronto, ON; Ottawa, ON; Montréal, QC; Moncton, NB; and, Halifax, NS). Spatially explicit estimates of propagule pressure, after accounting for parameter uncertainty, suggested that end users, especially releasers, were typically found in or near major cities (e.g., Victoria, BC; cities in the Greater Vancouver Area, BC; Calgary, AB; Edmonton, AB; Saskatoon, SK; Winnipeg, MB; Windsor, ON; London, ON; Kitchener-Waterloo-Cambridge, ON; Hamilton, ON; St. Catharines, ON; cities in the Greater Toronto Area; Barrie, ON; Ottawa-Gatineau, ON; cities in the Greater Montréal Area, QC; Sherbrooke, QC; Trois-Rivières, QC; Québec City, QC; and, Halifax, NS). This observation suggests that the positive relationship between human
population and propagule pressure of ornamental species (Copp et al. 2005,2006, Duggan et al. 2006) also exists for live seafood organisms.

## DISCUSSION

The distribution networks assembled for the aquarium, water garden, and live seafood trades provide directional estimates of the connectivity of organisms in trade into and within Canada, which can be used to forecast or backcast the movement of species and, potentially, their associated pathogens. For example, knowledge of a species of concern (e.g., presumptive AIS, endangered species, or pathogen) in a source country would allow the most likely corresponding port of entry into Canada to be identified, thereby allowing surveillance to be optimized. Alternatively, if such species or pathogens were discovered in Canadian ecosystems or network components, the networks could be used to better understand the locations (e.g., retailers, distribution hubs, and ports of entry) where the species or pathogens may have originated or flowed through. In these cases, network flows could identify other locations where the species has gone undetected. Future work could determine the degree to which speciesspecific flows deviate from bulk patterns. The assembled trade distribution networks, however, need to be interpreted with caution because the source countries identified may not represent the actual biogeographic origin or native range of the imported organisms. In addition, these networks were constructed using four months of import records with some inherent data quality issues (see below). Also, end-to-end traceability of organisms was not possible as transactions between distributors and retailers and those between retailers and end users were not quantified.
The focus on bulk propagule pressure as an endpoint allowed for the most inclusive comparison of the pathways by which live organisms are moved into and within Canada. Although the common approach to estimate propagule pressure involves proxy variables (e.g., species import records, volume of ballast water discharge, number of ship arrivals, and other indices of human activity, Bradie et al. 2013, Chan et al. 2015a), proxy variables prevent meaningful comparison of propagule pressure among pathways, and also limit the ability to incorporate other stages of the invasion process, where knowledge of organism abundance in the wild is necessary to determine species establishment. To address this issue, statistical estimates of propagule pressure have been developed for several major pathways in Canada or for some parts of Canada (e.g., ballast water, Casas-Monroy et al. 2014; live-bait angling, Drake and Mandrak 2014; recreational boating, Drake et al. 2017). This study provides national estimates of propagule pressure for the aquarium, water garden, and live seafood pathways in Canada. The aquarium pathway ( 347,650 organisms per year in the baseline scenario) appears to pose the greatest introduction risk, followed by the water garden (305,367 organisms per year) and live seafood (288,502 organisms per year) pathways. The estimated propagule pressure of these pathways appears to be lower than that of ships' ballast water, where the estimated annual number of zooplankton arriving at Canadian ports via ballast water discharges averaged 132 million organisms (Casas-Monroy et al. 2014). Pathway-level estimates of propagule pressure can be used to compare among other major pathways in Canada or specific regions of Canada, and when coupled with other stages of the invasion process (survival, establishment), provide a foundation to estimate the number of species establishing per year from a given pathway. Furthermore, a comparison of the reported number of organisms imported into Canada with the propagule pressure estimated for each pathway provided insight into the potential for organisms in trade to be released into the environment. It appears that relatively small proportions of the imported aquarium, water garden, and live seafood organisms are expected to be released, though they are 10 -fold greater for aquarium and water garden organisms ( $2.7 \%$ for both cases) than for live seafood organisms ( $0.1 \%$ ). However, these estimates did not take into account
changes in the number of organisms due to mortality or reproduction prior to release, which likely vary by pathway, or the release of organisms by end users who did not identify as participants of these pathways (e.g., the use of live seafood organisms for illegal stocking or mercy release).

Critical control points identified in this study could allow the greatest bulk (i.e. non-specific) volume of organisms in trade to be encountered for a range of AIS management actions. The actual intervention strategies would depend on the specific management objective. For instance, if the management objective was to optimize surveillance for particular species of concern (e.g., presumptive AIS), logical critical control points could include the major ports of entry highlighted in this study, which would limit subsequent redistribution of the species within Canada. However, a variety of alternative surveillance criteria could be incorporated, which would change the identity of control points. For example, ports of entry that are highly connected to the global network (e.g., Calgary, AB for the aquarium trade) could be prioritized to detect a greater variety of species or those with particular ecological characteristics that could enhance their invasion success in Canada. Major distribution hubs responsible for moving relatively large numbers of organisms in trade across the country, especially across provincial borders (e.g., Richmond, BC to Edmonton, AB for the water garden pathway), are logical postborder critical control points for a variety of surveillance goals. If the management objective was to prevent the release of organisms in trade without influencing import or sale, major cities highlighted here are logical critical control points, especially statistically significant hotspots of release, so that education, outreach, and/or enforcement can target risky end users.

While this study determined the pathway-level, spatially explicit estimates of propagule pressure for the aquarium, water garden, and live seafood trades and provides perspective about the movement of organisms in trade into and within Canada, a number of uncertainties remain. The species import records from CBSA's Pathfinder project contained the most detailed information on species imported into Canada, but there are several caveats that warrant attention. As mentioned in the Methods, a significant proportion of the import transactions were paper-based and import details were not recorded by Pathfinder and thus unavailable for analyses. The proportion of the transactions with missing import details was likely greater for invertebrates and plants than for fishes (H. Gerson, CBSA, pers. comm.) suggesting a possible taxonomic bias as well. In addition, only four months of import records from Pathfinder in 2018 were available for analysis due to limited resources available to support data acquisition and management. Although the dataset has a relatively short temporal coverage, it spanned the summer months, likely representing the peak of the aquarium and water garden trades in Canada. The seasonality of live seafood organisms is less clear. A comparison of the import records for aquarium fishes from Pathfinder with those from CFIA, after scaling to a 12-month period, further confirmed that the available Pathfinder data captured $\sim 97 \%$ of the annual aquarium fish imports. Another issue with the Pathfinder dataset was inconsistencies between the HS code description and the description of goods (597 records), likely due to the fact that the information was provided by the importers or custom brokers with little quality control and no validation in Canada. While these records were identified and corrected, it is possible that other data entry and processing errors existed. Furthermore, although the HS code system provides a convenient way for capturing wildlife trade data and has been commonly used to characterize organisms in trade, there are a few issues associated with the system (Gerson et al. 2008a, Chan et al. 2015b). First, the system categorizes species commodities into broad taxonomic groups, which is often insufficient for identifying species and tracking their movements into and within the country (Gerson et al. 2008b, Allen et al. 2017, Rhyne et al. 2017). For example, under this system, all live freshwater ornamental fishes are grouped under the HS code 03.01.11, making it difficult to detect specific species and quantify their associated propagule pressure unless species information is provided in the description of goods, which is not always
the case. Even when species information was provided in the description of goods, common rather than scientific names were often provided and organisms could be misidentified or mislabelled (Mandrak et al. 2014). Secondly, the HS codes are not very helpful in defining the intended use of imported species. Only ornamental fishes have designated codes, but it was still challenging to differentiate species intended for the aquarium trade from those for the water garden trade. Thirdly, it was also difficult to separate live specimens from fresh and chilled ones, especially species associated with the live seafood trade. Collectively, these issues have introduced uncertainty in the characterization of the movement of live organisms in trade into and within Canada, especially for the water garden and seafood trades. Maintaining long-term, detailed electronic import records of organisms in trade would help reduce uncertainty and refine invasion risk of organisms in trade. These details could include (but are not limited to): 1) species-level details, such as the adoption of the Taxonomic Serial Number (TSN) due to deficiencies noted in the HS code system (Gerson et al. 2008a,b), 2) clear indication of organisms status when imported (i.e. live versus fresh, chilled, or frozen), 3) standardized units of measurement (number of individuals rather than weight), and 4) source to destination traceability through the supply chain to the retailer. For example, CBSA's Pathfinder project provides a potential framework and includes some of the proposed elements (e.g., origin and destination of goods). Confirmed taxonomy and status as well as standardized unit of measurement would be helpful for identifying specific species (e.g., AIS listed in federal, provincial, or territorial legislations and regulations) and quantifying the propagule pressure of these species at smaller spatial scales across Canada (i.e. higher resolution). Additional information on the destination of goods from the port of entry to distributors and retailers would allow the tracking of imported organisms post-border, similar to some agricultural products.
The use of human population density to develop spatially-based estimates of propagule pressure for the aquarium, water garden, and live seafood trades is consistent with other studies (Buckley et al. 2021, Copp et al. 2007, 2010, Chucholl 2014). However, data errors and the analytical approach could have introduced uncertainty in the estimates. The human population and dwelling count data obtained from Statistics Canada's Census of Population Program likely contain errors (e.g., non-response and processing errors), though the quality of the data were assured and controlled via quality assessment activities throughout the census process (Statistics Canada 2019c). Nonetheless, the census data is the most comprehensive demographic data available for Canada. The discrepancies between Statistics Canada and Canada Post geographic boundaries may have affected the accuracy of geocoded data and estimates of population density for some FSAs, though the overall results should remain unchanged. Also, it was assumed that individuals and households were evenly distributed within an FSA when standardizing the spatial unit at the $50 \mathrm{~km} \times 50 \mathrm{~km}$ grid size. This may not always be the case but the basis to estimate densities otherwise was not available. Only unsummarized population and dwelling data would characterize the actual densities across the Canadian landscape. In general, the spatial estimates carry greater uncertainty for rural areas than for urban ones. This occurs because there is lower precision when calculating densities for grids in large, rural (i.e. northern) FSAs with low population or household counts than when calculating densities for grids in small, urban FSAs with high population or household counts.

Despite the knowledge that risky behaviour is occurring in the aquarium, water garden, and live seafood pathways, there is a poor understanding of why end users engage in release activity. Aggressive organism behaviour, large physical size, rapid reproduction, and frequent illness have been reported as common reasons for releasing unwanted aquarium and water garden organisms (Courtenay 1999, Gertzen et al. 2008), but little is known about the reasons for releasing live seafood organisms. It is possible that releasing live seafood organisms into the environment is perceived as a 'humane' disposal of unwanted or unconsumed live seafood, a phenomenon observed for aquarium and water garden organisms (Courtenay 1999, Copp et al.

2005, Gertzen et al. 2008). It may be that some aquarium, water garden, and live seafood organisms were acquired by the public for reasons beyond the intended uses and were subsequently released intentionally into the environment. Some cultural and religious groups release live ornamental and food species as an act of compassion or as a form of prayers to gods (i.e. mercy, prayer, or religious release) in Canada (Crossman and Cudmore 1999a). This practice involves a range of taxa (e.g., fishes, birds, amphibians, and reptiles) sourced from pet shops, aquaculture facilities, grocery stores, and wild populations (Crossman and Cudmore 1999a, Severinghaus and Chi 1999, Wasserman et al. 2018). The number of organisms released per release event varies widely depending on the occasion (e.g., personal vs formal ceremonial events) (Severinghaus and Chi 1999, Wasserman et al. 2018, Magellan 2019). These releases effectively belong to a separate pathway of non-consumers and thus are unnaccounted for. Vandalistic tendancies, such as purposefully taking part in illegal actions (e.g., illegal stocking), may also play a role (Drake et al. 2015b). These releases are a source of uncertainty. Even infrequent releases can lead to a large absolute number of propagules released, due to the sheer number of agents involved (Drake et al. 2014,2015b). Therefore, it is crucial to gain a better understanding of the motivations for release, so that risk reduction strategies can be developed. Engaging social scientists to characterize the social dimensions of the aquarium, water garden, and live seafood trades, similar to work that has been done for recreational boating and fishing (Drake et al. 2015b, Hunt et al. 2017, 2019), would help address knowledge gaps. Areas to investigate include the rationale for releasing species (especially for live seafood species), typical propagule size, number of release events per releaser, distance travelled for release, frequency or seasonality of release, and awareness of AIS issues at various spatial and temporal scales. While literature values were available to describe participation and release rates for end users, more relevant (e.g., data from Canada rather than the US; spatially-stratified by province or postal code) and recent data would reduce uncertainty associated with the propagule pressure estimates (see below).
The models developed to generate the spatially explicit estimates of propagule pressure for each pathway were parameterized using values derived mainly from peer-reviewed scientific articles (Chapman et al. 1997, Gertzen et al. 2008, Gordon et al. 2012) and government reports (Marson et al. 2009a,b). Although based on the best available information, there is uncertainty about these parameters because certain values are not specific to Canada (e.g., aquarium and water garden ownership rates derived from studies in the US) and may not be up to date (e.g., survey results from past decades). Very limited information was available for the live seafood trade. For example, parameter values were derived using the compiled information of retailers selling live seafood in Canada as a proxy. It was also assumed that model parameters, including the proportion of the Canadian population that were end users (i.e. $p(A q), p(W G)$, and $p(L F)$ ), urban versus rural (U:R) distribution of end users, the proportion of end users that were releasers (i.e. $p(R e l A q), p(R e l \mid W G)$, and $p($ Rel|LF) ), were constant across Canada as regionspecific information was not available. Inter-provincial variation in these values could significantly influence the number and spatial distribution of end users, release events, and propagule pressure. The zero-truncated Poisson distribution was selected for best describing the probability distribution of propagule size and the values for $\lambda$ based on the results of Gertzen et al. (2008). While the results were derived from a study for freshwater aquarium fishes in Montréal, QC, it was assumed that they were applicable to other taxa and that the parameters do not vary significantly by region in the absence of region-specific information. The same model was extended to the water garden pathway because pathway-specific information was not available and the aquarium and water garden pathways share many traits. The model also was adopted for the live seafood pathway, assuming that the average propagule size of live seafood is also small while recognizing that this may differ between taxonomic groups (i.e. a single fish or lobster may be released, while a handful of clams or mussels may be released). In
addition, it was assumed that end users purchase organisms in trade for their intended use and release organisms only when the organisms are not wanted (for aquarium and water garden organisms) or consumed (for live seafood organisms). The purchase and release of organisms in trade beyond their intended use (e.g., illegal stocking and mercy release) was unaccounted for here. Accidental release or escape of organisms in trade was also not considered due to the lack of records. This may be more common for water garden organisms, especially during flood events, which could elevate the introduction risk of the water garden pathway relative to that of the aquarium and live seafood pathways. There are likely demographic, geographic, and other factors that could affect model estimates but could not be accounted for because of the lack of data. For example, household type (e.g., condo vs detached home and income) may affect water garden ownership. Online sales could obsecure the spatial distribution of end users. Additional studies would help to better understand how model parameters might differ across the Canadian landscape and if there are additional parameters that could affect the propagule pressure estimates for each pathway.

Despite the uncertainty around the parameters, results of the sensitivity analyses revealed that changes in parameter values led to proportional directional changes in outputs. For the magnitude of mean propagule pressure of the aquarium, water garden, and live seafood trades, a $50 \%$ increase (or decrease) in a given parameter value typically led to a corresponding $50 \%$ increase (or decrease) in the output (i.e. a 1:1 change). All parameters considered including the proportion of the Canadian population that were end users (i.e. $p(A q), p(W G)$, and $p(L F)$ ), the proportion of end users that were releasers (i.e. $p(\operatorname{Rel} A q), p(\operatorname{Rel} \mid W G)$, and $p(\operatorname{Rel|LF})$ ), and the average number of organisms released per event (i.e. propagule size, $\lambda$ ) had the same effect on the model output. Therefore, increasing (or decreasing) ownership rate by $50 \%$ yielded the same results as increasing (or decreasing) release rate by $50 \%$ for all pathways, despite the fact that the introduction of organisms in trade is a sequential process. Essentially, each parameter acted as a scaler, sub-setting the Canadian population into those who participate in the activity, then those who release organisms, and finally the number of organisms released. For the spatial distribution of end users and releasers, a $10 \%$ shift in the $U: R$ value also produced a predictable outcome, but much less proportional than the parameters above. In general, urban-biased $p(A q), p(W G)$, or $p(L F)$ constricted the geographic extent of end users and releasers to the southern parts of Canada where the majority of the Canadian population reside, with individuals aggregated around major cities likely due to greater access to retail outlets. In contrast, rural-biased $p(A q), p(W G)$, or $p(L F)$ expanded the geographic extent of ends users and releasers to northern parts of Canada, with individuals more evenly distributed across the Canadian landscape. Altering $p(A q), p(W G), p(L F), p(R e l A q), p(R e l \mid W G)$, and $p(R e \| L F)$ yielded similar predictable results, where increased parameter values generally increased the geographic extent of end users and releasers, and vice versa. Regardless of the sensitivity scenario, there were always high numbers of end users and releasers projected in and around major cities (i.e. hotspots). The direction of these changes was not affected by spatial scale (i.e. grid- vs watershed-level), though the magnitude of change in terms of the number of grids or watersheds altered in relation to the baseline varied. Changes in the spatial distribution of releasers at the watershed level were smaller likely due to some integration within watersheds of multiple urban centers. The hot spot analysis revealed that the statistically significant areas where releasers aggregated were in and around major cities and remained unchanged regardless of the proportion of end users that were releasers for all pathways. Collectively, this suggests that the greatest potential risk of introduction is associated with urban watersheds. The general predictability of model outcomes in response to changes in parameter values suggest that propagule pressure estimates could be easily updated and interpreted when new information regarding the parameters is available.

The incorporation of additional stages of the invasion process including species survival, establishment, and spread (see Figure 1), and the magnitude of ecological impacts, is needed to understand the overall invasion risk of each pathway. Follow-up studies (e.g., screening-level and detailed-level risk assessments) that consider species-specific propagule pressure, the probability of survival if introduced into the environment, the subsequent probability of establishment, and the magnitude of ecological impacts would be needed to estimate invasion risk for each of the pathways given differences noted in species composition among them (Appendix B). For instance, while propagule pressure of the aquarium pathway appeared to be higher than that of the water garden pathway, a larger proportion of the water garden organisms, which are mostly temperate species, may be more likely to survive and establish in Canadian aquatic ecosystems compared to aquarium species, which typically originate from the tropics. Furthermore, the aquarium and live seafood pathways included both freshwater and marine species such that the specific invasion risk for each pathway will vary across Canada. The risk posed by live organisms in trade is also likely to differ by taxonomic group. Although beyond the scope of this assessment, the fishes, invertebrates, and plants associated with each of these three pathways are likely to pose different levels of invasion risk in different parts of Canada.

## TABLES

Table 1. Results of the literature review, which described the participation and release rates for aquarium owners. Parameters and values used for estimating propagule pressure (PP) of the aquarium pathway are also included. For each parameter except for $p(U \mid A q)$ and $p(R \mid A q)$, an asterisk denotes the baseline value and a dagger indicates the sensitivity analysis values. Note that no corrections were made to $p(A q)$ based on whether an area was considered urban or rural in the baseline scenario. See main text for justifications of values used.

| Parameter | Literature value | Reference | Values for estimating PP |
| :---: | :---: | :---: | :---: |
| Proportion of Canadian households owning aquaria, $p(A q)$ | 10.6\% | Chapman et al. 1997 | $\begin{gathered} 10.6 \% * \\ 15.9 \% \dagger \end{gathered}$ |
|  |  |  | 5.3\%† |
| Proportion of aquarium owners in urban $p(U \mid A q)$ vs. rural areas $p(R \mid A q)$ | 85.9\% and $14.1 \%$ for urban and rural aquarium owners, respectively | Calculated values based on survey data collected by Marson et al. 2009a | $\begin{array}{r} 86: 14 \dagger \\ 94: 6 \dagger \\ 77: 23 \dagger \end{array}$ |
| Proportion of aquarium owners releasing aquatic organisms (i.e. releasers), $\mathrm{p}(\mathrm{Rel\mid Aq})$ | 6.9\% for freshwater aquarium fishes, 1.1\% for aquarium animals, and $0.8 \%$ for aquarium plants | Gertzen et al. 2008, Marson et al. 2009a | $\begin{aligned} & 3.9 \% * \\ & 5.9 \% \dagger \\ & 2.0 \% \dagger \end{aligned}$ |
| Mean number of aquatic organisms released by aquarium owners per year (i.e. $\lambda$, average propagule size) | - | Assumed values based on results of Gertzen et al. 2008 | $6 *$ $9+$ $3 \dagger$ |

Table 2. Comparison of the proportion of urban and rural areas based on the Forward Sortation Areas (FSAs) classification (Government of Canada 2015) with that based on the 2016 census (Statistics Canada 2019a).

|  | FSA Urban <br> $(\%)$ | FSA Rural <br> $(\%)$ | Census <br> Urban (\%) | Census <br> Rural (\%) |
| :--- | :---: | :---: | :---: | :---: |
| Alberta | 85 | 15 | 84 | 16 |
| British Columbia | 89 | 11 | 86 | 14 |
| Manitoba | 72 | 28 | 74 | 26 |
| New Brunswick | 100 | 0 | 49 | 51 |
| Newfoundland \& Labrador | 55 | 45 | 58 | 42 |
| Nova Scotia | 69 | 31 | 57 | 43 |
| Nunavut/Northwest Territories | 26 | 74 | - | - |
| Ontario | 86 | 14 | 86 | 14 |
| Prince Edward Island | 49 | 51 | 45 | 55 |


|  | FSA Urban <br> $(\%)$ | FSA Rural <br> $(\%)$ | Census <br> Urban (\%) | Census <br> Rural (\%) |
| :--- | :---: | :---: | :---: | :---: |
| Quebec | 82 | 18 | 80 | 20 |
| Saskatchewan | 60 | 40 | 67 | 33 |
| Yukon | 77 | 23 | - | - |

Table 3. Results of the literature review, which described the participation and release rates of water garden owners. Parameters and values used for estimating propagule pressure (PP) of the water garden pathway are also included. For each parameter, an asterisk denotes the baseline value and a dagger indicates the sensitivity analysis values. See main text for justifications of values used.

| Parameter | Literature value | Reference | Values for estimating PP |
| :---: | :---: | :---: | :---: |
| Proportion of Canadian households owning water gardens, $\mathrm{p}(\mathrm{WG})$ | $3.9 \%$ and $14.4 \%$ for 1998 and 2004 values, respectively | Gordon et al. 2012 citing Crosson 2003 | $\begin{gathered} 9.2 \%^{*} \\ 13.7 \% \dagger \\ 4.6 \% \dagger \end{gathered}$ |
| Proportion of water garden owners in urban $\mathrm{p}(\mathrm{U} \mid \mathrm{WG})$ vs. rural $p(R \mid W G)$ areas | 74.4\% and 25.6\% for urban and rural water garden owners, respectively | Calculated values based on survey data collected by Marson et al. 2009b | $\begin{aligned} & 74: 26^{*} \\ & 82: 18 \dagger \\ & 67: 33 \dagger \end{aligned}$ |
| Proportion of water garden owners releasing aquatic organisms (i.e. releasers), $\mathrm{p}(\mathrm{Rel\mid WG})$ | 2.8\% for water garden animals, and $1.3 \%$ for water garden plants | Marson et al. 2009b | $\begin{aligned} & 3.9 \%^{*} \\ & 5.9 \% \dagger \\ & 2.0 \% \dagger \end{aligned}$ |
| Mean number of aquatic organisms released by water garden owners per year (i.e. $\lambda$, average propagule size) | - | Assumed values based on results of Gertzen et al. 2008 | $6 *$ $9 \dagger$ $3 \dagger$ |

Table 4. Results of the literature review, which described the participation and release rates for live seafood consumers. Parameters and values used for estimating propagule pressure (PP) of the live seafood pathway are also included. For each parameter, an asterisk denotes the baseline value and a dagger indicates the sensitivity analysis values. See main text for justifications of values used. Values for $p(L F)$ and $p(R e l \mid L F)$ are rounded to one decimal place for presentation.

| Parameter | Literature value | References | Values for estimating PP |
| :---: | :---: | :---: | :---: |
| Proportion of the population purchasing live seafood, $p(L F)$ | $0.88 \times 0.04$ ( $88.0 \%$ of the Canadian population were seafood consumers; $4.0 \%$ of the seafood consumers purchased live seafood) | Coletto et al. 2011, compiled retailer data (this study) | $\begin{aligned} & 3.5 \%^{*} \\ & 5.3 \% \dagger \\ & 1.8 \% \dagger \end{aligned}$ |
| Proportion of the population purchasing live seafood in urban $p(U \mid L F)$ vs. rural $p(R \mid L F)$ areas | $85.6 \%$ and $14.4 \%$ for live seafood retailers in urban and rural areas, respectively | Compiled retailer data (this study) | $\begin{array}{r} 86: 14^{*} \\ 94: 6 \dagger \\ 77: 23 \dagger \end{array}$ |
| Proportion of live seafood consumers releasing live seafood organisms (i.e. releasers), p (Rel\|LF) | - | Assumed values based on results of Gertzen et al. 2008 and Marson et al. 2009a,b | $\begin{aligned} & 3.9 \% * \\ & 5.9 \% \dagger \\ & 2.0 \% \dagger \end{aligned}$ |
| Mean number of live seafood organisms released by live seafood consumers per year (i.e. $\lambda$, average propagule size) | - | Assumed values based on results of Gertzen et al. 2008 | 6* 9 + + |

Table 5. Number of aquarium organisms imported into Canada between June 15 th, 2018 and October $15^{\text {th }}$ 2018 by source country. Source countries are arranged in descending order according to the number of imported organisms.

| Source country | \# of organisms |
| :--- | ---: |
| United States | $4,027,975$ |
| Indonesia | 93,963 |
| Sri Lanka | 73,021 |
| Singapore | 38,875 |
| Thailand | 21,327 |
| Australia | 10,001 |
| Germany | 8,114 |
| Philippines | 7,907 |
| Colombia | 4,614 |


| Source country | \# of organisms |
| :--- | ---: |
| Peru | 3,316 |
| Malaysia | 1,219 |
| Netherlands | 944 |
| Vietnam | 671 |
| Nicaragua | 628 |
| China | 565 |
| Tonga | 475 |
| Kenya | 402 |
| United Kingdom of Great Britain and Northern Ireland | 400 |
| Mexico | 350 |
| Taiwan (Province of China) | 332 |
| Fiji | 264 |
| Brazil | 232 |
| Dominican Republic | 151 |
| Myanmar | 134 |
| Ecuador | 99 |
| India | 92 |
| Maldives | 25 |
| Hong Kong (Special Administrative Region of China) | 15 |
| Puerto Rico | 12 |
| Belize | 11 |
| Portugal | 11 |
| Czech Republic | 9 |
| Marshall Islands | 8 |
| French Polynesia | 8 |
| France | 8 |
| Israel | 7 |
| Tunisia | $3,296,188$ |
| Japan | 1 |
| South Africa | 3 |
| Djibouti | 3 |
| Grand Total | 2 |

Table 6. Number of aquarium organisms imported into Canada between June $15^{\text {th }}, 2018$ and October $15^{\text {th }}$ 2018 by port of entry and source country. The ports of entry are listed in alphabetical order, whereas source countries are arranged in descending order according to the number of imported organisms.

| Port of entry | Source country | \# of organisms |
| :--- | :--- | ---: |
| Calgary, AB | United States | 889,936 |
|  | Indonesia | 79,639 |
|  | Sri Lanka | 59,735 |
|  | Singapore | 32,668 |
|  | Thailand | 11,340 |


| Port of entry | Source country | \# of organisms |
| :---: | :---: | :---: |
|  | Australia | 10,001 |
|  | Colombia | 1,739 |
|  | Netherlands | 944 |
|  | Nicaragua | 628 |
|  | Philippines | 484 |
|  | Mexico | 150 |
|  | Dominican Republic | 146 |
|  | Tonga | 108 |
|  | Fiji | 105 |
|  | Kenya | 69 |
|  | India | 42 |
|  | Maldives | 25 |
|  | Puerto Rico | 12 |
|  | Portugal | 11 |
|  | Belize | 10 |
|  | Marshall Islands | 8 |
|  | French Polynesia | 8 |
|  | France | 7 |
|  | Vietnam | 5 |
|  | Brazil | 2 |
|  | Djibouti | 1 |
| Total |  | 1,087,823 |
| Dorval, QC | Sri Lanka | 13,072 |
|  | United States | 4,345 |
|  | Peru | 3,125 |
|  | Indonesia | 1,563 |
|  | Philippines | 624 |
|  | Tonga | 361 |
|  | Mexico | 200 |
|  | Fiji | 154 |
|  | Dominican Republic | 5 |
|  | Tunisia | 3 |
|  | Belize | 1 |
| Total |  | 23,453 |
| Edmonton, AB | United States | 42,937 |
|  | Singapore | 4,129 |
|  | Thailand | 3,631 |
|  | Brazil | 230 |
|  | Sri Lanka | 200 |
|  | Indonesia | 165 |
|  | Peru | 100 |


| Port of entry | Source country | \# of organisms |
| :---: | :---: | :---: |
|  | China | 65 |
|  | India | 50 |
|  | Taiwan (Province of China) | 50 |
|  | Hong Kong (Special Administrative Region of China) | 9 |
|  | Czech Republic | 3 |
|  | Israel | 3 |
| Total |  | 51,572 |
| Halifax, NS | Germany | 8,114 |
|  | United Kingdom of Great Britain and Northern Ireland | 400 |
| Total |  | 8,514 |
| Hamilton, ON | United States | 474 |
|  | Indonesia | 361 |
|  | Philippines | 58 |
|  | Tonga | 6 |
|  | Fiji | 5 |
|  | Sri Lanka | 2 |
| Total |  | 906 |
| Mirabel, QC | United States | 1,293,751 |
|  | Colombia | 2,705 |
|  | Peru | 88 |
|  | Ecuador | 60 |
| Total |  | 1,296,604 |
| Niagara Falls, ON | United States | 8 |
| Total |  | 8 |
| Richmond, BC | Indonesia | 10,861 |
|  | Thailand | 6,201 |
|  | Philippines | 4,253 |
|  | Singapore | 2,029 |
|  | United States | 1,959 |
|  | Malaysia | 1,219 |
|  | China | 500 |
|  | Vietnam | 291 |
|  | Taiwan (Province of China) | 273 |
|  | Myanmar | 134 |
|  | Colombia | 120 |
|  | South Africa | 2 |
| Total |  | 27,842 |
| Toronto, ON | United States | 3,600 |
|  | Philippines | 2,488 |
|  | Indonesia | 1,374 |
|  | Vietnam | 375 |


| Port of entry | Source country | \# of organisms |
| :--- | :--- | ---: |
|  | Kenya | 333 |
|  | Thailand | 124 |
|  | Colombia | 50 |
|  | Singapore | 49 |
|  | Sri Lanka | 12 |
|  | Taiwan (Province of China) | 9 |
|  | Czech Republic | 6 |
|  | Hong Kong (Special Administrative Region of China) | 6 |
|  | Peru | 3 |
|  | Japan | 2 |
|  |  | 8,431 |
| Total | United States | $1,770,800$ |
| Windsor, ON | 39 |  |
|  | Ecuador | 31 |
| Total | Thailand | $1,770,870$ |
| Winnipeg, MB | United States | 20,165 |
| Total |  | 20,165 |

Table 7. Number of aquarium organisms imported into Canada between June 15th, 2018 and October 15 th 2018 by port of entry and distribution hub. The ports of entry are listed in alphabetical order, whereas the distribution hubs are arranged in descending order according to the number of imported organisms.

| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :--- | :--- | :--- | ---: |
| Calgary, AB | Calgary | AB | $1,087,599$ |
|  | Lethbridge | AB | 216 |
|  | High River | AB | 8 |
| Total |  |  | $1,087,823$ |
| Dorval, QC | Saint-Laurent | QC | 13,017 |
|  | Québec City | QC | 6,789 |
|  | Laval | QC | 3,647 |
| Total |  |  | 23,453 |
| Edmonton, AB | Edmonton | AB | 51,571 |
|  | Spruce Grove | AB | 1 |
| Total |  |  | 51,572 |
| Halifax, NS | Moncton | NB | 6,459 |
|  | Lutes Mountain | NB | 1,655 |
|  | Halifax | HS | 400 |
| Total |  | ON | 8,514 |
| Hamilton, ON | Windsor |  | 906 |
| Total |  | QC | 906 |
| Mirabel | LaSalle | $1,286,668$ |  |
|  | Montréal | 9,936 |  |


| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :---: | :---: | :---: | :---: |
| Total |  |  | 1,296,604 |
| Niagara Falls, ON | Vaughan | ON | 8 |
| Total |  |  | 8 |
| Richmond, BC | Winnipeg | MB | 10,380 |
|  | Edmonton | AB | 9,924 |
|  | Kamloops | BC | 5,388 |
|  | Burnaby | BC | 1,613 |
|  | Abbotsford | BC | 288 |
|  | Calgary | AB | 167 |
|  | Surrey | BC | 70 |
|  | Vancouver | BC | 6 |
|  | West Vancouver | BC | 6 |
| Total |  |  | 27,842 |
| Toronto, ON | Cambridge | ON | 2,488 |
|  | Mississauga | ON | 1,835 |
|  | Whitby | ON | 1,407 |
|  | Scarborough | ON | 590 |
|  | Milton | ON | 577 |
|  | Laval | QC | 375 |
|  | Goulais River | ON | 333 |
|  | Kitchener | ON | 202 |
|  | Vaughan | ON | 202 |
|  | Sudbury | ON | 179 |
|  | Thornhill | ON | 104 |
|  | Hamilton | ON | 97 |
|  | Brampton | ON | 12 |
|  | King City | ON | 10 |
|  | Belleville | ON | 8 |
|  | Brantford | ON | 4 |
|  | Toronto | ON | 3 |
|  | Wasaga Beach | ON | 3 |
|  | North York | ON | 2 |
| Total |  |  | 8,431 |
| Windsor, ON | Innisfil | ON | 1,770,800 |
|  | Mississauga | ON | 70 |
| Total |  |  | 1,770,870 |
| Winnipeg, MB | Winnipeg | MB | 20,165 |
| Total |  |  | 20,165 |

Table 8. Number of water garden organisms imported into Canada between June 15 th, 2018 and October $15^{\text {th }} 2018$ by source country. Source countries are arranged in descending order according to the number of imported organisms.

| Source country | \# of organisms |
| :--- | ---: |
| United States | $3,724,636$ |
| Thailand | 8,613 |
| Germany | 6,319 |
| Indonesia | 4,896 |
| Singapore | 4,741 |
| Peru | 2,754 |
| Sri Lanka | 2,450 |
| Colombia | 1,784 |
| Vietnam | 638 |
| Netherlands | 471 |
| United Kingdom of Great Britain and Northern Ireland | 400 |
| Brazil | 230 |
| Taiwan (Province of China) | 140 |
| China | 65 |
| India | 50 |
| Hong Kong (Special Administrative Region of China) | 15 |
| Portugal | 11 |
| Czech Republic | 9 |
| Japan | 2 |
| Grand total | $3,758,224$ |

Table 9. Number of water garden organisms imported into Canada between June 15 th, 2018 and October $15^{\text {th }} 2018$ by port of entry and source country. The ports of entry are listed in alphabetical order, whereas source countries are arranged in descending order according to the number of imported organisms.

| Port of entry | Source country | \# of organisms |
| :--- | :--- | ---: |
| Calgary, AB | United States | 610,770 |
|  | Colombia | 1,614 |
|  | Netherlands | 471 |
|  | Indonesia | 250 |
|  | Singapore | 100 |
|  | Thailand | 60 |
|  | Portugal | 11 |
| Total |  | 613,276 |
| Dorval, QC | Peru | 2,654 |
|  | Sri Lanka | 2,250 |
| Total |  | 4,904 |
| Edmonton, AB | United States | 39,481 |
|  | Singapore | 4,029 |
|  | Thailand | 3,314 |


| Port of entry | Source country | \# of organisms |
| :---: | :---: | :---: |
|  | Brazil | 230 |
|  | Sri Lanka | 200 |
|  | Indonesia | 165 |
|  | Peru | 100 |
|  | China | 65 |
|  | India | 50 |
|  | Hong Kong | 9 |
|  | Czech Republic | 3 |
| Total |  | 47,646 |
| Halifax, NS | Germany | 6,319 |
|  | United Kingdom of Great Britain and Northern Ireland | 400 |
| Total |  | 6,719 |
| Mirabel, QC | United States | 1,283,647 |
| Total |  | 1,283,647 |
| Richmond, BC | Thailand | 5,151 |
|  | Indonesia | 3,680 |
|  | Singapore | 569 |
|  | Vietnam | 263 |
|  | Taiwan (Province of China) | 140 |
|  | Colombia | 120 |
|  | United States | 8 |
| Total |  | 9,931 |
| Toronto, ON | Indonesia | 801 |
|  | Vietnam | 375 |
|  | United States | 270 |
|  | Thailand | 88 |
|  | Colombia | 50 |
|  | Singapore | 43 |
|  | Czech Republic | 6 |
|  | Hong Kong (Special Administrative Region of China) | 6 |
|  | Japan | 2 |
| Total |  | 1,641 |
| Windsor, ON | United States | 1,770,800 |
| Total |  | 1,770,800 |
| Winnipeg, MB | United States | 19,660 |
| Total |  | 19,660 |

Table 10. Number of water garden organisms imported into Canada between June 15 th, 2018 and October $15^{\text {th }} 2018$ by port of entry and distribution hub. The ports of entry are listed in alphabetical order, whereas the distribution hubs are arranged in descending order according to the number of imported organisms.

| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :---: | :---: | :---: | :---: |
| Calgary, AB | Calgary | AB | 613,106 |
|  | Lethbridge | AB | 162 |
|  | High River | $A B$ | 8 |
| Total |  |  | 613,276 |
| Dorval, QC | Québec City | QC | 2,654 |
|  | Saint-Laurent | QC | 2,250 |
| Total |  |  | 4,904 |
| Edmonton, AB | Edmonton | AB | 47,645 |
|  | Spruce Grove | AB | 1 |
| Total |  |  | 47,646 |
| Halifax, NS | Moncton | NB | 5,014 |
|  | Lutes Mountain | NB | 1,305 |
|  | Halifax | NS | 400 |
| Total |  |  | 6,719 |
| Mirabel, QC | LaSalle | QC | 1,281,357 |
|  | Montréal | QC | 2,290 |
| Total |  |  | 1,283,647 |
| Richmond, BC | Edmonton | AB | 4,854 |
|  | Winnipeg | MB | 3,514 |
|  | Kamloops | BC | 1,388 |
|  | Calgary | AB | 167 |
|  | Vancouver | BC | 5 |
|  | West Vancouver | BC | 3 |
| Total |  |  | 9,931 |
| Toronto, ON | Whitby | ON | 770 |
|  | Milton | ON | 468 |
|  | Laval | QC | 375 |
|  | King City | ON | 10 |
|  | Belleville | ON | 8 |
|  | Mississauga | ON | 3 |
|  | Wasaga Beach | ON | 3 |
|  | Toronto | ON | 2 |
|  | North York | ON | 2 |
| Total |  |  | 1,641 |
| Windsor, ON | Innisfil | ON | 1,770,800 |
| Total |  |  | 1,770,800 |
| Winnipeg. MB | Winnipeg | MB | 19,660 |


| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :--- | :--- | ---: | ---: |
| Total |  | 19,660 |  |

Table 11. Number of live seafood organisms imported into Canada between June 15th, 2018 and October 15 th 2018 by source country. Source countries are arranged in descending order according to the number of imported organisms.

| Source country | \# of organisms |
| :--- | ---: |
| United States | $81,955,780$ |
| Ireland | 258,772 |
| New Zealand | 133,545 |
| Saint Pierre and Miquelon (Territorial Collectivity of France) | 36,000 |
| France | 26,857 |
| Vietnam | 11,321 |
| South Korea | 5,449 |
| Iceland | 3,022 |
| Dominican Republic | 1,145 |
| Haiti | 1,138 |
| Taiwan (Province of China) | 600 |
| Cuba | 341 |
| Norway | 252 |
| Australia | 234 |
| Russian Federation | 160 |
| United Kingdom of Great Britain and Northern Ireland | 150 |
| Netherlands | 150 |
| Philippines | 6 |
| Indonesia | 2 |
| China | 1 |
| Grand total | $82,434,924$ |

Table 12. Number of live seafood organisms imported into Canada between June $15^{\text {th }}, 2018$ and October $15^{\text {th }} 2018$ by port of entry and source country. Source countries are arranged in descending order according to the number of imported organisms.

| Port of entry | Source country | \# of organisms |
| :--- | :--- | ---: |
| Belleville, ON | United States | $4,601,013$ |
| Total |  | $4,601,013$ |
| Calgary, AB | United States | 3,200 |
| Total |  | 3,200 |
| Charlottetown, PE | United States | 6 |
| Total |  | 6 |
| Dorval, QC | Ireland | 32 |
|  | Philippines | 3 |
|  | Indonesia | 2 |


| Port of entry | Source country | \# of organisms |
| :---: | :---: | :---: |
| Total |  | 37 |
| Fortune, NL | Saint Pierre and Miquelon (Territorial Collectivity of France) | 36,000 |
| Total |  | 36,000 |
| Halifax, NS | France | 26,316 |
|  | Ireland | 26,316 |
|  | Netherlands | 150 |
| Total |  | 52,782 |
| Hamilton, ON | United States | 80 |
|  | Philippines | 3 |
| Total |  | 83 |
| Mirabel, QC | United States | 48 |
| Total |  | 48 |
| Niagara Falls, ON | United States | 2,158,623 |
|  | New Zealand | 6,331 |
| Total |  | 2,164,954 |
| Ottawa, ON | United States | 50,000,000 |
| Total |  | 50,000,000 |
| Point Edward, ON | United States | 59,991 |
| Total |  | 59,991 |
| Richmond, BC | United States | 12,274,228 |
|  | New Zealand | 127,214 |
|  | Vietnam | 8,579 |
|  | Ireland | 1,429 |
|  | Taiwan (Province of China) | 600 |
|  | United Kingdom of Great Britain and Northern Ireland | 150 |
|  | South Korea | 65 |
| Total |  | 12,412,265 |
| Saint John, NB | United States | 7,480 |
| Total |  | 7,480 |
| St-Armand, QC | United States | 9,292 |
| Total |  | 9,292 |
| St-Bernard-de-Lacolle, QC | United States | 548,331 |
| Total |  | 548,331 |
| St-Stephen, NB | United States | 11,519,369 |
| Total |  | 11,519,369 |
| Surrey, BC | United States | 673,012 |
| Total |  | 673,012 |


| Port of entry | Source country | \# of organisms |
| :--- | :--- | ---: |
| Toronto, ON | Ireland | 230,995 |
|  | United States | 11,966 |
|  | Iceland | 3,022 |
|  | Vietnam | 2,742 |
|  | South Korea | 2,511 |
|  | Dominican Republic | 1,145 |
|  | Haiti | 1,138 |
|  | France | 541 |
|  | Cuba | 341 |
|  | Norway | 252 |
|  | Australia | 234 |
|  | Russian Federation | 160 |
|  | China | 1 |
|  |  | 255,048 |
|  | South Korea | 2,873 |
|  |  | 2,873 |
| Total | United States | 89,141 |
| Vancouver, BC |  | 89,141 |
| Total |  |  |
| Windsor, ON |  |  |
| Total |  |  |

Table 13. Number of live seafood organisms imported into Canada between June 15 ${ }^{\text {th }}, 2018$ and October $15^{\text {th }} 2018$ by port of entry and distribution hub. The ports of entry are listed in alphabetical order, whereas the distribution hubs are arranged in descending order according to the number of imported organisms.

| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :--- | :--- | :--- | ---: |
| Belleville, ON | Neguac | NB | $1,496,878$ |
|  | Tracadie | NB | $1,005,387$ |
|  | Cap-Pelé | NB | 674,177 |
|  | Caraquet | NB | 538,634 |
|  | Georgetown | PE | 187,629 |
|  | Richibucto | NB | 187,559 |
|  | Sainte-Thérèse-de-la- |  | 109,535 |
|  | Gatineau | QC | 98,836 |
|  | Val-Comeau | NB | 71,010 |
|  | Paspébiac | QC | 57,159 |
|  | Beach Point | PE |  |
|  | Sainte-Thérèse-de- |  | 38,480 |
|  | Gaspé | QC | 34,838 |
|  | Alberton | PE | 31,619 |
|  | Afton Station | NS | 23,988 |
|  | Corner Brook | NL | 17,988 |
|  | Grand-Barachois | NB | 12,658 |


| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :---: | :---: | :---: | :---: |
|  | Lower West Pubnico | NS | 5,922 |
|  | Escuminac | NB | 5,857 |
|  | Grande-Rivière | QC | 2,859 |
| Total |  |  | 4,601,013 |
| Calgary, AB | Lethbridge | AB | 3,200 |
| Total |  |  | 3,200 |
| Charlottetown, PE | Victoria | PE | 6 |
| Total |  |  | 6 |
| Dorval, QC | Montréal | QC | 32 |
|  | Québec City | QC | 5 |
| Total |  |  | 37 |
| Fortune, NL | Old Perlican | NL | 31,274 |
|  | Southern Harbour | NL | 4,726 |
| Total |  |  | 36,000 |
| Halifax, NS | Enfield | NS | 52,782 |
| Total |  |  | 52,782 |
| Hamilton, ON | Windsor | ON | 3 |
|  | St. Catharines | ON | 80 |
| Total |  |  | 83 |
| Mirabel, QC | Antigonish | NS | 48 |
| Total |  |  | 48 |
| Niagara Falls, ON | Scarborough | ON | 1,479,248 |
|  | Vaughan | ON | 295,104 |
|  | Brampton | ON | 136,082 |
|  | Toronto | ON | 119,702 |
|  | Woodbridge | ON | 117,845 |
|  | Mississauga | ON | 16,011 |
|  | Fredericton | NB | 925 |
|  | North York | ON | 37 |
| Total |  |  | 2,164,954 |
| Ottawa, ON | Montebello | QC | 50,000,000 |
| Total |  |  | 50,000,000 |
| Point Edward, ON | Scarborough | ON | 59,191 |
|  | Toronto | ON | 800 |
| Total |  |  | 59,991 |
| Richmond, BC | Chilliwack | BC | 12,000,000 |
|  | Abbotsford | BC | 167,226 |
|  | Vancouver | BC | 136,139 |
|  | Burnaby | BC | 105,488 |
|  | Scarborough | ON | 1,429 |


| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :---: | :---: | :---: | :---: |
|  | Langley | BC | 816 |
|  | Aldergrove | BC | 600 |
|  | Richmond | BC | 350 |
|  | Port Coquitlam | BC | 150 |
|  | Toronto | ON | 65 |
|  | Nanaimo | BC | 2 |
| Total |  |  | 12,412,265 |
| Saint John, NB | Bridgewater | NS | 7,480 |
| Total |  |  | 7,480 |
| Saint-Armand, QC | Scarborough | ON | 9,292 |
| Total |  |  | 9,292 |
| Saint-Bernard-deLacolle, QC | Scarborough | ON | 505,255 |
|  | Montréal | QC | 25,721 |
|  | Dorval | QC | 7,306 |
|  | Saint-Laurent | QC | 6,665 |
|  | Lachine | QC | 3,042 |
|  | Mississauga | ON | 342 |
| Total |  |  | 548,331 |
| St-Stephen, NB | Cap-Pelé | NB | 3,864,205 |
|  | Beach Point | PE | 1,052,087 |
|  | Georgetown | PE | 858,533 |
|  | Richibucto | NB | 810,299 |
|  | Paspébiac | QC | 801,306 |
|  | Shediac | NB | 664,114 |
|  | Wallace | NS | 597,630 |
|  | Alberton <br> Sainte-Thérèse-de-la- | PE | 579,309 |
|  | Gatineau | QC | 506,321 |
|  | Deer Island | NB | 210,406 |
|  | Fredericton | NB | 207,522 |
|  | Meteghan River | NS | 193,829 |
|  | Escuminac | NB | 164,554 |
|  | Val-Comeau | NB | 158,673 |
|  | Clark's Harbour | NS | 141,939 |
|  | Pointe-du-Chêne | NB | 141,840 |
|  | Barrington Passage | NS | 84,431 |
|  | Tracadie | NB | 77,225 |
|  | Centreville | NS | 64,264 |
|  | Yarmouth | NS | 53,987 |
|  | Port Elgin | NB | 50,225 |
|  | Souris | PE | 44,970 |


| Port of entry | City of distributor | Province of distributor | \# of organisms |
| :---: | :---: | :---: | :---: |
|  | Montague | PE | 32,395 |
|  | Afton Station | NS | 27,667 |
|  | Halifax | NS | 23,720 |
|  | Elmira | PE | 21,896 |
|  | Lower West Pubnico | NS | 17,697 |
|  | Pictou | NS | 17,405 |
|  | North Lake | PE | 12,658 |
|  | Sainte-Thérèse-de- |  |  |
|  | Gaspé | QC | 12,658 |
|  | Eastern Passage | NS | 9,450 |
|  | River John | NS | 7,680 |
|  | North East Point | NS | 4,905 |
|  | Shelburne County | NS | 2,035 |
|  | Lower East Pubnico | NS | 1,234 |
|  | Lamèque | NB | 300 |
| Total |  |  | 11,521,637 |
| Surrey, BC | Richmond | BC | 452,857 |
|  | Vancouver | BC | 120,162 |
|  | Langley | BC | 62,761 |
|  | Fanny Bay | BC | 20,624 |
|  | Union Bay | BC | 16,591 |
|  | Calgary | $A B$ | 17 |
| Total |  |  | 673,012 |
| Toronto, ON | Vaughan | ON | 210,918 |
|  | Scarborough | ON | 36,595 |
|  | Toronto | ON | 2,793 |
|  | Mossley | ON | 1,998 |
|  | Mississauga | ON | 1,633 |
|  | North York | ON | 831 |
|  | Markham | ON | 249 |
|  | York | ON | 30 |
|  | Fonthill | ON | 1 |
| Total |  |  | 255,048 |
| Vancouver, BC | Richmond | BC | 2,873 |
| Total |  |  | 2,873 |
| Windsor, ON | Markham | ON | 39,484 |
|  | Vaughan | ON | 39,213 |
|  | Toronto | ON | 10,444 |
| Total |  |  | 89,141 |

FIGURES


Figure 1. Invasion process of organisms in trade (modified from Chan et al. 2020). Box with solid outline and arrows depicts a simplified supply chain of organisms in trade, where organisms are transported ( $T$ ) from their native habitats to distributors (or wholesalers) in an introduced region and are subsequently distributed to retailers and end users. Some organisms may be transported ( $T$ ) from their native habitats to culture facilities outside of their native ranges, before being distributed to retailers and end users. Boxes with dotted outline and arrows represent the typical stages of biological invasions with barriers (in parentheses) that could prevent organisms from passing to the next stage. Thick arrows connecting the supply chain and the introduction stage of the invasion process indicate the opportunities at each point in the supply chain where organisms may transition from domestication, cultivation, or captivity to the natural environment via accidental or intentional introductions. The introduction stage is highlighted in red to emphasize the scope of this study.


Figure 2. Data analysis framework that follows a typical supply chain of organisms in trade to characterize the movement of organisms in trade into and within Canada. The framework involves estimating components such as the number and spatial distribution of organism entry points, distributor hubs, retailers, and end users (objective 1); quantifying the actions of end users that allow propagules to be released (objective 2); identifying aquatic organisms in trade in Canada based on available data (objective 3); developing spatially explicit estimates of propagule pressure, per pathway, including a description of key uncertainties (objective 4); and, identifying critical control points (objective 5). Solid boxes and numbered nodes depict the components in the organisms in trade supply chain. Solid lines between nodes illustrate connections based on empirical data, whereas dotted lines represent connections based on assumptions or estimations. Data and/or methods used to characterize the nodes and the connections are also shown.


Figure 3. Source countries from which aquarium organisms were imported into Canada between June $15^{\text {th }}, 2018$ and October $15^{\text {th }}$ 2018. Solid lines depict the movement of imported organism from 40 source countries to Canada, with the weight of the line representing the import quantities. $A U=$ Australia, $B R=$ Brazil, BZ = Belize, CN = China including Hong Kong and Taiwan, CO = Colombia, CZ = Czech Republic, $D E=$ Germany, $D J=$ Djibouti, $D O=$ Dominican Republic, $E C=$ Ecuador, $F J=F i j i, F R=$ France, $G B=$ United Kingdom, $I D=$ Indonesia, $I L=I$ srael, $I N=$ India, $J P=$ Japan, $K E=$ Kenya, $L K=$ Sri Lanka, $M H=$ Marshall Islands, $M M=$ Myanmar, $M V=$ Maldives, $M X=$ Mexico, $M Y=$ Malaysia, $N I=$ Nicaragua, $N L=$ Netherlands, $P E=$ Peru, $P R=$ French Polynesia, $P H=$ Philippines, $P R=$ Puerto Rico, $P T=$ Portugal, $S G$ = Singapore, $T H=$ Thailand, $T N=$ Tunisia, $T O=$ Tonga, US = United States, $V N=$ Vietnam, and $Z A=$ South Africa.


Figure 4. Ports of entry (labelled) for aquarium organisms between June $15^{\text {th }}, 2018$ and October $15^{\text {th }}$ 2018. The movements and the quantities of imported aquarium organisms from the port of entry to the distribution hubs are also shown.


Figure 5. Spatial distribution of the ports of entry (labelled), distributors, and retailers for aquarium organisms in Canada. The numbers of aquarium organisms being imported and distributed are also shown.


Figure 6. The expected numbers of $(A)$ aquarium owners and $(B)$ releasers of aquarium organisms per year in Canada generated through sensitivity analysis. The baseline number of aquarium owners was generated using the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of aquarium owners include: high p(Aq) = 15.9\% and low $p(A q)=5.3 \%$. The baseline number of releasers was generated using the baseline $p(A q)$ and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of releasers include: high $p(A q)=15.9 \%$, low $p(A q)=$ $5.3 \%$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.

Number of households owning
aquaria per year

| $\square$ | $1-3$ |
| :--- | :--- |
| $\square$ | $4-33$ |
|  | $34-571$ |
|  | $572-10,131$ |
|  | $10,132-180,143$ |
| $\square$ | Assumed 0 |

Figure 7. The expected numbers and spatial distributions of aquarium owners per year in Canada generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=$ $10.6 \%$, was used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$ and $(C)$ low $p(A q)=5.3 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 8. Percent change in the number of grids with (A) aquarium owners and $(B)$ releasers of aquarium organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of grids with aquarium owners was generated using the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with aquarium owners include: high $p(A q)=15.9 \%$ and low $p(A q)=5.3 \%$. The baseline number of grids with releasers was generated using the baseline $p(A q)$ and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with releasers include: high $p(A q)=15.9 \%$, low $p(A q)=5.3 \%$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.


Figure 9. The expected numbers and spatial distributions of aquarium owners per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, was used to generate the $(A)$ baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$ and $(C)$ low $p(A q)=5.3 \%$. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.


One-parameter-at-a-time sensitivity analysis scenarios

Figure 10. Percent change in the number of watersheds with $(A)$ aquarium owners and $(B)$ releasers of aquarium organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of watersheds with aquarium owners was generated using the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with aquarium owners include: high $p(A q)=15.9 \%$ and low $p(A q)=5.3 \%$. The baseline number of watersheds with releasers was generated using the baseline $p(A q)$ and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with releasers include: high $p(A q)=15.9 \%$, low $p(A q)=$ $5.3 \%$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.
 aquarium organisms per year

| $\square 1$ |
| :--- |
| $\square$ |
| $\quad 2-3$ |
| $4-33$ |
| $34-474$ |
| $475-7,026$ |
| $\square$ |
| $\quad$ Assumed 0 |

Figure 11. The expected numbers and spatial distributions of households releasing aquarium organisms (i.e. releasers) per year in Canada generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, and the baseline proportion of households owning aquaria that are releasers, $p(\operatorname{Re} \| A q)=3.9 \%$, were used to generate the $(A)$ baseline output. One-parameter-at-atime sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$, (C) low $p(A q)=5.3 \%$, (D) high $p(R e \| A q)=5.9 \%$, and $(E)$ low $p(R e \| A q)=2.0 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 12. The expected numbers and spatial distributions of households releasing aquarium organisms (i.e. releasers) per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, and the baseline proportion of households owning aquaria that are releasers, $p(R e \| A q)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high p(Aq) = 15.9\%, (C) low $p(A q)=5.3 \%$, $(D)$ high $p(R e \| A q)=5.9 \%$, and $(E)$ low $p(R e \| A q)=2.0 \%$. Values $<0.5$ were assumed zero. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.

D)

Hot spots of households releasing aquarium organisms

| Cold Spot-99\% Confidence |
| :---: |
| Cold Spot - 95\% Confidence |
| Cold Spot - 90\% Confidence |
| Not Significant |
| Hot Spot - 90\% Confidence |
| Hot Spot - 95\% Confidence |
| Hot Spot - 99\% Confidence |

Figure 13. Hot spots of households releasing aquarium organisms (i.e. releasers) in Canada generated for different sensitivity analysis scenarios. The baseline proportion of households owning aquaria, $p(A q)=$ $10.6 \%$, and the baseline proportion of households owning aquaria that are releasers, $p(\operatorname{Re} \| A q)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$, (C) low $p(A q)=5.3 \%$, (D) high $p(R e \| A q)=5.9 \%$, and $(E)$ low $p(R e \| A q)=$ 2.0\%. Red and orange areas represent statistically significant hot spots where households releasing aquarium organisms tend to aggregate calculated based on the Getis-Ord Gi* statistics. No statistically significant cold spots were identified.

D)
 aquaria per year

| $\square$ | $1-3$ |
| :--- | :--- |
| $\square$ | $4-33$ |
|  | $34-568$ |
| $569-10,087$ |  |
| $\square$ | $10,088-179,361$ |
| $\square$ | Assumed 0 |

Figure 14. The expected numbers and spatial distributions of aquarium owners per year in Canada generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=$ $10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas ( $U: R=86: 14$ ), was used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$, (C) low $p(A q)=5.3 \%$, (D) urban-biased $p(A q)$, corrected using $U: R=94: 6$, and $(E)$ rural-biased $p(A q)$, corrected using $U: R=77: 23$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 15. The expected numbers and spatial distributions of households releasing aquarium organisms (i.e. releasers) per year in Canada generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas $(U: R=86: 14)$, and the baseline proportion of households owing aquaria that are releasers, $p(\operatorname{Re} \| A q)=3.9 \%$, were used to generate the $(A)$ baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$, (C) low $p(A q)=5.3 \%$, (D) urban-biased $p(A q)$, corrected using $U: R=94: 6$, (E) rural-biased $p(A q)$, corrected using $U: R=77: 23$, (F) high $p(R e \| A q)=5.9 \%$, and $(G)$ low $p(R e \| A q)=2.0 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 16. Percent change in the number of grids with (A) aquarium owners and (B) releasers of aquarium organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of grids with aquarium owners was generated using the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas ( $U: R=86: 14$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with aquarium owners include: high $p(A q)=15.9 \%$; low $p(A q)=5.3 \%$; urban-biased $p(A q)$, corrected using $U: R=94: 6$; and rural-biased $p(A q)$, corrected using $U: R=77: 23$. The baseline number of grids with releasers was generated using the baseline $p(A q)$, corrected using baseline $U: R$, and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with releasers include: high p(Aq), low $p(A q)$ $=5.3 \%$, urban-biased $p(A q)$, rural-biased $p(A q)$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.


Figure 17. The expected numbers and spatial distributions of aquarium owners per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas ( $U: R=86: 14$ ), was used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(A q)=15.9 \%$, (C) low $p(A q)=5.3 \%$, (D) urban-biased $p(A q)$, corrected using $U: R=94: 6$, and (E) rural-biased $p(A q)$, corrected using $U: R=77: 23$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.


Figure 18. The expected numbers and spatial distributions of households releasing aquarium organisms (i.e. releasers) per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas (U:R = 86:14), and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high p(Aq) = 15.9\%, (C) low $p(A q)=5.3 \%$, (D) urban-biased $p(A q)$, corrected using $U: R=94: 6$, ( $E$ ) rural-biased $p(A q)$, corrected using $U: R=77: 23$, (F) high $p(R e \| A q)=5.9 \%$, and $(G)$ low $p(R e \| A q)=2.0 \%$. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.


Figure 19. Percent change in the number of watersheds with ( $A$ ) aquarium owners and ( $B$ ) releasers of aquarium organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of watersheds with aquarium owners was generated using the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, corrected using the estimated baseline proportion of aquarium owners in urban vs rural areas ( $U: R=86: 14$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with aquarium owners include: high $p(A q)=15.9 \%$; low $p(A q)=5.3 \%$; urban-biased $p(A q)$, corrected using $U: R=94: 6$; and rural-biased $p(A q)$, corrected using $U: R=77: 23$. The baseline number of watersheds with releasers was generated using the baseline $p(A q)$, corrected using baseline $U: R$, and the baseline proportion of households owing aquaria that are releasers, $p(R e \| A q)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with releasers include: high p(Aq), low $p(A q)$, urban-biased $p(A q)$, rural-biased $p(A q)$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.


Figure 20. Probability density of the expected number of aquarium organisms released by year in Canada estimated using (1) the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, (2) the baseline proportion of households owing aquaria that are releasers, $p(\operatorname{Re} \| A q)=3.9 \%$, and (3) the baseline mean number of aquarium organisms released per event (i.e. mean propagule size, lambda $=$ 6). The mean of the distribution and the $95 \%$ confidence interval are indicated by the solid and dotted lines, respectively.


Figure 21. The (A) expected mean number of aquarium organisms released per year in Canada, with the $95 \%$ confidence interval, and $(B)$ the percent change in the expected mean in relation to the baseline for different sensitivity scenarios. The baseline output was estimated using (1) the baseline proportion of households owning aquaria, $p(A q)=10.6 \%$, (2) the baseline proportion of households owing aquaria that are releasers, $p(\operatorname{Re} \| A q)=3.9 \%$, and (3) the baseline mean number of aquarium organisms released per event (i.e. mean propagule size, lambda $=6$ ). One-parameter-at-a-time sensitivity analysis scenarios include: high $p(A q)=15.9 \%$, low $p(A q)=5.3 \%$, high $p(R e \| A q)=5.9 \%$, and low $p(R e \| A q)=2.0 \%$.


Figure 22. Source countries from which water garden organisms were imported into Canada between June $15^{\text {th }}, 2018$ and October $15^{\text {th }}$ 2018. Solid lines depict the movement of imported organism from 19 source countries to Canada, with the weight of the line representing the import quantities. $B R=B r a z i l, C N$ = China including Hong Kong and Taiwan, CO = Colombia, CZ = Czech Republic, DE = Germany, GB = United Kingdom, ID = Indonesia, IN = India, JP = Japan, LK = Sri Lanka, NL = Netherlands, PE = Peru, PT = Portugal, SG = Singapore, $T H=$ Thailand, US = United States, and VN = Vietnam.


Figure 23. Ports of entry (labelled) for water garden organisms between June 15 th, 2018 and October $15^{\text {th }}$ 2018. The movements and the quantities of imported water garden organisms from the port of entry to the distribution hubs are also shown.


Figure 24. Spatial distribution of the ports of entry (labelled), distributors, and retailers for water garden organisms in Canada. The numbers of water garden organisms being imported and distributed are also shown.


Figure 25. The expected numbers of $(A)$ water garden owners and $(B)$ releasers of water garden organisms per year in Canada generated through sensitivity analysis. The baseline number of water garden owners was generated using the baseline proportion of households owning water gardens, $p$ (WG) $=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of water garden owners include: high $p(W G)=13.7 \%$ and low $p(W G)=4.6 \%$. The baseline number of releasers was generated using the baseline $p(W G)$, corrected using the baseline $U: R$, and the baseline proportion of households owing water gardens that are releasers, $p(R e \| W G)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of releasers include: high $p(W G)$, low $p(W G)$, high $p(\operatorname{Re} \| W G)=5.9 \%$, and low $p(R e \| W G)=2.0 \%$.


Figure 26. The expected numbers and spatial distributions of water garden owners per year in Canada generated through sensitivity analysis. The baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ), was used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(W G)=13.7 \%$, (C) low $p(W G)=4.6 \%$, (D) urban-biased $p(W G)$, corrected using $U: R=82: 18$, and $(E)$ rural-biased $p(W G)$, corrected using $U: R=67: 33$. Values < 0.5 were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 27. Percent change in the number of grids with (A) water garden owners and (B) releasers of water garden organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of grids with water garden owners was generated using the baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with water garden owners include: high $p(W G)=13.7 \%$; low $p(W G)=$ $4.6 \%$; urban-biased $p(W G)$, corrected using $U: R=82: 18$; and rural-biased $p(W G)$, corrected using $U: R=$ 67:33. The baseline number of grids with releasers was generated using the baseline $p(W G)$, corrected using the baseline U:R, and the baseline proportion of households owing water gardens that are releasers, $p(R e \| W G)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with releasers include: high $p(W G)$, low $p(W G)$, urban-biased $p(W G)$, rural-biased $p(W G)$, high $p(\operatorname{Re} \| W G)=5.9 \%$, and low $p(\operatorname{Re} \| W G)=2.0 \%$.


Figure 28. The expected numbers and spatial distributions of water garden owners per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ), was used to generate the (A) baseline output. One-parameter-at-atime sensitivity analysis scenarios include: (B) high $p(W G)=13.7 \%$, (C) low $p(W G)=4.6 \%$, (D) urbanbiased $p(W G)$, corrected using $U: R=82: 18$, and $(E)$ rural-biased $p(W G)$, corrected using $U: R=67: 33$. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.


Figure 29. Percent change in the number of watersheds with (A) water garden owners and (B) releasers of water garden organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of watersheds with water garden owners was generated using the baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with water garden owners include: high $p(W G)=13.7 \%$; low $p(W G)=4.6 \%$; urban-biased $p(W G)$, corrected using $U: R=82: 18$; and rural-biased $p(W G)$, corrected using $U: R=67: 33$. The baseline number of watersheds with releasers was generated using the baseline $p(W G)$, corrected using the baseline $U: R$, and the baseline proportion of households owing water gardens that are releasers, $p(R e \| W G)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with releasers include: high $p(W G)$, Iow $p(W G)$, urban-biased $p(W G)$, rural-biased $p(W G)$, high $p(\operatorname{Re\| } \mid W G)=5.9 \%$, and low $p(R e \| W G)=2.0 \%$.


Figure 30. The expected numbers and spatial distributions of households releasing water garden organisms (i.e. releasers) per year in Canada generated through sensitivity analysis. The baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas $(U: R=74: 26)$, and the baseline proportion of households owning water gardens that are releasers, $p(\operatorname{Rel} \mid W G)=3.9 \%$, were used to generate the ( $A$ ) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high p(WG) $=13.7 \%$, (C) low $p(W G)=4.6 \%$, (D) urban-biased $p(W G)$, corrected using $U: R=82: 18$, (E) rural-biased $p(W G)$, corrected using $U: R=67: 33$, (F) high $p(R e \| W G)=5.9 \%$, and (G) low $p(R e \| W G)=2.0 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 31. The expected numbers and spatial distributions of households releasing water garden organisms (i.e. releasers) per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=74: 26$ ), and the baseline proportion of households owning water gardens that are releasers, $p(\operatorname{Re} \| W G)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(W G)=13.7 \%$, (C) low $p(W G)=4.6 \%$, (D) urban-biased $p(W G)$, corrected using $U: R=82: 18$, (E) rural-biased $p(W G)$, corrected using $U: R=67: 33$, (F) high $p(R e \| W G)=5.9 \%$, and (G) low $p(R e \| W G)$ $=2.0 \%$. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.

Hot spots of households releasing water garden organisms

|  | Cold Spot - 99\% Confidence |
| :--- | :--- |
|  | Cold Spot - 95\% Confidence |
| Cold Spot - 90\% Confidence |  |
| $\square$ | Not Significant |
| $\square$ | Hot Spot - 90\% Confidence |
|  | Hot Spot - 95\% Confidence |
|  | Hot Spot - 99\% Confidence |

Figure 32. Hot spots of households releasing water garden organisms (i.e. releasers) in Canada generated for different sensitivity analysis scenarios. The baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas $(U: R=74: 26)$, and the baseline proportion of households owning water gardens that are releasers, $p(R e \| W G)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-atime sensitivity analysis scenarios include: $(B)$ high $p(W G)=13.7 \%$, (C) low $p(W G)=4.6 \%$, (D) urbanbiased $p(W G)$, corrected using $U: R=82: 18$, (E) rural-biased $p(W G)$, corrected using $U: R=67: 33$, ( $E$ ) high $p(\operatorname{Re\| } \mid W G)=5.9 \%$, and (F) low $p(R e \| W G)=2.0 \%$. Red and orange areas represent statistically significant hot spots where households releasing water garden organisms tend to aggregate calculated based on the Getis-Ord Gi* statistics. No statistically significant cold spots were identified.


Figure 33. Probability density of the expected number of water garden organisms released per year in Canada estimated using (1) the baseline proportion of households owning water gardens, p(WG) $=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas ( $U: R=$ 74:26), (2) the baseline proportion of households owing water gardens that are releasers, $p(R e \| W G)=$ $3.9 \%$, and (3) the baseline mean number of water garden organisms released per event (i.e. mean propagule size, lambda $=6$ ). The mean of the distribution and the $95 \%$ confidence interval are indicated by the solid and dotted lines, respectively.


Figure 34. The (A) expected mean number of water garden organisms released per year in Canada, with the $95 \%$ confidence interval, and $(B)$ the percent change in the expected mean in relation to the baseline for different sensitivity scenarios. The baseline output was generated using (1) the baseline proportion of households owning water gardens, $p(W G)=9.2 \%$, corrected using the estimated baseline proportion of water garden owners in urban vs rural areas (U:R = 74:26), (2) the baseline proportion of households owing water gardens that are releasers, $p(R e l \mid W G)=3.9 \%$, and (3) the baseline mean number of water garden organisms released per event (i.e. mean propagule size, lambda = 6). One-parameter-at-a-time sensitivity analysis scenarios include: high $p(W G)=13.7 \%$, low $p(W G)=4.6 \%$, high lambda $=9$, and low lambda $=3$.


Figure 35. Source countries from which live seafood organisms were imported into Canada between June $15^{\text {th }}, 2018$ and October $15^{\text {th }} 2018$. Solid lines depict the movement of imported organism from 20 source countries to Canada, with the weight of the line representing the import quantities. $A U=$ Australia, CN $=$ China including Taiwan, CU = Cuba, DO = Dominican Republic, FR = France, GB = United Kingdom, HT = Haiti, ID = Indonesia, IE = Ireland, IS = Iceland, $K R=$ South Korea, $N L=$ Netherlands, $N O=$ Norway, NU = New Zealand, PH = Philippines, PM = Saint Pierre and Miquelon (Territorial Collectivity of France), $R U=$ Russian Federation, US = United States, and VN = Vietnam.


Figure 36. Ports of entry (labelled) for live seafood organisms between June $15^{\text {th }}$, 2018 and October $15^{\text {th }}$ 2018. The movements and the quantities of imported live seafood organisms from the port of entry to the distribution hubs were also shown.


Figure 37. Spatial distributions of the ports of entry (labelled), distributors, and retailers for live seafood organisms in Canada. The numbers of live seafood organisms being imported and distributed are also shown.


Figure 38. The expected numbers of $(A)$ live seafood consumers and $(B)$ releasers of live seafood organisms per year in Canada generated through sensitivity analysis. The baseline number of live seafood consumers was generated using the baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas (U:R = 86:14). One-parameter-at-a-time sensitivity analysis scenarios for the number of live seafood consumers include: high $p(L F)=5.3 \%$ and low $p(L F)=1.8 \%$. The baseline number of releasers was generated using the baseline $p(L F)$, corrected using the baseline $U: R$, and the baseline proportion of the population purchasing live seafood that are releasers, $p(R e \| L F)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of releasers include: high p(LF), low $p(L F)$, high $p(R e l \mid L F)=5.9 \%$, and low $p(R e \| \mid L F)=2.0 \%$.


Figure 39. The expected numbers and spatial distributions of individuals purchasing live seafood per year in Canada generated through sensitivity analysis. The baseline proportion of the Canadian population purchasing live seafood, $p(L F)=5.3 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ), was used to generate the ( $A$ ) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high p(LF) $=5.3 \%$, (C) low $p(L F)=1.8 \%$, (D) urban-biased $p(L F)$, corrected using $U: R=94: 6$, and $(E)$ rural-biased $p(L F)$, corrected using U:R = 77:23. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 40. Percent change in the number of grids with (A) live seafood consumers and (B) releasers of live seafood organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of grids with live seafood consumers was generated using the baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with live seafood consumers include: high $p(L F)=5.3 \%$; low $p(L F)=1.8 \%$; urban-biased $p(L F)$, corrected using $U: R=94: 6$; and rural-biased $p(L F)$, corrected using $U: R=77: 23$. The baseline number of grids with releasers was generated using the baseline $p(L F)$, corrected using the baseline $U: R$, and the baseline proportion of the population purchasing live seafood that are releasers, $p(R e \| L F)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of grids with releasers include: high p(LF), low $p(L F)$, urban-biased $p(L F)$, rural-biased $p(L F)$, high $p($ Re $\| L F)=5.9 \%$, and low $p($ Re\| $\| L F)=2.0 \%$.

Number of individuals purchasing live seafood organisms per year

| $\square$ | $1-78$ |
| :--- | :--- |
| $\square$ | $79-706$ |
| $\square$ | $707-5,903$ |
| $\square$ | $5,904-48,928$ |
| $\square$ | $48,929-405,126$ |

Figure 41. The expected numbers and spatial distributions of live seafood consumers per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ), was used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(L F)=5.3 \%$, (C) low $p(L F)=1.8 \%$, (D) urban-biased $p(L F)$, corrected using $U: R=94: 6$, and (E) rural-biased $p(L F)$, corrected using U:R = 77:23. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.


Figure 42. Percent change in the number of watersheds with (A) live seafood consumers and (B) releasers of live seafood organisms in Canada in relation to the baseline for different sensitivity scenarios. The baseline number of watersheds with live seafood consumers was generated using the baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ). One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with live seafood consumers include: high $p(L F)=5.3 \%$; low $p(L F)=1.8 \%$; urban-biased $p(L F)$, corrected using $U: R=$ 94:6; and rural-biased $p(L F)$, corrected using $U: R=77: 23$. The baseline number of watersheds with releasers was generated using the baseline $p(L F)$, corrected using the baseline $U: R$, and the baseline proportion of the population purchasing live seafood that are releasers, $p(\operatorname{Re\| } \mid L F)=3.9 \%$. One-parameter-at-a-time sensitivity analysis scenarios for the number of watersheds with releasers include: high $p(L F)$, low $p(L F)$, urban-biased $p(L F)$, rural-biased $p(L F)$, high $p(R e \| L F)=5.9 \%$, and low $p(R e \| L F)=$ 2.0\%.


Figure 43. The expected numbers and spatial distributions of individuals releasing live seafood organisms (i.e. releasers) per year in Canada generated through sensitivity analysis. The baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ), and the baseline proportion of the population purchasing live seafood that are releasers, $p($ Rel $\mid L F)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high $p(L F)=5.3 \%$, (C) low $p(L F)=1.8 \%$, (D) urban-biased $p(L F)$ corrected using $U: R=94: 6$, ( $E$ ) rural-biased $p(L F)$, corrected using $U: R=77: 23$, (F) high $p(R e \| L F)=5.9 \%$, and $(G)$ low $p(R e \| L F)=2.0 \%$. Values $<$ 0.5 were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage.


Figure 44. The expected numbers and spatial distributions of individuals releasing live seafood organisms (i.e. releasers) per year in Canada at the watershed level generated through sensitivity analysis. The baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=$ 86:14), and the baseline proportion of the population purchasing live seafood that are releasers, $p(\operatorname{Re\| } \mid L F)$ $=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: $(B)$ high $p(L F)=5.3 \%$, (C) low $p(L F)=1.8 \%$, (D) urban-biased $p(L F)$ corrected using $U: R=94: 6$, ( $E$ ) rural-biased $p(L F)$, corrected using $U: R=77: 23$, (F) high $p(R e / L L F)=5.9 \%$, and (G) low $p($ Rel $\mid L F)=2.0 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage. Note that watersheds vary in size and some watersheds extend beyond the Canadian border.
 live seafood organisms

| Cold Spot - 99\% Confidence |
| :---: |
| Cold Spot - 95\% Confidence |
| Cold Spot - 90\% Confidence |
| Not Significant |
| Hot Spot - 90\% Confidence |
| Hot Spot - 95\% Confidence |
| Hot Spot-99\% Confidence |

Figure 45. Hot spots of individuals releasing live seafood organisms (i.e. releasers) in Canada generated for different sensitivity analysis scenarios. The baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=86: 14$ ), and the baseline proportion of the population purchasing live seafood that are releasers, $p(R e \| L F)=3.9 \%$, were used to generate the (A) baseline output. One-parameter-at-a-time sensitivity analysis scenarios include: (B) high p(LF) $=5.3 \%$, (C) low $p(L F)=1.8 \%$, (D) urban-biased $p(L F)$ corrected using $U: R=94: 6$, (E) rural-biased p(LF), corrected using $U: R=77: 23$, ( $F$ ) high $p(R e \| L F)=5.9 \%$, and (G) low $p(R e \| L F)=2.0 \%$. Values $<0.5$ were assumed zero. Each grid represents a $50 \mathrm{~km} \times 50 \mathrm{~km}$ spatial coverage. Red and orange areas represent statistically significant high-risk areas where individuals releasing live seafood organisms tend to aggregate calculated based on the Getis-Ord Gi* statistics. No statistically cold spots were identified.


Figure 46. Probability density of the expected number of live seafood organisms (freshwater, brackish water, and marine species) released per year in Canada estimated using (1) the baseline proportion of the Canadian population purchasing live seafood, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas (U:R = 86:14), (2) the baseline proportion of the population purchasing live seafood that are releasers, $p(\operatorname{Re} \| L F)=3.9 \%$, and (3) the baseline mean number of live seafood organisms released per event (i.e. mean propagule size, lambda $=$ 6). The mean of the distribution and the $95 \%$ confidence interval are indicated by the solid and dotted lines, respectively.


Figure 47. The $(A)$ expected mean number of live seafood organisms released per year in Canada, with the $95 \%$ confidence interval, and $(B)$ the percent change in the expected mean in relation to the baseline output for different sensitivity scenarios. The baseline output was generated using (1) the baseline proportion of the Canadian population purchasing live seafood organisms, $p(L F)=3.5 \%$, corrected using the estimated baseline proportion of individuals purchasing live seafood in urban vs rural areas ( $U: R=$ 86:14), (2) the baseline proportion of the population purchasing live seafood that are releasers, p(Rel|LF) $=3.9 \%$, and (3) the baseline mean number of live seafood organisms released per event (i.e. mean propagule size, lambda $=6$ ). One-parameter-at-a-time sensitivity analysis scenarios include: high $p(L F)=$ $5.3 \%$, low $p(L F)=1.8 \%$, high $p(R e \| \mid L F)=5.9 \%$, low $p(R e \| L F)=2.0 \%$, high lambda $=9$, and low lambda $=$ 3.

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## APPENDICES

Appendix A. Table summarizing the harmonized system (HS) codes and other government department (OGD) extensions used to identify import records for fish, invertebrate, and plant taxa associated with the aquarium, water garden, and live seafood pathways. For observed taxa, $F=$ fishes, $I=$ invertebrates, and $P=$ plants. Note that taxa observed in records imported under a particular HS code were not always consistent with that of the HS code description and there were discrepancies between the intended use of the imported organisms according to the description of goods when provided and the HS code description in some cases (599 of 8,192 records).

| $\begin{aligned} & \text { HS code } \\ & \text { (OGD) } \end{aligned}$ | HS code description | Observed taxa | Assigned pathway |
| :---: | :---: | :---: | :---: |
| 03.01.11 | Live ornamental fish, freshwater | F, I, P | Aquarium, water garden, live seafood |
| 03.01.19 | Live ornamental fish, other | F, I, P | Aquarium, water garden |
| 03.01.91 | Live trout | F | Live seafood |
| 03.01.92 | Live eels | F | Live seafood |
| 03.01.93 | Live carps | F | Live seafood |
| $\begin{aligned} & \text { 03.01.94, } \\ & \text { 03.01.95 } \end{aligned}$ | Live tunas | F | Live seafood |
| 03.01.99 | Other live fishes | F | Aquarium, water garden, live seafood |
| $\begin{aligned} & \text { 03.06.31, } \\ & 03.06 .32 \end{aligned}$ | Live, fresh, or chilled Rock Lobster and other sea crawfish | 1 | Live seafood |
| 03.06.32.00.10 | Live lobsters (Homarus spp.) | 1 | Live seafood |
| 03.06.33 | Live, fresh, or chilled crabs | 1 | Aquarium, live seafood |
| 03.06.34 | Live, fresh, or chilled Norway Lobster | 1 | Live seafood |
| 03.06.35 | Live, fresh, or chilled coldwater shrimps and prawns | 1 | Live seafood |
| 03.06.36.00.10 | Other live, fresh, or chilled in shell shrimps and prawns | 1 | Aquarium, live seafood, other |
| 03.07.11.10.00 | Live, fresh, or chilled in shell oysters | 1 | Live seafood |
| 03.07.21.00.10 | Live, fresh, or chilled in shell scallops | I | Live seafood |
| 03.07.31 | Live, fresh, or chilled mussels | I | Live seafood |
| 03.07.42 | Live, fresh, or chilled cuttlefish and squid | 1 | Live seafood |
| 03.07.51 | Live, fresh, or chilled octopus | 1 | Aquarium, live seafood |
| 03.07.60.90 | Snails, other than sea snails (other, not smoked) | 1 | Aquarium, water garden, live seafood, other |
| 03.07.71 | Live, fresh, or chilled clams, cockles, and ark shells | 1 | Live seafood |
| 03.07 .81 | Live, fresh, or chilled abalone | 1 | Live seafood |
| 03.07.82 | Live, fresh, or chilled stromboid conchs | 1 | Live seafood |
| 03.07.91 | Other live, fresh, or chilled clams | 1 | Aquarium, live seafood, other |
| 03.08.11 | Live, fresh, or chilled sea cucumbers | 1 | Live seafood |


| HS code (OGD) | HS code description | Observed taxa | Assigned pathway |
| :---: | :---: | :---: | :---: |
| 03.08.21 | Live, fresh, or chilled sea urchins | I | Live seafood, other |
| 03.08.30.90 | Jellyfish (other, not smoked) | I | Live seafood |
| 03.08.90.90 | Other aquatic invertebrates (other, not smoked) | I | Aquarium, live seafood, other |
| 06.01.20 | Live blubs, tubers, tuberous roots, corms, crowns, and rhizomes, in growth or in flower; chicory plants and roots | None | None |
| 06.02.10 (1204) | Live unrooted greenhouse aquatic plants | None | None |
| 06.02.90 (2494) | Live rooted greenhouse aquatic plants | P | Aquarium, water garden |
| 12.12.21 | Seaweeds and other algae; fit for human consumption | P | Other |
| 12.12.29 | Seaweeds and other algae; other | P | Other |

Appendix B. Table summarizing the aquatic organisms in trade observed in the Pathfinder dataset for import transactions from June $15^{\text {th }}, 2018$ to October $15^{\text {th }} 2018$. For taxa, $F=$ fishes, $I=$ invertebrates, and $P=$ plants. Fish species that have been documented by previous studies ( $0=$ none of the exmined studies, $1=$ Mandrak et al. 2014, $2=$ Gertzen et al. 2008, $3=$ Rixon et al. 2005) are noted. $A q=$ aquarium pathway, $W G=$ water garden pathway, and LF = live seafood pathway.

| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Abdopus sp. | Octopus | I | - | - | - | 1 |
| Ablabys taenianotus | Cockatoo Waspfish, Rouge Fish, Redskinfish | F | 0 | 1 | - | - |
| Acanthacaris caeca | Atlantic Deep Lobster, Atlantic Deepsea Lobster, Blind Deep Sea Lobster | I | - | - | - | 1 |
| Acanthemblemaria hancocki | Hancock's Blenny | F | 0 | 1 | - | - |
| Acanthochromis polyacanthus | Spiny Chromis | F | 0 | 1 | - | - |
| Acanthurus bariene | Black-spot Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus chronixis | Chronixis Surgeonfish | F | 0 | 1 | - | - |
| Acanthurus coeruleus | Blue Tang Surgeonfish, Blue Tang | F | 1 | 1 | - | - |
| Acanthurus guttatus | Whitespotted Surgeonfish, Mustard Surgeonfish, Spotted Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus japonicus | Japan Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus leucosternon | Powderblue Surgeonfish, Powder-blue Tang | F | 1 | 1 | - | - |
| Acanthurus lineatus | Lined Surgeonfish, Clown Surgeonfish, Striped Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus nigricans | Whitecheek Surgeonfish, Black Surgeonfish, Blackear Surgeonfish, Goldrim Surgeonfish, Gray Surgeonfish, Whiteface Surgeonfish, Whitetail Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus nigrofuscus | Brown Surgeonfish, Elongate Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus olivaceus | Orangespot Surgeonfish, Gendarmefish, Olive Surgeonfish, Orange-ear Surgeonfish, Orangeepaulette Surgeonfish, Orangeband Surgeonfish | F | 1 | 1 | - | - |
| Acanthurus pyroferus | Chocolate Surgeonfish, Powderblue Surgeonfish, Yellowspot Surgeon | F | 1 | 1 | - | - |
| Acanthurus sohal | Sohal Surgeonfish, Sohal Tang | F | 1 | 1 | - | - |
| Acanthurus triostegus | Convict Surgeonfish, Convict Tang, Fiveband Surgeonfish | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acanthurus tristis | Indian Ocean Mimic Surgeonfish | F | 1 | 1 | - | - |
| Acreichthys tomentosus | Bristle-tail File-fish, Matted Leatherjacket | F | 1 | 1 | - | - |
| Actinopterygii | Knifefish | F | 0 | 1 | - | - |
| Aegagropila linnaei | Moss Ball | P | - | 1 | - | - |
| Aglaonema simplex | Malayan Sword | P | - | 1 | 1 | - |
| Alestopetersius caudalis | Yellowtail Tetra, Yellow-tailed African Characin, Yellow-tailed African Tetra | F | 1 | 1 | - | - |
| Alismataceae | Oriental Sword | P | - | 1 | 1 | - |
| Alpheus bellulus | Pretty Snapping Shrimp, Tiger Snapping Shrimp, Goby's Shrimp | 1 | - | 1 | - | 1 |
| Alpheus bisincisus | Japanese Snapping Shrimp | 1 | - | - | - | 1 |
| Alpheus randalli | Randall's Snapping Shrimp, Randall's Pistol Shrimp, Snapping Shrimps, Red Banded Snapping Shrimp | 1 | - | 1 | - | - |
| Alpheus sp. | Yellow Pistol Shrimp | 1 | - | 1 | - | - |
| Alternanthera reineckii | Telanthera Plant, Temple Plant | P | - | 1 | 1 | - |
| Amblyeleotris aurora | Pinkbar Goby | F | 1 | 1 | - | - |
| Amblyghidodon curaco | Staghorn Damselfish, Clouded Damselfish, Baresnouted Sergeant Major | F | 0 | 1 | - | - |
| Amblyeleotris guttata | Spotted Prawn-goby, Orange Spotted Goby | F | 1 | 1 | - | - |
| Amblyeleotris wheeleri | Gorgeous Prawn-goby, Wheeler's Watchman Goby | F | 1 | 1 | - | - |
| Amblyeleotris yanoi | Flagtail Shrimpgoby, Flagtail Pinkbar Goby | F | 0 | 1 | - | - |
| Amblygobius phalaena | Whitebarred Goby, Sleeper Banded Goby | F | 1 | 1 | - | - |
| Ameiurus catus | White Catfish | F | 0 | - | - | 1 |
| Ammannia crassicaulis | - | P | - | 1 | 1 | - |
| Ammannia pedicellata | Golden Nesaea | P | - | 1 | 1 | - |
| Amphiprion allardi | Twobar Anemonefish, Allard's Clownfish | F | 0 | 1 | - | - |
| Amphiprion bicinctus | Twoband Anemonefish | F | 1 | 1 | - | - |
| Amphiprion clarkii | Yellowtail Clownfish, Clark's Anemonefish, Black Clown, Brown Anemonefish, Chocolate Clownfish, Sea Bee | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Amphiprion frenatus | Tomato Clownfish, Blackback Anemonefish, Fire Clown, Onebar Anemonefish, Red Clown | F | 1 | 1 | - | - |
| Amphiprion melanopus | Cinnamon Clownfish, Fire Clownfish, Red and Black anemonefish, Black-backed Anemonefish, Dusky Anemonefish | F | 1 | 1 | - | - |
| Amphiprion ocellaris | Clown Anemonefish, Common Clownfish, False Clown Anemonefish, Ocellaris Clownfish | F | 1 | 1 | - | - |
| Amphiprion percula | Orange Clownfish, Blackfinned Clownfish, Clown Anemonefish | F | 1 | 1 | - | - |
| Amphiprion perideraion | Pink Anemonefish, Pink Skunk Clownfish | F | 1 | 1 | - | - |
| Amphiprion polymnus | Saddleback Clownfish, Brownsaddle Clownfish | F | 1 | 1 | - | - |
| Amphiprion sandaracinos | Yellow Clownfish, Orange Skunk Clownfish, Orange Anemonefish | F | 1 | 1 | - | - |
| Amphiprion sebae | Sebae Clownfish | F | 1 | 1 | - | - |
| Anampses lineatus | Deep-sea Wrasse, Lined Wrasse | F | 1 | 1 | - | - |
| Anampses meleagrides | Spotted Wrasse, Yellow-tail Tamarin | F | 1 | 1 | - | - |
| Ancistrus dolichopterus | Bushymouth Catfish, Bluechin Xenocara | F | 1 | 1 | 1 | - |
| Ancistrus hoplogenys | Spotted Bristlenose Pleco | F | 1 | 1 | 1 | - |
| Ancistrus sp. | Bristlenose Plecostomus, Bushy Nose Plecostomus, Bristlenose Catfish, Bushy Nose Catfish | F | - | 1 | 1 | - |
| Ancistrus tamboensis | Bristlenose Plecostomus, Bushy Nose Plecostomus, Bristlenose Catfish, Bushy Nose Catfish | F | 1 | 1 | 1 | - |
| Ancistrus temminckii | Bristlenose Plecostomus, Bushy Nose Plecostomus, Bristlenose Catfish, Bushy Nose Catfish | F | 1 | 1 | 1 | - |
| Ancylomenes venustus | Beautiful Transparent Shrimp, Graceful Anemone Shrimp | 1 | - | 1 | - | - |
| Andinoacara pulcher | Blue Acara, Blue Acara Cichlid | F | 0 | 1 | - | - |
| Anguilla australis | Short-finned Eel, Australia Short-finned Eel, Eel, River Eel, Short-finned Freshwater Eel, Shortfin Eel, Silver Eel | F | 1 | - | - | 1 |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Anguilla sp. | Eel | F | - | - | - | 1 |
| Antennarius maculatus | Warty Frogfish, Largespotted Angler, Red/Orange Angler | F | 1 | 1 | - | - |
| Antennarius pictus | Painted Frogfish | F | 0 | 1 | - | - |
| Antennarius striatus | Striated Frogfish, Black Angler, Splitlure Frogfish | F | 1 | 1 | - | - |
| Anthias anthias | Swallowtail Seaperch, Barbier | F | 0 | 1 | - | - |
| Anubias barteri | Anubias | P | - | 1 | 1 | - |
| Anubias barteri x Anubias congensis | Anubias Frazeri | P | - | 1 | 1 | - |
| Anubias nana $\times$ Anubias gilletii | Anubias Nangi | P | - | 1 | 1 | - |
| Aphyocharax anisitsi | Bloodfin Tetra, Bloodfin, True Bloodfin | F | 1,2 | 1 | 1 | - |
| Aphyocharax nattereri | Dawn Tetra, White Spot Tetra | F | 0 | 1 | - | - |
| Aphyocharax rathbuni | Redflank Bloodfin, Rathbun's Bloodfin | F | 1 | 1 | 1 | - |
| Aphyosemion australe | Lyretail Panchax, Cape Lopez Lyretail, Chocolate Australe, Chocolate Lyretail, Gold Australe, Gold Lyretail, Lyre-tailed Panchax, Orange Australe | F | 1 | 1 | - | - |
| Apistogramma agassizii | Agassiz's Dwarf Cichlid | F | 1 | 1 | 1 | - |
| Apistogramma atahualpa | Atahualpa Dwarf Cichlid | F | 1 | 1 | - | - |
| Apistogramma borellii | Umbrella Cichlid, Borelli's Dwarf Cichlid, Dwarf Chichlid, Yellow Dwarf Cichlid | F | 1 | 1 | 1 | - |
| Apistogramma cacatuoides | Cockatoo Cichlid, Cockatoo Dwarf Cichlid, Crested Dwarf Cichlid | F | 1 | 1 | 1 | - |
| Apistogramma cruzi | Dwarf cichlid | F | 1 | 1 | 1 | - |
| Apistogramma sp. | Dwarf cichlid | F | - | 1 | 1 | - |
| Apistogramma uaupesi | Dwarf cichlid | F | 0 | 1 | 1 | - |
| Apistogramma velifera | Dwarf cichlid | F | 0 | 1 | 1 | - |
| Aplysia sp. | Sea slug | I | - | 1 | - | - |
| Apolemichthys trimaculatus | Threespot Angelfish | F | 1 | 1 | - | - |
| Apolemichthys xanthurus | Yellowtail Angelfish, Indian Yellowtail Angelfish | F | 1 | 1 | - | - |
| Aponogeton boivinianus | - | P | - | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Aponogeton capuronii | - | P | - | 1 | 1 | - |
| Apostichopus californicus | California Sea Cucumber, Giant Sea Cucumber, Giant California Sea Cucumber, Giant Red Sea Cucumber, Sea Cucumber | 1 | - | - | - | 1 |
| Apteronotus albifrons | Black Ghost, Apteronotid Eel, Black ghost Knifefish | F | 1 | 1 | 1 | - |
| Apteronotus leptorhynchus | Brown Ghost Knifefish | F | 1 | 1 | - | - |
| Archaster typicus | Common Sea Star, Sandstar | 1 | - | 1 | - | - |
| Ariopsis seemanni | Tete Sea Catfish | F | 0 | 1 | - | - |
| Arothron hispidus | White-spotted Puffer, Stars and Stripes Puffer | F | 1 | 1 | - | - |
| Arothron manilensis | Narrow-lined Puffer | F | 1 | 1 | - | - |
| Arothron nigropunctatus | Blackspotted Puffer, Arothron Dog Face Puffer | F | 1 | 1 | - | - |
| Astraea sp. | Snail | I | - | 1 | - | - |
| Astraea tecta | Astraea Turbo Snail, West Indian Starsnail | 1 | - | 1 | - | - |
| Astralium phoebium | Longspine Starsnail, Long-spined Star-shell | 1 | - | 1 | - | - |
| Astronotus ocellatus | Oscar, Astronotus, Marble Cichlid, Red Oscar, Velvet Cichlid | F | 1,3 | 1 | 1 | - |
| Astropecten polyacanthus | Brown Spotted Combstar, Starfish | I | - | 1 | - | - |
| Astyanax jordani | Cave Tetra | F | 1 | 1 | 1 | - |
| Atelomycterus marmoratus | Coral Catshark | F | 1 | 1 | - | - |
| Atherinops affinis | Topsmelt Silverside, Topsmelt | F | 0 | 1 | - | - |
| Atrosalarias fuscus | Brown Coral Blenny | F | 1 | 1 | - | - |
| Atrosalarias hosokawai | Hosokawa's Coral Blenny | F | 0 | 1 | - | - |
| Aulonocara sp. | Malawi Cichlid | F | - | 1 | 1 | - |
| Austrovenus stutchburyi | Stutchbury's Enus, New Zealand Cockle | I | - | - | - | 1 |
| Babylonia sp. | Snail | 1 | - | 1 | - | - |
| Babylonia spirata | Spiral Babylon, Snail | I | - | 1 | - | - |
| Bacopa caroliniana | Blue Waterhyssop, Blue Water-hyssop, Lemon Bacopa | P | - | 1 | 1 | - |
| Bacopa monnieri | Herb of Grace, Indian Pennywort, Bacopa, Coastal water-hyssop, Coastal Waterhyssop, Herb-of-grace, Moneywort | P | - | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Badis autumnum | Badis | F | 0 | 1 | - | - |
| Badis badis | Badis, Blue perch, Red badis | F | 1 | 1 | - | - |
| Baidis sp. | Badis | F | - | 1 | - | - |
| Balistoides conspicillum | Clown triggerfish | F | 1 | 1 | - | - |
| Barbodes semifasciolatus | Chinese Barb, China Barb, Gold Barb, Green Barb, Halfbanded Barb, Schubert's Barb | F | 0 | 1 | 1 | - |
| Bartholomea annulata | Ringed Anemone, Corkscrew Anemone, Curly-que Anemone | I | - | 1 | - | - |
| Baryancistrus beggini | Blue Panaque | F | 0 | 1 | - | - |
| Baryancistrus sp. | Loricariid catfish | F | - | 1 | - | - |
| Baryancistrus xanthellus | Gold Nugget Pleco | F | 0 | 1 | - | - |
| Berghia verrucicornis | Sea slug | I | - | 1 | - | - |
| Betta sp. | Betta | F | - | 1 | 1 | - |
| Betta splendens | Siamese Fighting Fish | F | 1,2,3 | 1 | 1 | - |
| Bivalvia | Clam | I | - | - | - | 1 |
| Bivalvia | Mussel | 1 | - | - | - | 1 |
| Bivalvia | Oyster | 1 | - | - | - | 1 |
| Blenniella chrysospilos | Red-spotted Blenny, Red-spotted Blennellia, Orange-spotted Blenny | F | 1 | 1 | - | - |
| Bodianus anthioides | Lyretail Hogfish | F | 1 | 1 | - | - |
| Boehlkea fredcochui | Cochu's Blue Tetra, Blue Tetra | F | 1 | 1 | 1 | - |
| Boraras brigittae | Chili Rasbora | F | 0 | 1 | - | - |
| Boraras urophthalmoides | Least Rasbora, Exclamation-point Rasbora, Miniature Rasbora | F | 0 | 1 | - | - |
| Bothus pantherinus | Leopard Flounder, Panther Flounder | F | 0 | 1 | - | - |
| Botia histrionica | Loach | F | 1 | 1 | - | - |
| Botia kubotai | Loach | F | 1 | 1 | 1 | - |
| Botia lohachata | Reticulate Loach, Pakistani Loach | F | 1 | 1 | 1 | - |
| Botia striata | Zebra Loach | F | 1 | 1 | 1 | - |
| Brevibora dorsiocellata | Eyespot Rasbora, Hi-spot Rasbora | F | 0 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Busycotypus canaliculatus | Channeled Whelk | 1 | - | - | - | 1 |
| Cabomba caroliniana | Carolina Fanwort, Carolina Water-shield, Washigton-grass, Washington-plant, Fanwort, Fishgrass, Carolina Watershield | P | - | 1 | 1 | - |
| Calcinus elegans | Elegant Hermit, Electric Blue Hermit Crab | 1 | - | 1 | - | - |
| Calcinus laevimanus | Hawaiian Hermit, Dwarf Zebra Hermit Crab | I | - | 1 | - | - |
| Calcinus latens | Hidden Hermit | I | - | 1 | - | - |
| Callinectes sapidus | Blue Crab, Bluepoint | 1 | - | - | - | 1 |
| Calloplesiops altivelis | Comet, Marine Betta | F | 1 | 1 | - | - |
| Cancer borealis | Jonah Crab | I | - | - | - | 1 |
| Cancer magister | Dungeness Crab, Common Edible Crab, Market Crab | 1 | - | - | - | 1 |
| Cancer pagurus | Edible Crab, European Edible Crab, Brown Crab | 1 | - | - | - | 1 |
| Canthigaster amboinensis | Spider-eye Puffer | F | 1 | 1 | - | - |
| Canthigaster bennetti | Bennett's Sharpnose Puffer | F | 1 | 1 | - | - |
| Canthigaster coronata | Crowned Puffer | F | 0 | 1 | - | - |
| Canthigaster jactator | Hawaiian Whitespotted Toby | F | 1 | 1 | - | - |
| Canthigaster janthinoptera | Honeycomb Toby | F | 1 | 1 | - | - |
| Canthigaster solandri | Spotted Sharpnose, Blue Dot Toby Puffer | F | 1 | 1 | - | - |
| Canthigaster valentini | Valentin's sharpnose puffer | F | 1 | 1 | - | - |
| Cephalopholis miniata | Coral Hind, Coral Grouper, Coral Rock Cod, Coral Cod, Coral Trout, Roung-tailed Trout, Vermilion Seabass | F | 1 | 1 | - | - |
| Caranx crysos | Blue runner, Crevalle, Hardtail, Runner, Yellow Mackerel | F | 0 | - | - | 1 |
| Carassius auratus | Goldfish | F | 1,2,3 | 1 | 1 | 1 |
| Caridina cantonensis? | Bee Shrimp? | I | - | 1 | - | - |
| Caridina logemani? | Crystal Red Shrimp | I | - | 1 | - | - |
| Caridina sp. | Shrimp | 1 | - | 1 | - | - |
| Carnegiella strigata | Marbled Hatchetfish | F | 1 | 1 | 1 | - |
| Caulerpa serrulata | Cactus Tree Alga | P | - | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Centromochlus perugiae | Honeycomb Catfish, Oil Catfish | F | 0 | 1 | - | - |
| Centropyge acanthops | Orangeback Angelfish, African Pygmy Angelfish, Flameback Angelfish | F | 1 | 1 | - | - |
| Centropyge argi | Cherubfish | F | 1 | 1 | - | - |
| Centropyge bicolor | Bicolor Angelfish, Two-colored Angelfish | F | 1 | 1 | - | - |
| Centropyge bispinosa | Twospined Angelfish, Coral Beauty, Dusky Angelfish | F | 1 | 1 | - | - |
| Centropyge eibli | Blacktail Angelfish, Eibl's Angelfish, Scribbled Angelfish, Red Stripe Angelfish | F | 1 | 1 | - | - |
| Centropyge ferrugata | Rusty Angelfish | F | 1 | 1 | - | - |
| Centropyge fisheri | Orange Angelfish, White-tailed Angelfish, Whitetail Angelfish, Fisher's Pygmy Angelfish, Yellowtail Angelfish | F | 1 | 1 | - | - |
| Centropyge flavipectoralis | Yellowfin Angelfish, Yellowfin Pygmy Angelfish | F | 1 | 1 | - | - |
| Centropyge flavissima | Lemonpeel Angelfish, Lemonpeel Pygmy Angelfish | F | 1 | 1 | - | - |
| Centropyge heraldi | Yellow Angelfish, Herald's Angelfish | F | 1 | 1 | - | - |
| Centropyge loriculus | Flame Angel, Japanese Pygmy Angelfish, Flaming Angelfish | F | 1 | 1 | - | - |
| Centropyge multispinis | Dusky Angelfish, Dusky Cherub, Multispined Angelfish | F | 1 | 1 | - | - |
| Centropyge nox | Midnight Angelfish | F | 1 | 1 | - | - |
| Centropyge potteri | Russet Angelfish, Potter's Angelfish | F | 1 | 1 | - | - |
| Centropyge tibicen | Keyhole Angelfish, Black Angelfish | F | 1 | 1 | - | - |
| Centropyge vrolikii | Pearlscale Angelfish, Pearl-scaled Angelfish | F | 1 | 1 | - | - |
| Centrostephanus coronatus | Crowned Sea Urchin | , | - | 1 | - | - |
| Cephalopoda | Octopus | 1 | - | 1 | - | - |
| Ceratophyllum demersum | Hornwort, Coon's Tail, Common Hornwort, Coon'stail, Coontail, Rigid Hornwort | P | - | 1 | 1 | - |
| Ceratopteris thalictroides | Water Fern, Water Horn Fern, Water Sprite, Watersprite | P | - | 1 | 1 | - |
| Cerithium californica | Cerith White Cone Tip Snail | 1 | - | 1 | - | - |
| Cerithium sp. | Snail | I | - | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- | LF


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- | LF


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Chromobotia macracanthus | Clown Loach, Tiger Botia | F | 1 | 1 | 1 | - |
| Chrysiptera cyanea | Sapphire Devil, Blue Devil, Cornflower Sergeantmajor | F | 1 | 1 | - | - |
| Chrysiptera hemicyanea | Azure Demoiselle | F | 1 | 1 | - | - |
| Chrysiptera parasema | Goldtail Demoiselle, Yellowtail Damselfish | F | 1 | 1 | - | - |
| Chrysiptera rex | King Demoiselle, Pink Damselfish | F | 0 | 1 | - | - |
| Chrysiptera rollandi | Rolland's Demoiselle, Black Cap | F | 1 | 1 | - | - |
| Chrysiptera springeri | Springer's Demoiselle, Springer's Damselfish, Blue Sapphire Damselfish | F | 1 | 1 | - | - |
| Chrysiptera talboti | Talbot's Demoiselle, Talbot's Damselfish | F | 1 | 1 | - | - |
| Chrysiptera taupou | Southseas Devil | F | 1 | 1 | - | - |
| Chrysiptera unimaculata | Onespot Demoiselle, Onespot Damselfish | F | 0 | 1 | - | - |
| Cichla kelberi | Kelberi Peacock Bass | F | 0 | 1 | - | - |
| Cichlasoma trimaculatum | Three Spot Cichlid, Red Eyed Cichlid, Threespot Cichlid | F | 1 | 1 |  |  |
| Cichlidae | Cichlid | F | 0 | 1 | - | - |
| Ciliopagurus strigatus | Halloween Hermit Crab | 1 | - | 1 | - | - |
| Cirrhilabrus condei | Conde's Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus cyanogularis | Blue-throated Fairy-wrasse, Sailfin Fairy Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus cyanopleura | Blueside Wrasse, Blue-side Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus exquisitus | Exquisite Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus filamentosus | Whip-fin Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus flavidorsalis | Yellowfin Fairy Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus isosceles | Pintail Fairy-wrasse, Splendid Pintail Fairy Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus katherinae | Katherine's Wrasse, Katherine's Fairy Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus lanceolatus | Long-tailed Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus lineatus | Purplelined Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus lubbocki | Lubbock's Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus pylei | Pyle's Wrasse, Blue-margin Fairy-wrasse | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Cirrhilabrus rubeus | Ruby Longfin Fairy Wrasse, Blue and Red Fairy Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus rubrimarginatus | Red-margined Wrasse, Pink Margin Fairy Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus rubripinnis | Redfin Wrasse, Redfin Fairy Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus rubrisquamis | Rosy-scales Fairy Wrasse, Red Velvet Fairy Wrasse | F | 0 | 1 | - | - |
| Cirrhilabrus ryukyuensis | - | F | 0 | 1 | - | - |
| Cirrhilabrus scottorum | Scott's Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus solorensis | Red-eye Wrasse | F | 1 | 1 | - | - |
| Cirrhilabrus temminckii | Threadfin Wrasse, Peacock Wrasse, Blue-stripe Flasher, Japanese Rainbow Wrasse, Temminck's Fairy Wrasse | F | 1 | 1 | - | - |
| Cirrhitops fasciatus | Redbarred Hawkfish, Ringed Hawkfish | F | 1 | 1 | - | - |
| Cirrhitichthys aprinus | Spotted Hawkfish | F | 1 | 1 | - | - |
| Cirrhitichthys falco | Dwarf Hawkfish | F | 1 | 1 | - | - |
| Cirrhitichthys sp. | - | F | - | 1 | - | - |
| Clibanarius digueti | Red Leg Hermit | I | - | 1 | - | - |
| Condylactis gigantea | Giant Caribbean Anemone, Giant Sea Anemone | , | - | 1 | - | - |
| Condylactis sp. | Anemone | 1 | - | 1 | - | - |
| Congochromis sabinae | Cichlid | F | 0 | 1 | - | - |
| Copadichromis borleyi | Haplochromis Borleyi Redfin | F | 1 | 1 |  | - |
| Cordyline fruticosa | Broadleaf Palm-lily, Good-luck-plant, Palm-lily, Ti, Tiplant, Tree-of-kings | P | - | 1 | 1 | - |
| Cordyline sp. | Cordyline | P | - | 1 | 1 | - |
| Coris aygula | Clown Coris, Clown Wrasse, False Clownwrasse, Humphead Wrasse, Hump-headed Wrasse, RedBlotched Rainbowfish, Twin Spot Wrasse | F | 1 | 1 | - | - |
| Coris gaimard | African Coris, Yellowtail Coris, Clown Wrasse | F | 1 | 1 | - | - |
| Corydoras adolfoi | Adolf's Catfish | F | 1 | 1 | - | - |
| Corydoras aeneus | Bronze Corydoras, Bronze Catfish, Lightspot Corydoras, Wavy Catfish | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Corydoras agassizii | Agassiz's Cory | F | 1 | 1 | 1 | - |
| Corydoras arcuatus | Skunk Corydoras, Arched Corydoras, Skunk Catfish | F | 1 | 1 | 1 | - |
| Corydoras brevirostris | Spotted Corydoras | F | 0 | 1 | 1 | - |
| Corydoras elegans | Elegant Corydoras, Elegant Catfish | F | 1 | 1 | 1 | - |
| Corydoras melini | Bandit Corydoras, False Bandit Catfish | F | 1 | 1 | - | - |
| Corydoras paleatus | Peppered Corydoras, Blue Leopard Corydoras, Mottled Corydoras, Peppered Catfish | F | 1 | 1 | 1 | - |
| Corydoras pantanalensis | Pantana Corydoras | F | 0 | 1 | - | - |
| Corydoras punctatus | Spotfin Corydoras, Spotted Corydoras | F | 1 | 1 | 1 | - |
| Corydoras pygmaeus | Pygmy Corydoras, Pygmy Catfish | F | 1 | 1 | 1 | - |
| Corydoras robineae | Bannertail Catfish, Flagtail Catfish | F | 0 | 1 | - | - |
| Corydoras sarareensis | Corydoras | F | 0 | 1 | - | - |
| Corydoras schwartzi | Schwartz's Catfish | F | 1 | 1 | 1 | - |
| Corydoras septentrionalis | Dusky Corydoras | F | 0 | 1 | 1 | - |
| Corydoras sodalis | False Network Catfish | F | 0 | 1 | - | - |
| Corydoras sp. | Corydoras, catfish | F | - | 1 | 1 | - |
| Corydoras splendens | Emerald Catfish, Emerald Brochis, Green Catfish, Shortbody Catfish | F | 0 | 1 | - | - |
| Corydoras sterbai | Corydoras | F | 1 | 1 | 1 | - |
| Corydoras tukano | Corydoras | F | 0 | 1 | - | - |
| Corythoichthys intestinalis | Scribbled Pipefish, Dragonface Pipefish | F | 1 | 1 | - | - |
| Crassostrea gigas | Giant Cupped Oyster, Pacific Oyster, Japanese Oyster, Japanese Pacific Oyster, Oyster, Pacific Giant Oyster | 1 | - | - | - | 1 |
| Crassostrea virginica | American Cupped Oyster, Eastern Cupped Oyster, Eastern Oyster, American Oyster, Common Atlantic Oyster, Cove Oyster | 1 | - | - | - | 1 |
| Crinum calamistratum |  | P | - | 1 | 1 | - |
| Cromileptes altivelis | Humpback Grouper, Panther Grouper | F | 1 | 1 | - | - |
| Crossocheilus latius | Stone Roller | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Crossocheilus oblongus | Siamese Flying Fox, Gray Flying Fox, Siamese Algae Eater | F | 0 | 1 | 1 | - |
| Cryptocentrus caeruleomaculatus | Blue-speckled Prawn-goby | F | 0 | 1 | - | - |
| Cryptocentrus cinctus | Yellow Prawn-goby, Yellow Watchman Prawn, Yellow Shrimp Goby | F | 1 | 1 | - | - |
| Cryptocentrus fasciatus | Y-bar Shrimp Goby | F | 1 | 1 | - | - |
| Cryptocentrus leptocephalus | Pink-speckled Shrimpgoby | F | 1 | 1 | - | - |
| Cryptocoryne crispatula | Balansae Plant | P | - | 1 | 1 | - |
| Cryptocoryne pontederiifolia | - | P | - | 1 | 1 | - |
| Cryptocoryne spiralis | Crypt Spiralis | P | - | 1 | 1 | - |
| Cryptocoryne usteriana | Crypt Usteriana | P | - | 1 | 1 | - |
| Cryptocoryne wendtii | Wendt's Water Trumpet, Wendt's Watertrumpet | P | - | 1 | 1 | - |
| Ctenochaetus binotatus | Twospot Surgeonfish | F | 1 | 1 | - | - |
| Ctenochaetus striatus | Striated Surgeonfish | F | 1 | 1 | - | - |
| Ctenochaetus strigosus | Spotted Surgeonfish, Striated Surgeonfish, Bristletoothed Surgeonfish, Goldring Surgeonfish, Yelloweye Surgeonfish, Kole Yellow Eye Tang | F | 1 | 1 | - | - |
| Ctenochaetus tominiensis | Tomini Surgeonfish | F | 1 | 1 | - | - |
| Ctenochaetus truncatus | Indian Gold-ring Bristle-tooth | F | 0 | 1 | - | - |
| Ctenogobiops tangaroai | Tangaroa Shrimpgoby | F | 1 | 1 | - | - |
| Cyclichthys orbicularis | Birdbeak Burrish | F | 0 | 1 | - | - |
| Cyphotilapia frontosa | Humphead Cichlid | F | 1 | 1 | 1 | - |
| Cyprinidae | Barb | F | - | 1 | - | - |
| Cyprinidae | Rasbora | F | - | 1 | - | - |
| Cypriniformes | Loach | F | - | 1 | - | - |
| Cyprinocirrhites polyactis | Swallowtail Hawkfish | F | 1 | 1 | - | - |
| Cyprinus carpio | Common Carp | F | 1,3 | - | - | 1 |
| Cyprinus carpio | Koi, Koi Carp | F | 1,3 | 1 | 1 | - |
| Cyrtocara moorii | Hump-head | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Danio albolineatus | Pearl Danio, Gold Danio, Golden Danio, Spotted Danio | F | 1 | 1 | 1 | - |
| Danio choprae | Glowlight Danio | F | 1,2 | 1 | - | - |
| Danio erythromicron | Emerald Dwarf Rasbora | F | 0 | 1 | - | - |
| Danio margaritatus | Galaxy Rasbora, Celestial Pearl Danio, Celestichthys Pearl Danio | F | 0 | 1 | - | - |
| Danio rerio | Zebra Danio, Leopard Danio, Rerio, Striped Danio, Zebra, Zebrafish | F | 1,2 | 1 | 1 | - |
| Danio sp. | Danio | F | - | 1 | - | - |
| Dascyllus aruanus | Whitetail Dascyllus, Banded Humbug, Black and White Damselfish, Humbug Damselfish, Threestripe Damselfish, White-tailed Damselfish | F | 1 | 1 | - | - |
| Dascyllus melanurus | Blacktail Humbug, Fourstripe Damselfish | F | 1 | 1 | - | - |
| Dascyllus reticulatus | Reticulate Dascyllus, Two-stripe Damselfish | F | 1 | 1 | - | - |
| Dascyllus trimaculatus | Threespot Dascyllus, Domino Damselfish, Threespot Damselfish, Whitespot Humbug | F | 1 | 1 | - | - |
| Dasyatis pastinaca | Common Stingray | F | 0 | 1 | - | - |
| Dawkinsia filamentosa | Blackspot Barb, Featherfin Barb, Filament Barb, Longfin Barb, Mahecola | F | 0 | 1 | - | - |
| Decapoda | Cleaner shrimp | 1 | - | 1 | - | - |
| Decapoda | Crab | 1 | - | - | - | 1 |
| Decapoda | Crawfish | 1 | - | - | - | 1 |
| Decapoda | Lobster | 1 | - | - | - | 1 |
| Decapoda | Shrimp | 1 | - | 1 | 1 | - |
| Decapodiformes | Squid | 1 | - | - | - | - |
| Dekeyseria pulchra | Pretty Pleco | F | 1 | 1 | 1 | - |
| Dendrochirus biocellatus | Twospot Turkeyfish, Ocellated Lionfish, Twinspot Lionfish | F | 1 | 1 | - | - |
| Dendrochirus brachypterus | Dwarf Lionfish, Shortfin Turkeyfish, Featherfish, Shortfin Lionfish, Shortspined Butterfly-cod, Zebra Firefish, Fuzzy Dwarf Lionfish | F | 1 | 1 | - | - |
| Dendrochirus zebra | Zebra Turkeyfish, Zebra Lionfish, Dwarf Lionfish | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Desmopuntius pentazona | Fiveband Barb, Belted Barb, Sixband Barb, Tiger Barb | F | 0 | 1 | - | - |
| Devario aequipinnatus | Giant Danio | F | 1 | 1 | 1 | - |
| Diadema setosum | Porcupine Sea Urchin, Black Longspine Urchin, Long-spined Urchin | 1 | - | 1 | - | - |
| Dicrossus filamentosus | Chessboard Cichlid, Checkerboard Lyretail, Lyrefinned Checkerboard Cichlid | F | 0 | 1 | - | - |
| Didiplis diandra | Waterpurslane, Water Hedge | P | - | 1 | 1 | - |
| Dimidiochromis compressiceps | Malawi Eyebiter | F | 1 | 1 | - | - |
| Diodon holocanthus | Longspined Porcupinefish, Black-blotched <br> Porcupinefish, Long-spine Porcupinefish, Spotted <br> Porcupinefish, Balloonfish | F | 1 | 1 | - | - |
| Diodon hystrix | Spot-fin Porcupinefish, Spotted Porcupinefish, Porcupinefish | F | 1 | 1 | - | - |
| Dolabella auricularia | Shoulderblade Sea Cat, Blunt-end Sea Hare, Eared Sea Hare | 1 | - | 1 | - | - |
| Domecia acanthophora | Elkhorn Coral crab, Acanthophora Elkhorn Coral Crab | 1 | - | 1 | - | - |
| Dormitator latifrons | Pacific Fat Sleeper | F | 1 | - | - | 1 |
| Doryrhamphus excisus excisus | Bluestripe Pipefish | F | 1 | 1 | - | - |
| Doryrhamphus janssi | Janss' Pipefish | F | 0 | 1 | - | - |
| Dunckerocampus dactyliophorus | Ringed Pipefish | F | 0 | 1 | - | - |
| Dunckerocampus multiannulatus | Many-banded Pipefish | F | 0 | 1 | - | - |
| Echeneis naucrates | Live Sharksucker, Slender Sharksuker | F | 1 | 1 | - | - |
| Echidna catenata | Chain Moray | F | 1 | 1 | - | - |
| Echidna nebulosa | Starry Moray, Snowflake Moray, White Moray | F | 1 | 1 | - | - |
| Echinodorus sp. | St. Elmo's Fire | P | - | 1 | 1 | - |
| Echinodorus paniculatus | Amazon Swordplant | P | - | 1 | 1 | - |
| Echinodorus peruensis | Amazon Red Leaf | P | - | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Echinodorus sp. | Frans Stoffels | P | - | 1 | 1 | - |
| Echinodorussp. | Sword Kleiner Prinz Pot | P | - | 1 | 1 | - |
| Echinoidea | Sea urchin | 1 | - | 1 | - | 1 |
| Echinometra sp. | Sea urchin | 1 | - | 1 | - | - |
| Ecsenius bicolor | Bicolor Blenny, Bicolor Coralblenny, Two-colored Benny | F | 1 | 1 | - | - |
| Ecsenius bimaculatus | Twinspot Coralblenny, Two Spot Bimaculatus Blenny | F | 1 | 1 | - | - |
| Ecsenius lineatus | Linear Blenny, Dot Dash Blenny, Lined Combtooth Blenny | F | 1 | 1 | - | - |
| Ecsenius midas | Persian Blenny, Midas Coralblenny | F | 1 | 1 | - | - |
| Ecsenius namiyei | Black Comb-tooth, Namiye's Coralblenny | F | 1 | 1 | - | - |
| Ecsenius stigmatura | Tailspot Coralblenny | F | 1 | 1 | - | - |
| Eigenmannia virescens | Glass Knifefish, Glass Knife Fish, Green Knifefish | F | 1 | 1 | 1 | - |
| Elacatinus figaro | Barber Goby | F | 0 | 1 | - | - |
| Elacatinus oceanops | Neon Goby | F | 0 | 1 | - | - |
| Eleocharis parvula | Dwarf Hairgrass, Dwarf Spike-rush, Dwarf spikerush, Dwarf Spikesedge, Little-head SpikeRush, Little-head Spikerush | P | - | 1 | - | - |
| Elysia crispata | Lettuce Seaslug, Lettuce Slug, Frilly Sea Slug | 1 | - | 1 | - | - |
| Engina mendicaria | Bumble Bee Snail | 1 | - | 1 | - | - |
| Engina sp. | Snail | 1 | - | 1 | - | - |
| Enoplometopus debelius | Debelius Reef Lobster, Reef Lobster, Violet-spotted Reef Lobster, Purple/Orange Reef Lobster | 1 | - | 1 | - | - |
| Entacmaea quadricolor | Bulb-tentacle Sea Anemone, Bubble-tip Anemone, Bulb Tentacle Anemone | 1 | - | 1 | - | - |
| Epalzeorhynchos bicolor | Redtail Sharkminnow, Red-tailed Labeo, Redtail Shark, Redtailed Black Shark | F | 1 | 1 | 1 | - |
| Epalzeorhynchos frenatus | Rainbow Sharkminnow, Green Fringelip Labeo, Rainbow Shark, Redfin Shark, Whitefin Shark, Whitetail Sharkminnow | F | 1 | 1 | 1 | - |
| Epalzeorhynchos kalopterus | Flying Fox | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Epicystis crucifera | Red Beaded Anemone, Beaded Anemone, Rock Flower Anemone | I | - | 1 | - | - |
| Epinephelinae | Grouper | F | 0 | - | - | 1 |
| Exallias brevis | Leopard Blenny, Leopard Red Sailfin Blenny | F | 1 | 1 | - | - |
| Forcipiger flavissimus | Longnose Butterfly Fish, Longnose Butterflyfish, Long-nosed Butterflyfish, Forceps fish | F | 1 | 1 | - | - |
| Fromia milleporella | Red Starfish | 1 | - | 1 | - | - |
| Fromia monilis | Peppermint Sea Star, Necklace Sea Star | 1 | - | 1 | - | - |
| Fundulopanchax gardneri | Blue Lyretail, Gardner's Killi, Nigerian Killi, SteelBlue Aphyosemion | F | 1 | 1 | 1 | - |
| Fundulus heteroclitus | Mummichog | F | 0 | - | - | - |
| Garra flavatra | Panda Gara | F | 0 | 1 | - | - |
| Garra rufa | Red Garra | F | 0 | 1 | - | - |
| Gastromyzon punctulatus | Hillstream Loach | F | 0 | 1 | - | - |
| Gastropoda | Conch | 1 | - | - | - | 1 |
| Gastropoda | Snail | 1 | - | 1 | 1 | 1 |
| Gastropoda | Whelk | 1 | - | - | - | 1 |
| Genicanthus lamarck | Blackstriped Angelfish, Lamarck's Angelfish | F | 1 | 1 | - | - |
| Genicanthus melanospilos | Spotbreast Angelfish, Swallowtail Angelfish, Blackspot Angelfish | F | 1 | 1 | - | - |
| Genicanthus semifasciatus | Japanese Swallow, Masked Swallowtail Angelfish | F | 1 | 1 | - | - |
| Genicanthus watanabei | Blackedged Angelfish, Watanabe's Angelfish | F | 1 | 1 | - | - |
| Geophagus altifrons | Eartheating Cichlid | F | 1 | 1 | - | - |
| Geophagus brasiliensis | Pearl Cichlid, Pearl Eartheater | F | 1 | 1 | - | - |
| Geophagus winemilleri | Stripetail Cichlid | F | 0 | 1 | - | - |
| Gephyrochromis sp. | Malawi Cichlid | F | 0 | 1 | - | - |
| Glossolepis incisus | Red Rainbowfish, Salmon-red Rainbow Fish | F | 1 | 1 | 1 | - |
| Glossolepis pseudoincisus | Tami River Rainbowfish | F | 0 | 1 | - | - |
| Glossolepis wanamensis | Lake Wanam Rainbowfish | F | 0 | 1 | - | - |
| Gobiodon atrangulatus | - | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gobiodon citrinus | Poison Goby | F | 1 | 1 | - | - |
| Gobiodon histrio | Broad-barred Goby, Green Clown Goby | F | 1 | 1 | - | - |
| Gobiodon okinawae | Okinawa Goby, Yellow Clown Goby | F | 1 | 1 | - | - |
| Gobiodon rivulatus | Rippled Coralgoby | F | 1 | 1 | - | - |
| Gobioides broussonnetii | Violet Goby | F | 1 | 1 | - | - |
| Gomphosus caeruleus | Green Birdmouth Wrasse | F | 1 | 1 | - | - |
| Gramma loreto | Royal Gramma, Fairy Basslet | F | 1 | 1 | - | - |
| Gramma melacara | Blackcap Basslet, Blackcap Gamma | F | 1 | 1 | - | - |
| Gymnocorymbus ternetzi | Black Tetra, Black Widow, Blackamoor, Butterfly Tetra, Petticoat Tetra | F | 1, 3 | 1 | 1 | - |
| Gymnothorax melatremus | Dwarf Moray | F | 0 | 1 | - | - |
| Gymnothorax tile | Indian mud moray | F | 1 | 1 | - | - |
| Gyrinocheilus aymonieri | Siamese Algae Eater, Chinese Algae Eater, Indian Algae Eater, Siamese Headbreather, Sucker Loach, Sucking Loach | F | 1,2, 3 | 1 | 1 | - |
| Haemulon flavolineatum | French Grunt, Open-mouthed Grunt, Yellow Grunt | F | 1 | - | - | - |
| Halichoeres biocellatus | Red-lined Wrasse, Twospot Wrasse | F | 0 | 1 | - | - |
| Halichoeres chloropterus | Pastel-green Wrasse, Green Wrasse | F | 1 | 1 | - | - |
| Halichoeres chrysus | Canary Wrasse, Golden Rainbowfish | F | 1 | 1 | - | - |
| Halichoeres hortulanus | Checkerboard Wrasse | F | 1 | 1 | - | - |
| Halichoeres iridis | Radiant Wrasse | F | 1 | 1 | - | - |
| Halichoeres leucoxanthus | Canarytop Wrasse, Whitebelly Wrasse, Lemon Meringue Wrasse | F | 0 | 1 | - | - |
| Halichoeres melanurus | Tail-spot Wrasse | F | 1 | 1 | - | - |
| Halichoeres ornatissimus | Ornamented Wrasse | F | 1 | 1 | - | - |
| Halichoeres radiatus | Puddingwife Wrasse, Puddingwife | F | 0 | 1 | - | - |
| Halichoeres sp. | Red X-mas Checkerboard Wrasse | F | - | 1 | - | - |
| Halichoeres zeylonicus | Goldstripe Wrasse, Ceylon Wrasse | F | 0 | 1 | - | - |
| Haliotis rufescens | Red Abalone | I | - | - | - | 1 |
| Haliotis sp. | Abalone | I | - | - | - | 1 |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Haludaria fasciata | Melon Barb | F | 0 | 1 | - | - |
| Haplochromis sp. | Cichlid | F |  | 1 | 1 | - |
| Hasemania nana | Silvertip Retra, Silver-tipped Retra | F | 1 | 1 | 1 | - |
| Helostoma temminkii | Kissing Gourami, Green Kisser, Pink Kisser | F | 1,3 | 1 | 1 | - |
| Hemigrammus bleheri | Firehead Tetra, Brilliant Rummynose Tetra, Rednose Tetra, Rummy-nose Tetra | F | 1,2 | 1 | 1 | - |
| Hemigrammus erythrozonus | Glowlight Tetra, Fire Neon, Glo-lite Tetra | F | 1,2,3 | 1 | 1 | - |
| Hemigrammus filamentosus | Phoenix Tetra | F | 0 | 1 | - | - |
| Hemigrammus pulcher | Garnet Tetra, Black Wedge Tetra, Pretty Tetra | F | 1 | 1 | - | - |
| Hemigrammus rhodostomus | Rummy-nose Tetra, Rednose Tetra, Rednosed Tetra | F | 1 | 1 | 1 | - |
| Hemitaurichthys polylepis | Pyramid Butterflyfish, Brushytoothed Butterflyfish, Shy Butterflyfish | F | 1 | 1 | - | - |
| Hemitaurichthys zoster | Brown-and-white Butterflyfish, Zoster Butterflyfish, Black Pyramid Butterflyfish | F | 1 | 1 | - | - |
| Heniochus acuminatus | Pennant Coralfish, Longfin Bannerfish, Featherfin Coralfish, Wimple Fish, Heniochus Black and White Butterflyfish | F | 1 | 1 | - | - |
| Heniochus chrysostomus | Threeband Pennantfish, Threeband Pennant Butterflyfish, Threeband Bannerfish, Pennant Bannerfish | F | 1 | 1 | - | - |
| Heniochus monoceros | Masked Bannerfish | F | 1 | 1 | - | - |
| Heniochus singularius | Singular Bannerfish | F | 1 | 1 | - | - |
| Heniochus varius | Horned Bannerfish, Horned Bull-fish, Humphead Bannerfish, HunchbackedBbullfish, Hunchbacked Coralfish | F | 1 | 1 | - | - |
| Herichthys cyanoguttatus | Rio Grande Cichlid, Rio Grande Perch, Texas Cichlid | F | 1 | 1 | 1 | - |
| Heros efasciatus | Green Severum Cichlid | F | 0 | 1 | - | - |
| Heros severus | Banded Cichlid, Convict Fish, Deacon, Sedate Cichlid, Severum, Striped Cichlid | F | 1 | 1 | 1 | - |
| Heros severus x Amphilophus labiatus | Blood Parrot Cichlid | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Herotilapia multispinosa | Rainbow Cichlid | F | 1 | 1 | - | - |
| Heteractis aurora | Beaded Sea Anemone, Beaded Sand Anemone | 1 | - | 1 | - | - |
| Heteractis crispa | Leathery Sea Anemone, Sebae Anemone, Actinarians | 1 | - | 1 | - | - |
| Heteroconger hassi | Spotted Garden-eel | F | 0 | 1 | - | - |
| Hexabranchus morsomus | Sea slug | I | - | - | - | - |
| Holacanthus tricolor | Rock Beauty | F | 1 | 1 | - | - |
| Hologymnosus doliatus | Pastel Ringwrasse, Ringed Wrasse | F | 0 | 1 | - | - |
| Holothuria atra | Lollyfish, Black Sea Cucumber | I | - | 1 | - | - |
| Holothuria edulis | Pinkfish, Pinkfish Sea Cucumber, Red-black | 1 | - | 1 | - | - |
| Holothuria scabra | Sand Fish, Golden Sandfish, Caledonian Sand Bed Sifting | I | - | 1 | - | - |
| Holothuroidea | Sea cucumber | 1 | - | 1 | - | 1 |
| Homarus americanus | American Lobster, Maine Lobster, Northern Lobster | 1 | - | - | - | 1 |
| Homarus sp. | Lobster | 1 | - | - | - | 1 |
| Hoplolatilus starcki | Stark's Tilefish, Starck's Tilefish | F | 1 | 1 | - | - |
| Hydrocotyle leucocephala | Brazilian Pennywort | P | - | 1 | 1 | - |
| Hygrophila corymbosa | Starhorn, Temple Plant | P | - | 1 | 1 | - |
| Hygrophila difformis | Water Wisteria | P | - | 1 | 1 | - |
| Hygrophila sp. | Araguaia | P | - | 1 | 1 | - |
| Hymenocera picta | Harlequin Shrimp | I | - | 1 | - | - |
| Hypancistrus debilittera | Colombian Zebra Pleco | F | 0 | 1 | - | - |
| Hypancistrus furunculus | Yellow Zebra Pleco | F | 0 | 1 | - | - |
| Hypancistrus inspector | Snowball Pleco | F | 1 | 1 | 1 | - |
| Hypancistrus sp. | Pleco | F | - | 1 | - | - |
| Hypancistrus sp. | Queen Arabesque Pleco | F | - | 1 | - | - |
| Hyphessobrycon amandae | Ember Tetra | F | 1 | 1 | - | - |
| Hyphessobrycon anisitsi | Buenos Aires Tetra, Diamond Spot Characin | F | 1 | 1 | - | - |
| Hyphessobrycon columbianus | Tetra | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Hyphessobrycon eques | Jewel Tetra, Blood Characin, Callistus, Callistus Tetra, Serpa Tetra, Serpae Tetra | F | 1,2 | 1 | 1 | - |
| Hyphessobrycon flammeus | Flame Tetra, Red Rio, Red Retra, Tetra Von Rio | F | 1 | 1 | 1 | - |
| Hyphessobrycon heliacus | Kitty Tetra | F | 0 | 1 | - | - |
| Hyphessobrycon herbertaxelrodi | Black Neon Tetra, Black Neon, Black Tetra | F | 1,2,3 | 1 | 1 | - |
| Hyphessobrycon loretoensis | Loreto Tetra | F | 1 | 1 | - | - |
| Hyphessobrycon margitae | Red and Blue Peru Tetra | F | 0 | 1 | - | - |
| Hyphessobrycon megalopterus | Black Phantom Tetra | F | 1 | 1 | 1 | - |
| Hyphessobrycon pulchripinnis | Lemon Tetra | F | 1,2 | 1 | 1 | - |
| Hyphessobrycon rosaceus | Rosy Tetra, Black-flag Tetra | F | 1 | 1 | 1 | - |
| Hyphessobrycon roseus | Yellow Phantom Tetra | F | 1 | 1 | 1 | - |
| Hyphessobrycon sweglesi | Red Phantom Tetra, Swegles's Tetra | F | 1 | 1 | - | - |
| Hypoptopomatinae sp. | Otocinclus Negros | F | 0 | 1 | - | - |
| Hyporthodus flavolimbatus | Yellowedge Grouper | F | 0 | 1 | - | - |
| Hypostomus plecostomus | Suckermouth Catfish, Spotted Pleco | F | 1 | 1 | 1 | - |
| Hypseleotris compressa | Empire Gudgeon | F | 0 | 1 | - | - |
| Ictalurus furcatus | Blue Catfish | F | 1 | - | - | 1 |
| Ictiobus sp. | White Buffalo | F | - | - | - | 1 |
| Inpaichthys kerri | Royal Tetra | F | 1 | 1 | - | - |
| lodotropheus sprengerae | Lavender Mbuna | F | 1 | 1 | - | - |
| Jasus edwardsii | Red Rock Lobster, Southern Rock Lobster, Spiny Rock Lobster | 1 | - | - | - | 1 |
| Jordanella floridae | Flagfish | F | 1 | 1 | - | - |
| Julidochromis regani | Convict Julie | F | 1 | 1 | 1 | - |
| Koumansetta hectori | Hector's Goby | F | 1 | 1 | - | - |
| Koumansetta rainfordi | Old Glory, Court Jester Goby, Rainford's Goby | F | 1 | 1 | - | - |
| Labidochromis caeruleus | Blue Streak Hap | F | 1 | 1 | 1 | - |
| Labidochromis sp. | Malawi Cichlid | F | - | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Labroides dimidiatus | Bluestreak Cleaner Wrasse, Cleaner Wrasse, Common Cleaner Wrasse | F | 1 | 1 | - | - |
| Lactoria cornuta | Longhorn Cowfish, Trunkfish | F | 1 | 1 | - |  |
| Laetacara dorsigera | Redbreast Acara, Redbreast Acquidens, Smiling Acara, Yellowlip Acara | F | 1 | 1 | - | - |
| Lates calcarifer | Barramundi, Giant Seaperch, Japanese Seabass, Asian Seabass, Barramundi Perch, Giant Perch, Palmer, Silver Barramundi | F | 1 | - | - | 1 |
| Leporacanthicus galaxias |  | F | 0 | 1 | - | - |
| Leporacanthicus triactis | Three Beacon Pleco | F | 0 | 1 | - | - |
| Leporinus fasciatus | Banded Leporinus, Black-banded Leporinus | F | 1 | 1 | - | - |
| Leptochilus pteropus | Java Fern | P | - | 1 | 1 | - |
| Linckia laevigata | Blue Linckia, Blue Sea Star, Blue Linckia Sea Star | I | - | 1 | - | - |
| Lithodes aequispinus | Golden King Crab, Golden King Crab, Brown King Crab | 1 | - | - | - | 1 |
| Litopenaeus vannamei | Whiteleg Shrimp, Pacific White Shrimp | 1 | - | - | - | 1 |
| Loricariidae | Plecostomus | F | - | 1 | - | - |
| Ludwigia glandulosa | Cylindricfruit Primrose-willow, Ludwigia Peruensis | P | - | 1 | 1 | - |
| Ludwigia inclinata | Ludwigia Cuban | P | - | 1 | 1 | - |
| Ludwigia mullertii | - | P | - | 1 | 1 | - |
| Ludwigia repens | Creeping Primrose-willow, Broad Leaf Ludwigia | P | - | 1 | 1 | - |
| Lutjanus sebae | Emperor Red Snapper, Red Emperor Snapper, Emperor Snapper | F | 1 | 1 | - | - |
| Lutjanus viridis | Blue and Gold Snapper | F | 0 | 1 | - | - |
| Lutraria lutraria | Mud-dwelling Mactra, European Otter Clam? | 1 | - | - | - | 1 |
| Lysmata amboinensis | Scarlet Cleaner Shrimp, Skunk Cleaner Shrimp | 1 | - | 1 | - | - |
| Lysmata debelius | Blood Red Fire Shrimp, Blood Shrimp, Fire Shrimp, Scarlet Cleaner Shrimp | I | - | 1 | - | - |
| Lysmata grabhami | Cleaner Shrimp, White-striped Cleaner Shrimp, Redbacked Cleaner Shrimp, Scarlet-striped Cleaner Shrimp | 1 | - | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- | LF


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mercenaria mercenaria | Northern Quahog, Bay Quahog, Hardshell Clam, Cherrystone, Chowder Clam, Forma Notata Northern Quahog, Hard Clam, Littleneck, Pumpkin, Quahog, Topneck | 1 |  | - | - | 1 |
| Mesocentrotus franciscanus | Red Sea Urchin | 1 | - | 1 | - | - |
| Mespilia globulus | Globular Sea Urchin, Blue Tuxedo Urchin | 1 | - | 1 | - | - |
| Metynnis fasciatus | Striped Silver Dollar | F | 0 |  | - | - |
| Micracanthicus vandragti | Pleco | F | 0 | 1 | - | - |
| Microctenopoma ansorgii | Ornate Ctenopoma, Orange Ctenopoma, Ornate Climbing Perch, Pretty Ctenopoma, Rainbow Ctenopoma | F | 0 | 1 | - | - |
| Microdevario kubotai | Neon Green Rasbora | F | 0 | 1 | - | - |
| Micropterus salmoides | Largemouth Black Bass, Bass, Black Bass, Green Bass, Largemouth, Largemouth Bass, Northern Largemouth Bass, Green Trout | F | 1 | - | - | 1 |
| Mikrogeophagus altispinosus | Bolivian Ram Cichlid | F | 1 | 1 | 1 | - |
| Mikrogeophagus ramirezi | Ram Cichlid, Butterfly Cichlid, Dwarf Cichlid, Ram | F | 1 | 1 | 1 | - |
| Mimagoniates microlepis | Blue Tetra | F | 0 | 1 | - | - |
| Misgurnus anguillicaudatus | Pond Loach, Chinese Muddy Loach, Japanese Weatherfish, Oriental Weatherfish | F | 1 | 1 | 1 | - |
| Mithraculus sculptus | Green Clinging Crab, Spider Crab, Emerald Crab | 1 | - | 1 | - | - |
| Moenkhausia oligolepis | Glass Tetra, Redeye Tetra | F | 1 | 1 | 1 | - |
| Moenkhausia pittieri | Diamond Tetra, Diamond Characin, Pittier's Tetra | F | 1 | 1 | 1 | - |
| Moenkhausia sanctaefilomenae | Redeye Tetra, Red-eye Tetra, Yellow-banded Moenkhausia, Yellowhead Characin | F | 1, 3 | 1 | 1 | - |
| Moenkhausia sp. | Tetra | F | - | 1 | - | - |
| Monodactylus argenteus | Silver Moony, Silver Moonfish, Diamond Moonfish, Diamondfish, Fingerfish, Kitefish, Natal Moonie, Sea Kite, Silver and Black Butterflyfish, Silver Batfish, Silver Mono, Singapore Angelfish | F | 1 | 1 | - | - |
| Morone saxatilis | Striped Bass, Rockfish, Striped Sea-bass, Linesider, Roccus, Rock | F | 1 | - | - | 1 |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mugil cephalus | Flathead Grey Mullet, Black Mullet, Callifaver Mullet, Common Mullet, Grey Mullet, Striped Mullet | F | 0 | - | - | 1 |
| Mulloidichthys martinicus | Yellow Goatfish, Chope, King Mullet, Salmonete Amarillo | F | 0 | 1 | - | - |
| Mytilus galloprovincialis | Mediterranean Mussel, Mediterranean Blue Mussel, Bay Mussel | I | - | - | - | 1 |
| Nannostomus beckfordi | Golden Pencilfish, Anomalous Pencilfish, Aripiranga Pencilfish, Beckford's Pencil Fish, Brown Pencilfish | F | 1 | 1 | 1 | - |
| Nannostomus marginatus | Dwarf Pencilfish | F | 0 | 1 | - | - |
| Nardoa tuberculata | Yellow Spotted Nardoa | F | 0 | 1 | - | - |
| Naso brevirostris | Spotted Unicornfish, Brown Unicornfish, Shortnose Unicornfish, Shortsnout Unicornfish | F | 1 | 1 | - | - |
| Naso elegans | Elegant Unicornfish, Orangespine Unicornfish, Blonde Naso Tang | F | 1 | 1 | - | - |
| Naso lituratus | Orangespine Unicornfish, Barcheek Unicornfish, Masked Unicornfish, Orange-spine Unicornfish, Redlip Surgeonfish, Striped Unicornfish, Naso Tang | F | 1 | 1 | - | - |
| Naso unicornis | Bluespine Unicornfish, Short-nose Unicornfish, Unicorn Tang | F | 1 | 1 | - | - |
| Naso vlamingii | Bignose Unicornfish, Scibbled Unicornfish, Vlaming's Unicornfish, Zebra Unicornfish | F | 1 | 1 | - | - |
| Nassarius distortus | Necklace Nassa, Distorted Nassa | 1 | - | 1 | - | - |
| Nassarius sp. | Snail | 1 | - | 1 | - | - |
| Nemateleotris decora | Elegant Firefish, Purple Firefish | F | 1 | 1 | - | - |
| Nemateleotris exquisita | Exquisite Firefish | F | 0 | 1 | - | - |
| Nemateleotris helfrichi | Helfrichs' Dartfish | F | 0 | 1 | - | - |
| Nemateleotris magnifica | Fire Goby | F | 1 | 1 | - | - |
| Nematobrycon lacortei | Rainbow Tetra | F | 1 | 1 | 1 | - |
| Nematobrycon palmeri | Emperor Tetra, Rainbow Tetra | F | 1 | 1 | 1 | - |
| Neocaridina davidi | Cherry Shrimp | 1 | - | 1 | - | - |
| Neocirrhites armatus | Flame Hawkfish, Brilliant Red Hawkfish, Red Hawkfish | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Neoglyphidodon oxyodon | Bluestreak Damselfish, Javanese Damselfish, Bluebanded Damselfish, Bluevelvet Damselfish | F | 1 | 1 | - | - |
| Neolamprologus brichardi | Lyretail Cichlid | F | 1 | 1 | 1 | - |
| Neolamprologus leleupi | Lemon Cichlid | F | 1 | 1 | 1 | - |
| Neopetrolisthes maculatus | Small-dot Anemone Crab, Anemone Crab, Porcelain Anemone Crab, Porcelain Crab, Spotted Porcelain Crab | 1 | - | 1 | - | - |
| Neosynchiropus ocellatus | Ocellated Dragonet, Scooter Blenny | F | 0 | 1 | - | - |
| Nerita sp. | Snail | I | - | 1 | - | - |
| Neritina turrita | Turreted Nerite, Tiger Nerite Snail | 1 | - | 1 | 1 | - |
| Neritina waigiensis | Red Netrite Snail | 1 | - | 1 | - | - |
| Neritina zebra | Nerita Snail | 1 | - | 1 | - | - |
| Nothobranchius guentheri | Redtail Notho | F | 1 | 1 | - | - |
| Novaculichthys taeniourus | Rockmover Wrasse, Dragon Wrasse | F | 1 | 1 | - | - |
| Octopus bimaculoides | Lesser Twospotted Octopus, California Two-spot Octopus | 1 | - | 1 | - | - |
| Octopus vulgaris | Common Octopus, Common Atlantic Octopus | 1 | - | 1 | - | - |
| Odontodactylus scyllarus | Reef Odontodactylid Mantis Shrimp, Mantis Shrimp, Peacock Mantis Shrimp | 1 | - | 1 | - | 1 |
| Odonus niger | Red-toothed Triggerfish, Redtoothed Triggerfish, Niger Triggerfish | F | 1 | 1 | - | - |
| Oncorhynchus mykiss | Rainbow Trout, Baiser, Coast Rainbow Trout, Kamloops Trout, Lord-fish, Silver Trout, Steelhead, Steelhead Trout, Coast Range Trout, Hardhead, Kamloops, Redband, Salmon Trout | F | 1 | - | - | 1 |
| Ophiocoma sp. | Brittle Star | 1 | - | 1 | - | - |
| Ophiopogon japonicus | Dwarf Lilyturf, Mondo-grass, Ophiopogon, Snake'sbeard | P | - | 1 | 1 | - |
| Opistognathus aurifrons | Yellowhead Jawfish | F | 1 | 1 | - | - |
| Opistognathus macrognathus | Banded Jawfish | F | 1 | 1 | - | - |
| Opistognathus randalli | Gold-specs Jawfish, Black Cap Jawfish | F | 0 | 1 | - | - |
| Opistognathus robinsi | Spotfin Jawfish | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Oreochromis mossambicus | Mozambique Tilapia, Mozambique Cichlid, Redbelly Tilapia, Java Tilapia, Largemouth Kurper, Mozambique Mouthbrooder | F | 0 | - | - | 1 |
| Oreochromis niloticus | Nile Tilapia, Mozambique Tilapia | F | 1 | - | - | 1 |
| Oryzias latipes | Japanese Rice fish, Japanese Medaka, Rice Fish, Ricefish | F | 0 | 1 | - | - |
| Oryzias woworae | Daisy's Ricefish | F | 0 | 1 | - | - |
| Osphronemidae | Gourami | F | - | 1 | - | - |
| Osteoglossidae | Arowana | F | - | 1 | - | - |
| Osteoglossum bicirrhosum | Arawana, Aruana, Silver Aruana | F | 1 | 1 | 1 | - |
| Ostorhinchus cyanosoma | Yellowstriped Cardinalfish | F | 0 | 1 | - | - |
| Ostracion cubicus | Yellow Boxfish | F | 1 | 1 | - | - |
| Ostracion meleagris | Whitespotted Boxfish, Moa | F | 1 | 1 | - | - |
| Ostracion solorensis | Reticulate Boxfish | F | 0 | 1 | - | - |
| Otocinclus sp. | Otocinclus Catfish | F | - | 1 | - | - |
| Otocinclus affinis | Golden Otocinclus, Dwarf Sucking Catfish, Midget Sucker Fish | F | 1,2 | 1 | 1 | - |
| Otocinclus macrospilus | Dwarf Oto | F | 0 | 1 | - | - |
| Otocinclus vittatus | Otocinclus Catfish | F | 1 | 1 | - | - |
| Oxycirrhites typus | Longnose Hawkfish | F | 1 | 1 | - | - |
| Oxyeleotris marmorata | Marble Goby, Marbled Sleeper | F | 1 | - | - | 1 |
| Paguristes cadenati | Red Reef Hermit, Red Reef Hermit Crab | I | - | 1 | - | - |
| Paguroidea | Hermit crab | 1 | - | 1 | - | - |
| Palaemonetes sp. | Caridean Shrimp | I | - | 1 | - | - |
| Pampus argenteus | Silver Pomfret | F | 0 | - | - | 1 |
| Panaqolus albomaculatus | Mustard Spot Pleco | F | 0 | 1 | - | - |
| Panaqolus changae | Armoured catfish | F | 0 | 1 | - | - |
| Panaqolus maccus | Clown Panaque | F | 0 | 1 | - | - |
| Panaqolus sp. | Armoured catfish | F | - | 1 | - | - |
| Panaque cochliodon | Armoured catfish | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Paralichthys olivaceus | Bastard Halibut, False Halibut, Olive Flounder | F | 0 | - | - | 1 |
| Paralithodes camtschaticus | Red King Crab, King Crab | 1 | - | - | - | 1 |
| Parapercis punctulata | Spotted Sandperch | F | 1 | 1 | - | - |
| Parapercis schauinslandii | Redspotted Sandperch, Lyretail Grubfish, Flagfin Weever | F | 1 | 1 | - | - |
| Parupeneus barberinoides | Bicolor Goatfish | F | 1 | 1 | - | - |
| Parupeneus barberinus | Dash-and-dot Goatfish, Dot-dash Goatfish, Dashdot Goatfish, Yellow Back Goatfish | F | 0 | 1 | - | - |
| Parupeneus cyclostomus | Gold-saddle Goatfish, Yellowsaddle Goatfish | F | 1 | 1 | - | - |
| Parupeneus multifasciatus | Manybar Goatfish | F | 0 | 1 | - | - |
| Pecten maximus | Great Atlantic Scallop, European Sea Scallop, King Scallop | 1 | - | - | - | 1 |
| Pectinoidea | Scallop | 1 | - | - | - | 1 |
| Pelvicachromis pulcher | Rainbow Krib, Common Krib, Kribensis, Pink Krib, Purple Cichlid, Rainbow Cichlid | F | 1 | 1 | 1 | - |
| Perca flavescens | American Yellow Perch, American Perch, Lake Perch, Perch, Yellow Perch, European Perch | F | 0 | - | - | - |
| Percnon gibbesi | Nimble Spray Crab, Sally Lightfoot Crab | 1 | - | 1 | - | - |
| Periclimenes brevicarpalis | Glass Anemone Shrimp, Anemone Shrimp, Pacific Clown Anemone Shrimp, White Patched Anemone Shrimp | 1 | - | 1 | - | - |
| Periophthalmus barbarus | Atlantic Mudskipper | F | 1 | - | - | - |
| Pervagor janthinosoma | Blackbar Filefish | F | 1 | 1 | - | - |
| Pervagor melanocephalus | Redtail Filefish | F | 1 | 1 | - | - |
| Pethia conchonius | Rosy Barb | F | 0 | 1 | 1 | - |
| Pethia nigrofasciata | Black Ruby Barb, Black-ruby Barb, Purple-headed Barb, Purplehead Barb | F | 0 | 1 | 1 | - |
| Pethia padamya | Odessa Barb | F | 0 | 1 | - | - |
| Pethia ticto | Ticto Barb, Firefin Barb, Tic-tac-toe Barb, Twospot Barb | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Petromyzon marinus | Sea Lamprey, Lake Lamprey, Eel Sucker, Green Lamprey, Lamper, Lamprey Eel, Nine Eyes, Shad Lamprey, Spotted Lamprey, Sucker | F | 0 | - | - | - |
| Phenacogrammus interruptus | Congo Tetra | F | 1 | 1 | 1 | - |
| Pholidichthys leucotaenia | Convict Blenny, Engineer Goby | F | 1 | 1 | - | - |
| Phyllorhiza punctata | Australian Spotted Jellyfish, Spotted Jellyfish | 1 | - | - | - | - |
| Plectorhinchus lineatus | Yellowbanded Sweetlips | F | 1 | 1 | - | - |
| Plectropomus laevis | Blacksaddled Coralgrouper | F | 1 | 1 | - | - |
| Pictichromis paccagnellae | Royal Dottyback | F | 0 | 1 | - | - |
| Pictichromis porphyrea | Magenta Dottyback | F | 0 | 1 | - | - |
| Pimelodus pictus | Pictus Cat | F | 1 | 1 | - | - |
| Pimephales promelas | Fathead Minnow, Black-head Minnow, Rosey Reds | F | 1 | 1 | 1 | - |
| Placopecten magellanicus | Deep Sea Scallop, American Sea Scallop, Sea Scallop, Atlantic Deep Sea Scallop, Atlantic Sea Scallop, North Atlantic Sea Scallop | 1 | - | - | - | 1 |
| Platax orbicularis | Orbicular Batfish, Dusky Batfish, Narrowbanded Batfish, Orbiculate Batfish, Sicklefish | F | 1 | 1 | - | - |
| Platax pinnatus | Dusky Batfish, Long-finned Batfish, Longfin Batfish | F | 1 | 1 | - | - |
| Platax teira | Longfin Batfish, Orbicular Batfish, Tiera Batfish, Roundface Batfish | F | 1 | 1 | - | - |
| Plectorhinchus chaetodonoides | Harlequin Sweetlips | F | 1 | 1 | - | - |
| Plectranthias inermis | Chequered Perchlet | F | 1 | 1 | - | - |
| Plectranthias nanus | Bownband Perchlet | F | 0 | 1 | - | - |
| Plectropomus leopardus | Leopard Coralgrouper, Spotted Coralgrouper | F | 1 | - | - | 1 |
| Plotosus lineatus | Striped Eel Catfish | F | 0 | 1 | - | - |
| Poecilia latipinna | Sailfin Molly | F | 1,3 | 1 | 1 | - |
| Poecilia reticulata | Guppy | F | 1,2,3 | 1 | 1 | - |
| Poecilia sp. | Molly | F | - | 1 | 1 | - |
| Poecilia sphenops | Molly, Mexican Molly | F | 1,2,3 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Poecilia velifera | Sail-fin Molly, Giant Sailfin Molly, Sailfin Molly, Yucatan Molly | F | 1 | 1 | 1 | - |
| Poecilia wingei | Endler's Livebearer | F | 0 | 1 | - | - |
| Pogostemon stellatus | - | P | - | 1 | 1 | - |
| Polychaeta | Polychaete worm | 1 | - | 1 | - | - |
| Polypterus delhezi | Barred Bichir | F | 0 | 1 | - | - |
| Polypterus endlicherii | Saddled Bichir | F | 0 | 1 | - | - |
| Polypterus ornatipinnis | Ornate Bichir | F | 1 | 1 | - | - |
| Polypterus senegalus | Gray Bichir | F | 1 | 1 | 1 | - |
| Polypterus sp. | Bichir | F | - | 1 | - | - |
| Pomacanthidae | Angels | F | - | 1 | - | - |
| Pomacentrus alleni | Andaman damsel | F | 1 | 1 | - | - |
| Pomacentrus coelestis | Neon Damselfish | F | 1 | 1 | - | - |
| Pomacanthus imperator | Emperor Angelfish, Imperial Angelfish | F | 1 | 1 | - | - |
| Pomacanthus navarchus | Bluegirdled Angelfish, Majestic Angelfish | F | 1 | 1 | - | - |
| Pomacanthus paru | French Angelfish, Angelfish | F | 1 | 1 | - | - |
| Pomacanthus semicirculatus | Semicircle Angelfish, Koran Angelfish | F | 1 | 1 | - | - |
| Pomacanthus sexstriatus | Sixbar Angelfish, Sixband Angelfish | F | 1 | 1 | - | - |
| Pomacentrus sulfureus | Sulphur Damsel | F | 1 | 1 | - | - |
| Pomacanthus xanthometopon | Yellowface Angelfish, Bluefaced Angelfish, Blueface Angelfish | F | 1 | 1 | - | - |
| Pomacea bridgesii | Spike-topped Apple Snail?, Mystery Snail? | 1 | - | 1 | - | - |
| Pomacea diffusa? | Spike-topped apple Snail? | , | - | 1 | - | - |
| Pomacea glauca | Apple Snail | 1 | - | 1 | - | - |
| Potamotrygon hystrix | Porcupine River Stingray | F | 1 | 1 | 1 | - |
| Potamotrygon motoro | South American Freshwater Stingray | F | 1 | 1 | - | - |
| Premnas biaculeatus | Spinecheek Anemonefish, Maroon Clownfish | F | 1 | 1 | - | - |
| Prionobrama filigera | Glass Bloodfin, Glass Bloodfish | F | 1 | 1 | - | - |
| Pristella maxillaris | X-ray Tetra, Albino Pristella, Pristella, Pristella Tetra, Water Goldfinch, X-ray Fish | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Pseudohemiodon apithanos | Armoured catfish | F | 0 | 1 | 1 | - |
| Pseudojuloides cerasinus | Smalltail Wrasse, Pencil Wrasse | F | 1 | 1 | - | - |
| Pseudomugil furcatus | Forktail Rainbowfish | F | 1 | 1 | 1 | - |
| Pseudomugil luminatus | Red Neon Blue Eye Rainbowfish | F | 0 | 1 | - | - |
| Pseudotropheus sp. | Mbuna Cichlid | F | 0 | 1 | - | - |
| Pterapogon kauderni | Banggai Cardinal Fish | F | 1 | 1 | - | - |
| Ptereleotris evides | Blackfin Dartfish, Spottail Gudgeon, Scissortail Dartfish | F | 1 | 1 | - | - |
| Ptereleotris heteroptera | Blacktail Goby, Pale Gudgeon, Blue Gudgeon Dartfish | F | 1 | 1 | - | - |
| Ptereleotris zebra | Chinese Zebra Goby, Zebra Barred Dartish | F | 1 | 1 | - | - |
| Pterois antennata | Broadbarred Firefish, Spotfin Lionfish, Antennata Lionfish | F | 1 | 1 | - | - |
| Pterois lunulata | Luna Lion Fish, Dragon's Beard Fish | F | 1 | 1 | - | - |
| Pterois volitans | Red Lionfish, Lionfish, Ornate Butterfly-cod, Red Firefish, Turkeyfish, Colored volitan lionfish | F | 1 | 1 | - | - |
| Pterois volitans | Red lionfish, Lionfish, Ornate butterfly-cod, Red firefish, Turkeyfish, Colored Volitan Lionfish | F | 1 | 1 | - | - |
| Pterophyllum altum | Altum Angelfish | F | 1 | 1 | 1 | - |
| Pterophyllum scalare | Freshwater Angelfish | F | 1,2,3 | 1 | 1 | - |
| Pterophyllum sp. | Angelfish | F | 3 | 1 | - | - |
| Pterophyllum sp. | Platinum Angelfish | F | 3 | 1 | - | - |
| Pterygoplichthys anisitsi | Snow Pleco, Parana Sailfin Catfish, Royal Plec, Southern Sailfin Catfish | F | 1 | 1 | - | - |
| Pterygoplichthys gibbiceps | Leopard Pleco, Sailfin Pleco | F | 1 | 1 | 1 | - |
| Pterygoplichthys sp. | Suckermouth armoured catfish | F | 2 | 1 | 1 | - |
| Puntigrus tetrazona | Sumatra Barb, Partbelt Barb, Tiger Barb, Tiger | F | 0 | 1 | 1 | - |
| Puntius titteya | Cherry Barb, Crimson Carplet, Titteya | F | 1 | 1 | 1 | - |
| Pygocentrus nattereri | Red Piranha, San Francisco Piranha, Redbelly Piranha | F | 1,3 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Pygoplites diacanthus | Regal Angelfish, Royal Angelfish, Bluebanded Angelfish, Royal Empress Angelfish | F | 1 | 1 | - | - |
| Rasbora kalochroma | Clown Rasbora, Bigspot Rasbora, Clown Barb, Iridescent Rasbora, Red Barb, Redember Rasbora | F | 1 | 1 | - | - |
| Rhinecanthus aculeatus | White-banded Triggerfish, Lagoon Triggerfish, (Humu) Picasso Triggerfish | F | 1 | 1 | - | - |
| Rhinecanthus rectangulus | Wedge-tail Triggerfish, Reef Triggerfish, Rectangular Triggerfish | F | 1 | 1 | - | - |
| Rhinomuraena quaesita | Ribbon Moray, Ribbon Eel, Leaf-nosed Moray Eel, Bernis Eel | F | 1 | 1 | - | - |
| Rhinopias frondosa | Weedy Scorpionfish | F | 1 | 1 | - | - |
| Rhynchocinetes durbanensis | Hingebeak Shrimp, Durban Hinge-beak Shrimp, Camel Shrimp | 1 | - | 1 | - | - |
| Rhynchocinetes sp. | Dancing Shrimp | 1 | - | 1 | - | - |
| Rocio octofasciata | Jack Dempsey | F | 0 | 1 | - | - |
| Rotala macrandra | Rotala Macranda, Red Bacopa | P | - | 1 | 1 | - |
| Rotala nanjenshan | Rotala Nanjenshan | P | - | 1 | 1 | - |
| Rotala wallichii | Rotala Wallichii | P | - | 1 | 1 | - |
| Ruditapes philippinarum | Japanese Carpet Shell, Japanese Littleneck, Japanese Littleneck Clam, Japanese Carpet Shell, Japanese Clam, Manila Clam, Short-necked Clam, Littleneck, Pacific Littleneck, Steamer | 1 | - | - | - | 1 |
| Ruditapes variegatus | Variegated Carpet Shell, Littleneck Clam | 1 | - | - | - | 1 |
| Sabellastarte sp. | Common Feather Duster | 1 | - | 1 | - | - |
| Sabellastarte spectabilis | Indian Feather Duster Worm | 1 | - | 1 | - | - |
| Salarias fasciatus | Jewelled Blenny, Jeweled Blenny, Sailfin/Algae Blenny | F | 1 | 1 | - | - |
| Salarias guttatus | Breast-spot Blenny, Fine-spotted Blenny | F | 0 | 1 | - | - |
| Salarias ramosus | Starry Blenny | F | 0 | 1 | - | - |
| Salarias segmentatus | Segmented Blenny, Segmented Sailfin Blenny | F | 1 | 1 | - | - |
| Salmo salar | Atlantic Salmon, Bay Salmon, Breeder, Caplin-scull Salmon, Fiddler, Grayling, Grilse, Grilt, Landlocked | F | 1 | - | - | 1 |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Salmon, Ouananiche, Ouinanish, Outside Salmon, Parr, Salmon, Salmon Peel, Slink, Smolt, Spring Fish, Spring Salmon, Winnish, Sebago Salmon |  |  |  |  |  |
| Salmoninae | Trout | F | 0 | - | - | 1 |
| Saururus cernuus | Lizard's Tail | P | - | 1 | 1 | - |
| Sawbwa resplendens | Sawbwa Barb | F | 1 | 1 | - | - |
| Scaridae | Parrotfish | F | - | 1 | - | - |
| Scartella cristata | Molly Miller | F | 0 | 1 | - | - |
| Scatophagus argus | Spotted Scat, Argus Fish, Common Scat, Leopard Scat, Spotted Butterfish | F | 1 | 1 | - | - |
| Sciaenochromis sp. | Malawi Cichlid | F | - | 1 | - | - |
| Scophthalmus maximus | Turbot | F | 1 | - | - | 1 |
| Scorpaenichthys marmoratus | Cabezon, Bullhead, Giant Marbled Sculpin, Muddler, Sculpin, Sea Raven | F | 1 | 1 | - | - |
| Sebastes caurinus | Copper Rockfish, Rock Cod | F | 1 | - | - | 1 |
| Sebastes rastrelliger | Grass Rockfish | F | 0 | - | - | 1 |
| Sebastes schlegelii | Korean Rockfish | F | 0 | - | - | 1 |
| Selaginella sp. | Lesser Clubmosses, Spike-mosses, Spikemosses | P | - | 1 | 1 | - |
| Selene vomer | Lookdown, Dollarfish, Hairfinned dory, Horsehead, Jorobado | F | 1 | 1 | - | - |
| Semicossyphus pulcher | California Sheephead | F | 0 | - | - | 1 |
| Serranus tigrinus | Harlequin Bass | F | 1 | 1 | - | - |
| Serranus tortugarum | Chalk Bass | F | 1 | 1 | - | - |
| Serripes groenlandicus | Greenland Smoothcockle, Greenland Cockle | I | - | - | - | 1 |
| Shinnersia rivularis | Rio Grande Bugheal, Mexican Oak Leaf | P | - | 1 | 1 | - |
| Sicyopus exallisquamulus | Red Lipstick Goby | F | 0 | 1 | - | - |
| Siganus corallinus | Blue-spotted Spinefoot, Coral Rabbitfish, Coral Spinefoot, Ocellated Trange Spinefoot, Orange spinefoot, Spotted Rabbitfish, Spotted Spinefish | F | 1 | 1 | - | - |
| Siganus doliatus | Barred Spinefoot, Barhead Spinefoot, Two-barred Rabbitfish | F | 0 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Siganus puellus | Masked Spinefoot, Bluelined Spinefoot, Maiden Spinefoot | F | 1 | 1 | - | - |
| Siganus uspi | Bicolored Foxface | F | 1 | 1 | - | - |
| Siganus unimaculatus | Blotched Foxface, Foxface, One Spot Foxface, One Spot Tabbitfish | F | 0 | 1 | - | - |
| Siganus virgatus | Barhead Spinefoot, Double-barred Spinefoot | F | 1 | 1 | - | - |
| Siganus vulpinus | Foxface, Common foxface, Foxface Rabbitfish | F | 1 | 1 | - | - |
| Signigobius biocellatus | Twinspot Goby | F | 1 | 1 | - | - |
| Siliqua patula | Pacific Razor, Pacific Razor-clam, Pacific Razor Clam, Razor Clam | 1 | - | - | - | 1 |
| Siluriformes | Catfish | F | - | 1 | 1 | 1 |
| Skiffia multipunctata | Spotted Skiffia | F | 0 | 1 | - | - |
| Spathiphyllum wallisii | Brazilian Sword, Peace Lily | P | - | 1 | 1 | - |
| Sphaeramia nematoptera | Pajama Cardinalfish | F | 1 | 1 | - | - |
| Spisula murchisoni | Storm Surf Clam | I | - | - | - | 1 |
| Stegastes leucostictus | Beaugregory | F | 1 | 1 | - | - |
| Stenopus hispidus | Banded Coral Shrimp, Banded Boxer Shrimp, Cleaner Shrimp, American Flag Shrimp, Redbanded Coral Shrimp | 1 | - | 1 | - | - |
| Stenotomus chrysops | Scup | F | 0 | - | - | 1 |
| Stichodactyla sp.? | Fluorescent Green Carpet Anemone? | 1 | - | 1 | - | - |
| Stichodactyla tapetum | Actinarians, Mini-carpet Anemone | 1 | - | 1 | - | - |
| Stiphodon atropurpureus | Blue Neon Goby | F | 0 | 1 | - | - |
| Stonogobiops nematodes | Filament-finned Prawn-goby, Hi Fin Red Banded Goby | F | 1 | 1 | - | - |
| Stonogobiops xanthorhinica | Yellownose Prawn-goby | F | 1 | 1 | - | - |
| Strombus sp. | Conche | 1 | - | 1 | - | 1 |
| Strongylocentrotus purpuratus | Purple Urchin, Purple Sea Urchin, Pacific Purple Urchin | 1 | - | 1 | - | - |
| Symphorichthys spilurus | Sailfin Snapper | F | 1 | 1 | - | - |
| Symphysodon aequifasciatus | Blue Discus, Brown Discus, Green Discus | F | 1 | 1 | 1 | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- | LF


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG |
| :--- | :--- | :--- | :--- | :--- | :--- | LF


| Scientific name | Common or trade name | Taxa | Previous studies? | Aq | WG | LF |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Uaru amphiacanthoides | Uaru, Chocolate Cichlid, Triangle Cichlid, Uaru Cichlid | F | 1 | 1 | 1 | - |
| Uaru fernandezyepezi | Uaru Cichlid | F | 0 | 1 | - | - |
| Urobatis halleri | Haller's Round Ray, Round Stingray | F | 1 | 1 | - | - |
| Uropterygius concolor | Unicolor Snake Moray, Brown Moray, Uniform Reef Eel | F | 1 | 1 | - | - |
| Valenciennea bella | Bella Goby | F | 0 | 1 | - | - |
| Valenciennea longipinnis | Long-finned Goby | F | 1 | 1 | - | - |
| Valenciennea puellaris | Maiden Goby, Diamond Watchman Goby | F | 1 | 1 | - | - |
| Valenciennea sexguttata | Sixspot Goby, Sleeper Blue Dot Goby, Chalk Goby | F | 1 | 1 | - | - |
| Valenciennea strigata | Blueband Goby, Sleeper Gold Head Goby, Golden Head Sleeper, Yellowheaded Sleeper Goby | F | 1 | 1 | - | - |
| Valenciennea wardii | Ward's Sleeper, Tiger Watchman Goby | F | 1 | 1 | - | - |
| Vallisneria sp. | Contortion Val | P | - | 1 | 1 | - |
| Vallisneria spiralis | Coiled Vallisneria, Eelgrass, Eelweed, Tape-grass, Tapegrass, Straight Eelgrass, Straight Vallisneria, Italian Val | P | - | 1 | 1 | - |
| Vallisneria torta | Corkscrew Vallisneria | P | - | 1 | 1 | - |
| Vesicularia dubyana | Java Moss | P | - | 1 | - | - |
| Xanthichthys auromarginatus | Gilded Triggerfish | F | 1 | 1 | - | - |
| Xanthichthys caeruleolineatus | Outrigger Triggerfish | F | 0 | 1 | - | - |
| Xiphophorus hellerii | Green Swordtail, Red Swordtail, Swordtail | F | 1,3 | 1 | 1 | - |
| Xiphophorus maculatus | Southern Platyfish, Platy | F | 1,3 | 1 | 1 | - |
| Xiphophorus montezumae | Montezuma Swordtail, Mexican Swordtail | F | 0 | 1 | - | - |
| Xiphophorus sp. | Platy, Platyfish | F | 2 | 1 | 1 | - |
| Xiphophorus variatus | Variable platyfish, Sunset platy, Variegated | F | 1 | 1 | 1 | - |
| Zanclus cornutus | Moorish Idol | F | 1 | 1 | - | - |
| Zebrasoma desjardinii | Indian Sail-fin Surgeonfish, Indian Sailfin Tang, Sailfin Tang, Desjardin's Sailfin Tang | F | 1 | 1 | - | - |
| Zebrasoma flavescens | Yellow Tang, Lemon Sailfin, Somber Surgeonfish, Yellow Sailfin Tang | F | 1 | 1 | - | - |


| Scientific name | Common or trade name | Taxa | Previous <br> studies? | Aq | WG | LF |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Zebrasoma rostratum | Longnose Surgeonfish, Black Tang | F | 0 | 1 | - | - |
| Zebrasoma scopas | Twotone Tang, Brown Tang, Scopas Tang, Brush- <br> tail Tang | F | 1 | 1 | - |  |
| Zebrasoma xanthurum | Yellowtail Tang, Purple Tang, Red Sea Sailfin, | F | 1 | 1 | - |  |
| Zebrasoma velifer | Yellowtail Surgeonfish <br> Sailfin Tang | F | 1 | 1 | - |  |

