Species Invasions from Commerce in Live Aquatic Organisms: Problems and Possible Solutions

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In the Laurentian Great Lakes region, commercial activities involving live fish bait, horticultural and water-garden plants, biological supplies, pets, and live food are the principal pathways for intentional introductions of live aquatic organisms. We sampled species for sale in these trades and found that the risks of new invasions and of spreading known invaders are high. Moreover, most animals were identified by common name only, and even though scientific names were more often applied to plants, consumers cannot be certain what species they are receiving because misidentification is common. Finally, 90 percent of plant orders arrived contaminated with unordered live organisms. The policy goal of US and Canadian national and state or provincial agencies is to reduce the risk of harmful introductions. Our results demonstrate that meeting this goal will require accurate identification of species by vendors, the removal of known and likely invasive species from trade, and reductions in the number of contaminant organisms.

Keywords: aquatic invasive species, vectors, trade, contaminant organisms, Great Lakes

Intentional introductions of nonindigenous species proceed on a worldwide scale with little voluntary or regulatory screening to reduce introductions of harmful species (Lodge et al. 2006). Although the vast majority of intentionally introduced species bring economic wealth to their new location—otherwise no one would go to the trouble of importing them—a large number also spread and cause economic or environmental harm (i.e., become invasive), or both. In the United States, for example, plants grown in nurseries and greenhouses produced retail sales of US$15.7 billion in 2004 (Jerardo 2005). At the same time, annual economic losses caused by invasive plants, the majority of which have been intentionally introduced for the ornamental trade, are estimated to be at least US$34.7 billion (Pimentel et al. 2005). The situation is similar for other taxa and countries, creating a paradox for policymakers who aim to simultaneously encourage trade and minimize the costs of invasive species. In the United States, as in most other countries, policymakers do not place strong restrictions on the import and transport of live nonindigenous organisms. Consequently, the number of invasive species introduced by these pathways continues to increase (Ricciardi 2001, Levine and D'Antonio 2003, Lodge et al. 2006).

Invasion risks are present for all trades that transport live organisms, including the aquaculture (Naylor et al. 2001), nursery plant (Reichard and White 2001, Maki and Galatowitsch 2004), live food (Weigle et al. 2005), pet (Rixon et al. 2005), and bait (Mills et al. 1993) trades. The risks posed can usefully be broken down into three categories. First, some species being sold will become invasive. In the United States, 85 percent of established nonnative woody plant species were introduced through the horticultural trade (Reichard and Hamilton 1997), and 26 percent and 16 percent of nonindigenous freshwater fish that occur beyond their native range in the United States (both US and non-US natives) were introduced through the aquarium and bait trades, respectively (Fuller et al. 1999).

Second, the escape or release of additional individuals of already invasive species may introduce genetic diversity that can enhance invasiveness (Cox 2004) or establish new populations. In most countries, lists of species banned from trade are short, and do not include all species known to be invasive. Thus, many invaders remain in active trade. In the United States, there are 19 aquatic and 72 terrestrial plant species prohibited at the national level (USDA 2005), while some 5000 nonindigenous plant species are established beyond

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cultivation (Morse et al. 1995). Many states regulate more species than does the federal government, but state rules may have limited effectiveness when species can cross borders from neighboring states that do not have similar regulations. Furthermore, the large mail-order and Internet trade in live organisms has proved difficult to monitor and control (Maki and Galatowitsch 2004).

Finally, trades involving live organisms can introduce so-called contaminant species that hitchhike in or on the species of primary interest. These are defined as any live organisms delivered through trade but not specifically purchased, and range from seeds or invertebrates in the soil of potted plants to pathogens and parasites of the organism purchased. Although it is often difficult to trace the source of contaminant organisms, some serious invaders are known to have been introduced in this way. Examples include the yellow starthistle (*Centaurea solstitialis*), which was introduced into the United States as a seed contaminant of alfalfa (Sheley et al. 1999), and the pathogen that causes sudden oak death (*Phytophthora ramorum*), which invaded the United States and Europe on nursery plants (Ivors et al. 2006).

A greater awareness of the economic and environmental impacts of invasive species is leading many industries and countries to consider how voluntary industry practices, regulatory risk assessments, and quarantine measures could be modified to reduce the risks of further harm. In the United States, for example, the Department of Agriculture is considering a requirement to screen plant species for invasiveness before importation is permitted. Thus, as policymakers increasingly ask how risks can be minimized, it is important to understand exactly how these risks are currently manifested in each commercial pathway. Only with a rigorous assessment of risks can effective policy be constructed.

We have assessed the invasion risks posed by trades in the southern basin of Lake Michigan that deal in live aquatic organisms. The Great Lakes already contain more than 180 established nonindigenous species, many of which were originally introduced through commerce (Mills et al. 1993, Ricciardi 2001). We identified five retail trades that sell live aquatic organisms in the region: live bait, live food, biological supplies, nursery (including water-garden) plants, and pets (including aquarium animals and plants). The bait and live food trades in the Great Lakes region are represented primarily by stores; the biological supply trade is represented primarily by mail and Internet businesses; and the pet and nursery trades have both stores and mail or Internet businesses. We purchased and identified organisms of all species that we considered likely to be able to establish in the Great Lakes basin from each of these sources. This enabled us to assess the risks of new invasions and of spreading already invasive species. To investigate the risk from accidental transport of contaminant species, we purchased additional aquatic plants and identified the unordered invertebrates that accompanied them. Finally, we compared our species identifications with those provided by the vendors.

Acquiring samples

Our goal was to sample the diversity of aquatic species for sale in the Great Lakes Basin that are capable of becoming established in the region. To begin, we spent three weeks surveying (but not purchasing from) local stores and Internet sites involved in the live bait, biological supply, nursery, and pet trades. During the survey, to the extent possible through vendor-supplied information and our own observations, we recorded the names of the species available for sale at approximately 30 Internet nursery sites, 30 pet sites, 5 biological supply sites, and 5 each of local bait, pet, and nursery stores. This survey suggested that the plant and fish species sold by small stores constituted a subset of those sold by large stores and sites, probably because many stores share wholesale suppliers. Thus we could sample the taxonomic diversity of these two taxa by purchasing from a small number of large vendors.

Other taxa, especially mollusks, crustaceans, and amphibians, occurred less often in trade and were generally identified by vendors at a very coarse level (e.g., "freshwater clam," "tadpole"). For these taxa, then, it was not possible to determine the sample size required to identify the total diversity being sold. Because practical limitations dictated that we sample these taxa in the same way as the fish and plants, we may have sampled a smaller proportion of total diversity for them. The live food trade in the region is represented primarily by a small number of stores in Chicago and Detroit, and we sampled as many of these as we could locate. In total, we purchased from 22 large stores and Internet sites (three bait, seven live food, two biological supply, six nursery, and four pet suppliers).

From each vendor, we purchased samples of all plants and animals that were (a) nonindigenous to the Great Lakes region and (b) already established, or considered able to establish, in the Great Lakes region. The Great Lakes basin covers a wide range of latitudes (41° to 51° N) and climate zones, making it difficult to specify the species that could establish there on the basis of their geographic origins. Instead, all species that are currently established in temperate or colder zones of the world were considered capable of becoming established in the Great Lakes basin. In addition, we purchased any species whose geographic origin was uncertain. The largest group of organisms not purchased was tropical fish, which have high diversity in the pet trade but pose a negligible invasion risk to the Great Lakes. The stores sampled ranged southeast from Chicago around the southern basin of Lake Michigan and as far east as Niles, Michigan, a distance of approximately 160 kilometers. We also purchased from live food stores in Detroit, Michigan. Internet-based biological supply, nursery, and pet dealers sampled were located across the United States, but concentrated in the states of California, Texas, and Florida.

Identifying the species

We identified all species sampled to the lowest level possible using a variety of standard keys (e.g., Hobbs 1972, Burch

1982, Powell et al. 1998, Scott and Crossman 1998, Crow and Hellquist 2000, Thorp and Covich 2001). More specific keys were used when required by species taxonomy or geographic origin. Identifications were usually at the species level, but a number of organisms could be identified only at the genus level, often because they were juvenile animals, or plants without flowers. We also recorded the name under which each sample was sold, and when organisms were identified with a binomial species name, we classified the identification as "scientific." All other names, including organisms identified only by genus (e.g., *Myriophyllum* sp.), were classified as "common." We compared the scientific names provided by vendors with our own identifications.

We used a variety of sources, including Mills and colleagues (1993), Crow and Hellquist (2000), Ricciardi (2001), and Czarapata (2005), to determine which of the sampled species are established in the Great Lakes basin. These species were considered invasive if they were listed as harmful in any of the above sources, if we could find other published evidence of their having negative economic or environmental impacts, or if their sale was restricted by any of the US states and Canadian provinces that border the Great Lakes. For species not established in the Great Lakes, we conducted a literature search using a variety of sources, including Web of Science, FishBase, and *A Global Compendium of Weeds* (Randall 2002), to determine whether they are native to, or established in, other temperate regions of the world, and whether they are considered invasive in those regions. Species not established in temperate or colder regions were excluded from further analysis.

Additional aquatic plant samples were purchased to determine the number and diversity of contaminant invertebrates arriving in the Great Lakes basin. Although plant contaminants were also observed, these have already been studied (Maki and Galatowitsch 2004), so we concentrated our efforts on animals. For the analysis of contaminants, trade designations differed slightly from those described above. First, local pet and nursery stores were called, respectively, "local pet" and "local nursery." Internet-based pet and nursery retailers were combined into "Internet pet/nursery" because of the large overlap between these trades in terms of species sold, and because plants purchased over the Internet spend several days in transit before delivery, which may affect contaminant survival. We did not lump the biological supply trade with the other Internet trades because, although it is entirely Internet based, it sells organisms for purposes different from those of Internet pet/nursery vendors, and thus may have different practices and outcomes. We purchased from a total of five local pet, five local nursery, five Internet pet/nursery, and four biological supply vendors.

Different morphologies of aquatic plants are known to support different numbers of invertebrates (Cyr and Downing 1988). We therefore divided the diversity of available plants into five morphological classes: floating small-leaved (e.g., *Lemna* spp.), floating broad-leaved (e.g., *Pistia stratiotes*), submersed small-leaved (e.g., *Myriophyllum* spp.), submersed broad-leaved (e.g., *Vallisneria americana*), and emergent (e.g., *Iris pseudacorus*). From each outlet we purchased up to four species of each morphology, depending on availability (not all plant types were available from all vendors). A total of 115 plant samples were purchased.

When the plants arrived, we shook them in a tub of water to remove contaminants. This removed most animals, and we then visually inspected the stems and leaves of all plants for additional organisms. All contaminants found were preserved and later identified at the order level. More detailed identification of this diverse range of organisms was not feasible given the uncertainty of their geographic origins. To enable comparison of densities among samples, we measured plant damp weight after contaminants were removed.

Species in trade

A total of 117 taxa were identified from our sampling, with plants making up 68 percent of all species (table 1). There was a large overlap in the plants sold by the nursery, pet, and biological supply trades, although a number of plant species were sold only by the pet or the nursery trade. In contrast, almost all animal species were uniquely available from one trade (table 1).

Accuracy of vendor identifications. The vast majority of animal samples purchased were identified only by common name, with the pet, live food, and bait trades using common names exclusively (figure 1a). Common names varied from relatively robust (e.g., "goldfish" was consistently applied to *Carassius auratus*) to taxonomically uninformative. Examples of the latter came from all industries, but were most conspicuous in the bait trade, where fish are sold according to size rather than taxonomy.

Plants were more likely than animals to be identified by scientific name (figure 1b). The nursery trade applied scientific names in 67 percent of cases, and 84 percent of these identifications were correct. Identifications were less reliable for the

Table 1. Number of taxa (mostly species) identified from each of five trades (pet, nursery, live food, bait, and biological supplies), grouped by broad taxonomic categories.

Category	Pet	Nursery	Live food	Bait	Biological supplies	Total taxa
Plants	32 (15)	61 (41)	–	–	10 (0)	79
Fish	3 (1)	2 (0)	5 (5)	3 (2)	4 (3)	14
Mollusks	7 (5)	–	–	–	3 (1)	8
Crustaceans	3 (3)	–	–	1 (1)	1 (1)	5
Amphibians	6 (4)	1 (0)	1 (0)	–	2 (1)	7
Insects	–	–	–	1 (1)	–	1
Annelids	–	–	–	–	2 (2)	2

Note: Figures in parentheses are the number of taxa unique to the trade.

pet trade: 85 percent of plants were identified by scientific name, but with only 59 percent accuracy. For plants, as for animals, common names ranged from robust (e.g., water hyacinth was consistently applied to *Eichornia crassipes*) to taxonomically uninformative (e.g., "submersed plant"). Inaccurate scientific names ranged from those with the correct genus but wrong species to those containing undescribed genera.

Species already established in the region. Eighteen of the plant species sampled are already established in the Great Lakes basin (table 2). Some of these are serious and widespread invaders (e.g., Eurasian watermilfoil), whereas others have no known impacts (e.g., water mint). A number of species in the latter group, however, are invasive in temperate regions elsewhere (table 2).

Eleven of the 38 animal species sampled are established nonnative species in the Great Lakes basin (table 2). Four of these are native to some parts of the Great Lakes basin but have become established elsewhere through game fish stocking (e.g., largemouth bass) or baitfish release (e.g., golden shiner). None of these four species is considered invasive. The remaining seven species are not native to the Great Lakes basin, and four of these are known to cause harm within the Great Lakes basin (table 2).

Potential future invaders. We sampled eight species that are not already established in the Great Lakes region, but that are invasive in temperate or colder environments elsewhere (table 3). Species in this category include the floating-leaved water hawthorn, an invader in southern Australia (Gunasekera 2003), and the African clawed frog, which is invasive in California and also established in the United Kingdom (Tinsley and McCoid 1996).

Invertebrate contaminants of aquatic plants. Ninety percent of the plants ordered for contaminant analysis arrived with associated live invertebrate animals. Contaminant numbers differed among macrophyte morphologies and trades (figure 2), with floating small-leaved plants containing by far the greatest number of contaminants (an average of 6.59 organisms per gram [g] of plant). Fewer contaminants were found in

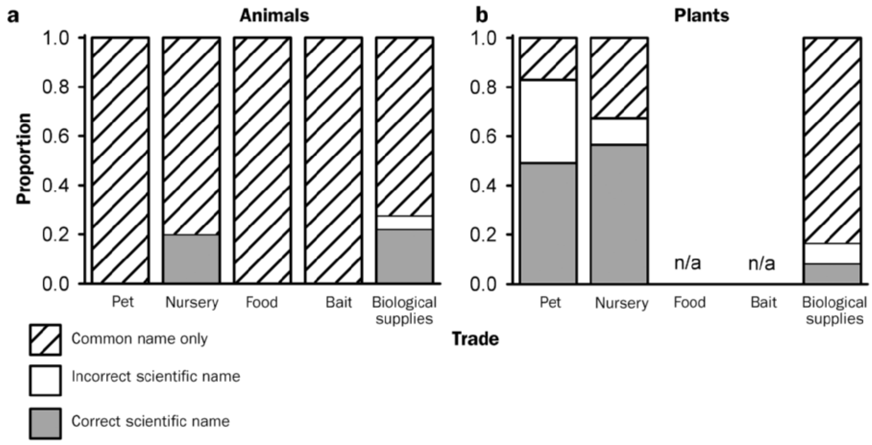

Figure 1. Proportion of (a) animal and (b) plant purchases that were correctly identified (i.e., correct scientific name), incorrectly identified (i.e., incorrect scientific name), or ambiguously identified (i.e., common name only) by vendors in the pet, nursery (includes water-garden), live food, live bait, and biological supply trades. Abbreviation: n/a, not applicable.

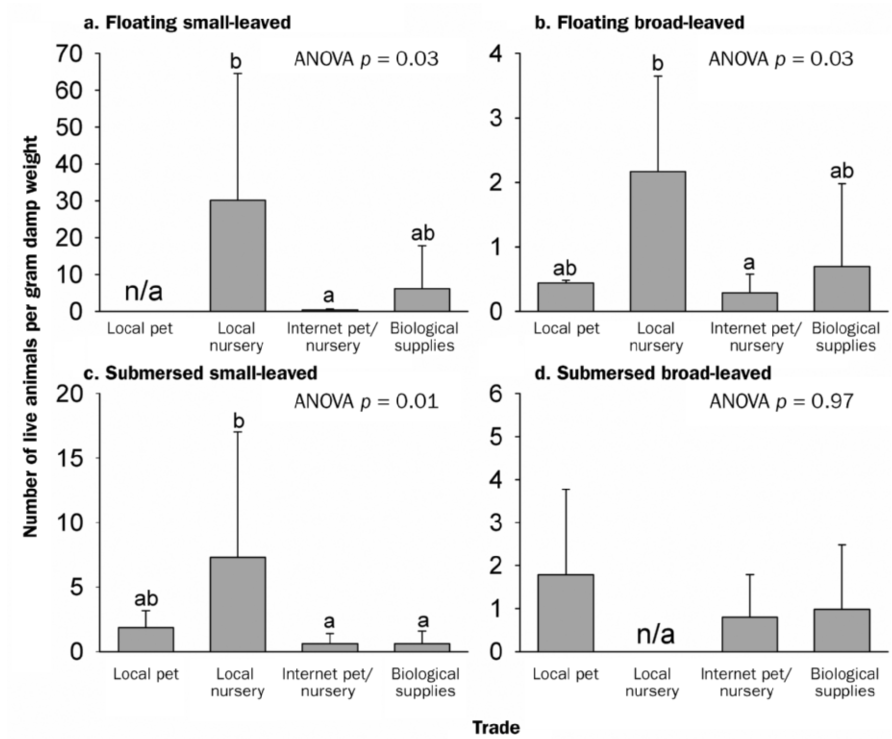

Figure 2. Number of live animals (per gram damp plant weight, ± 1 standard deviation) recovered from plants with different morphologies (a–d) purchased from local pet stores, local nursery stores, Internet-based pet and nursery sites, and biological supply stores. The p *value from a one-way ANOVA (analysis of variance) is given for each plant morphology, and significant differences (Tukey's test) are indicated by different letters. Note the different scales. Abbreviation: n/a, not applicable.*

Table 2. Nonindigenous species (not including contaminant species) purchased in the Great Lakes region that already have populations established in the Laurentian Great Lakes basin.

Species	Trade	Native range	Great Lakes impacts	Temperate zone impacts
Plants				
Cabomba caroliniana (Cabomba)	Nursery	South America	No	Yes
Egeria densa (Brazilian waterweed)	Pet	South America	No	Yes
Eichornia crassipes (water hyacinth)	Pet, nursery	South America	No	No
Glyceria maxima (tall mannagrass)	Nursery	Europe, Asia	No	Yes
Hydrocharis morsus-ranae (European frog-bit)	Nursery	Europe, Asia	Likely	Yes
Iris pseudacorus (yellow iris)	Nursery	Africa, Europe, Asia	Yes	Yes
Lysimachia nummularia (moneywort)	Nursery	Europe, Asia	Yes	Yes
Marsilea quadrifolia (water shamrock)	Nursery	Europe	No	Yes
Mentha aquatica (water mint)	Nursery	Europe	No	No
Myosotis scorpioides (water forget-me-not)	Nursery	Europe, Asia	Yes	Yes
Myriophyllum aquaticum (parrot feather)	Pet, nursery	South America	Likely	Yes
Myriophyllum spicatum (Eurasian watermilfoil)	Pet, nursery	Africa, Europe, Asia	Yes	Yes
Najas minor (lesser naiad)	Pet	Africa, Europe, Asia	No	Yes
Nymphoides peltata (yellow floating-heart)	Pet, nursery	Europe, Asia	No	Yes
Pistia stratiotes (water lettuce)	Pet, nursery	South America	No	No
Potamogeton crispus (curly-leafed pondweed)	Pet, nursery	Africa, Europe, Asia, Australia	Yes	Yes
Trapa natans (water chestnut)	Pet	Asia	Likely	Yes
Typha angustifolia (narrow-leaved cattail)	Nursery	Europe	Yes	Yes
Fish				
Ameiurus melas (black bullhead)	Biological supplies	North America (including Great Lakes)	No	Yes
Carassius auratus (goldfish)	Pet, nursery	Asia	Yes	Yes
Cyprinus carpio (common carp, koi)	Pet, nursery	Europe, Asia	Yes	Yes
Gambusia affinis (mosquitofish)	Bait	North America	No	Yes
Micropterus salmoides (largemouth bass)	Live food	North America (including Great Lakes)	No	Yes
Misgurnus anguillicaudatus (Oriental weatherloach)	Pet	Asia	No	Unknown
Notemigonus crysoleucas (golden shiner)	Bait	North America (including Great Lakes)	No	No
Pimephales promelas (fathead minnow)	Bait, biological supplies	North America (including Great Lakes)	No	No
Mollusks				
Corbicula fluminea (Asiatic clam)	Nursery	Asia	Yes	Yes
Crayfish				
Orconectes rusticus (rusty crayfish)	Bait	North America	Yes	Yes
Procambarus clarkii (Louisiana crayfish)	Biological supplies	North America	Likely	Yes

Source: Information on Great Lakes impacts for plants, Czarapata 2005; for fish, Fuller et al. 1999; for mollusks, McMahon 2000; for crayfish, Lodge et al. 2000.

floating broad-leaved (0.98 organisms per g), submersed small-leaved (2.46 organisms per g), submersed broad-leaved (0.82 organisms per g), and emergent (0.19 organisms per g) plants. One-way ANOVA (analysis of variance) comparing contaminant density among the five plant types was significant ($p = 0.036$), with the only significant difference (according to Tukey's test) among plant types occurring between small-leaved floating and emergent plants. Figure 2 does not include a panel for emergent plants because these were available only from local nursery stores and Internet pet/nursery sites, the number of contaminants on them was relatively low, and no significant differences existed among store types. Similar contaminant taxa were recorded for all trades, with the dominant groups being mollusks (> 99 percent gastropods), insects, ostracods, and oligochaetes (figure 3).

Preventing future invasions

Many harmful nonindigenous aquatic species in the Great Lakes basin were introduced through the trades in live aquatic organisms (Mills et al. 1993, Ricciardi 2001, Czarapata 2005). Our results indicate that these trades remain strong pathways for the spread and introduction of invasive species. There is a strong impetus to reduce the risks of future introductions from these trades, however, because the official policy of both national (United States [NISC 2001], Canada [Anonymous 2004]), and state and provincial (e.g., Indiana,

Table 3. Species purchased in the Great Lakes region that pose a risk of becoming invaders.

Species	Trade	Native range	Invasive range
Plants			
Aponogeton distachyos (water hawthorn)	Nursery	Africa	Australia
Houttuynia cordata (chameleon plant)	Nursery	Asia	New Zealand, North America
Marsilea mutica (water fern)	Nursery	Australia	Australia, New Zealand, North America
Ophiopogon japonicus (Mondo grass)	Nursery	Asia	South America
Ranunculus lingua (greater spearwort)	Nursery	Europe	Europe
Salvinia auriculata (eared watermoss)	Nursery	South America	Australia, Asia, Africa, North America
Fish			
Aristichthys nobilis (bighead carp)	Live food	Asia	North America
Amphibia			
Xenopus laevis (African clawed frog)	Pet, biologial supplies, live food	Africa	Europe, North America, South America

Note: Although none of these species is currently established in the Great Lake basin, each of them is invasive in temperate regions other than the Great Lakes.

Ontario [Anonymous 2002, Seng and White 2003]) governments is to prevent the introduction of new invasive species to the Great Lakes basin, and to restrict the spread of established invasive species. While these policy goals have clear implications for commerce, it is important also to recognize that the trades in live organisms benefit society in many ways. Below we discuss how our results can inform steps to reduce invasion risks while causing minimal interruption to these trades.

Any efforts to reduce invasion risks from the trades in live aquatic organisms will require retailers and government agencies to know the scientific names of the species sold. Currently, however, the majority of organisms sold are identified by incorrect scientific names or by taxonomically ambiguous common names. Because few retailers propagate their own organisms, most identifications—indeed, most of the tags on plants we encountered—were applied by growers or wholesalers before the organisms were sold to retailers. It is not clear how these industries arrive at their identifications, but it is possible that many species are misidentified when they are first imported, with domestic growers and distributors perpetuating the misidentification. This suggests that the most effective way to ensure that all species in trade are accurately identified may be through (a) certification programs requiring accurate identifications by importers, (b) greater inspection of organisms at the place of import to provide continuing incentives for accurate identifications, and (c) a system of regulations and penalties to encourage accurate identifications by wholesalers and retailers.

Some of the most damaging invasive species in the Great Lakes basin remain available for purchase. Eurasian watermilfoil, for example, is advertised for sale despite being a costly invader across the United States (Czarapata 2005). In one Great Lakes state, Indiana, this species occurs in 24 percent of lakes (INDNR 1998), and the state government spends more than US$600,000 annually on its control (INDNR 2005). Other known invaders sampled include the rusty crayfish, which drastically alters lake and stream ecosystems (Rosenthal et al. 2006) and reduces populations of some game fish in the upper Midwest (Wilson et al. 2004), and the Asiatic clam, which has massive impacts across the United States (McMahon 2000), including the fouling of power station water intakes in Lake Erie (Keller et al. 2007a). Because these species are already established and have other pathways of transport (e.g., Eurasian watermilfoil can be transported among water bodies on boat trailers), removing them from trade will not fully curb their spread in the future. Nevertheless, it is likely to be an important part of any comprehensive plan to limit that spread.

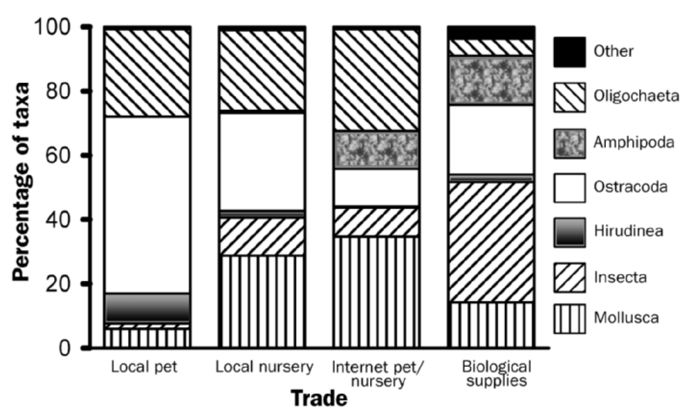

Figure 3. Average taxonomic diversity of contaminant animals recovered from purchased plants from local pet stores, local nursery stores, Internet-based pet and nursery vendors, and biological suppliers.

Broadly speaking, there are three policy approaches that could be adopted with regard to the introduction of new invasive species through commerce: First, allow any and all new species; second, allow no new species; or, third, prescreen species for the likelihood of becoming invasive and allow in trade only those that pose a low risk. The first option is similar to current practices in most Great Lakes jurisdictions, but our results, and the history of invasions from commerce, show that it will not achieve national and state policy goals. The second option is not desirable because it would severely and unnecessarily restrict trade. The most promising alternative, therefore, is to develop and apply risk assessment tools similar to those used for plant imports to Australia (Pheloung et al. 1999) and New Zealand (Champion and Clayton 2000). These countries allow or prohibit species in commerce on the basis of a risk assessment of each new species proposed for introduction. Because only a small proportion of introduced plant species become invasive (Reichard and White 2001), risk assessment offers the opportunity to exclude the few damaging species while allowing beneficial species. The proportion of animal species that becomes invasive is greater than that for plant species (Jeschke and Strayer 2005), meaning that more animal species than plant species would presumably be prohibited under a risk assessment policy. The bulk of animal species sold by the trades in live aquatic organisms in the Great Lakes region are, however, tropical fish, and these would not be affected if such risk-based policies were instituted on a regional basis. In addition to the environmental benefits that the exclusion of invasive species would provide, a policy of risk assessment, such as that practiced in Australia, produces net economic benefits for the importing nation (Keller et al. 2007b).

In the United States, risk assessments are already available for terrestrial woody plants (Reichard and Hamilton 1997), for mollusks (Keller et al. 2007a), and for fish in the Great Lakes (Kolar and Lodge 2002) and California (Moyle and Marchetti 2006). Further risk assessments could be developed to determine the risks posed by other taxa in trade in the Great Lakes region. In our sampling, we identified six plant and two animal species that are not established in the Great Lakes basin, but that are invasive in temperate habitats elsewhere (table 3). Our preliminary assessment, then, is that these species pose high risks of invasion, yet this assessment should be treated cautiously. Although these species are all established invaders in temperate regions, this does not necessarily mean that they can establish in the Great Lakes basin, or that their negative impacts there would be similar to those seen elsewhere. More sophisticated risk assessment protocols designed for the Great Lakes basin, modeled on those available for other taxa (e.g., Kolar and Lodge 2002, Keller et al. 2007a), would lend more certainty to predictions of establishment and impacts than we can provide here.

In addition to assessing environmental benefits from a risk assessment policy, it is also important to consider the costs of restricting commerce in certain species. Our sampling identified 79 plant and 38 animal species available for sale and considered able to establish in the Great Lakes basin. Removing all known Great Lakes invaders from trade would mean that 11 percent of these plant species, and 13 percent of the animal species, would no longer be available to Great Lakes basin retailers. Because the trades sell many species that are not likely to be able to become established (which we did not attempt to sample), the true reduction in the percentage of species available for sale would be much lower.

Although we do not know the financial value of established invaders to the various trades, a simple projection of the costs of Eurasian watermilfoil control in Indiana to other states and provinces indicates that it would be economically rational to remove at least the worst invaders from trade. For any species, however, it will be necessary to consider the benefits from having that species in trade, the degree to which removing it from trade would reduce its rate of spread, and the likely harm from additional spread. Additionally, any efforts to reduce the risk of new invasive species, such as risk assessment or inspections, will have direct costs associated with implementation. These costs should be taken into account, and the investment in risk reduction optimized by considering, for example, the value of the imports in question, the costs of invaders, and the degree to which additional investment in risk reduction will actually reduce the future harm from invaders (Shogren 2000, Batabyal and Lee 2006). Thus, the balance of projected costs and benefits should drive policy (Leung et al. 2002). The most comprehensive such analysis—for the Australian weed risk assessment—concluded that a risk assessment policy provides net financial benefits in addition to environmental benefits (Keller et al. 2007b).

We offer two examples of how this approach may work. First, bighead carp is currently established in the Mississippi drainage basin, where it has large environmental and economic impacts. The Great Lakes are connected to the Mississippi drainage area by the Chicago Sanitary and Ship Canal, and several million dollars have already been spent on the construction and operation of electric barriers to prevent bighead carp and other species from moving through this waterway. An additional US$7.65 million will be spent in 2008 to maintain and upgrade those barriers (USACE 2007). Despite these costs, and despite concerns that bighead carp will cause serious damage if it reaches the Great Lakes, we saw the fish being sold live in food stores in Chicago, much closer to Lake Michigan than the electric barriers are. The City of Chicago has since banned the sale of live specimens, judging that the potential costs of having this species in trade outweigh the benefits. In contrast, goldfish, which are valuable to the pet industry, are a relatively minor invader in the Great Lakes basin, and their range is unlikely to expand through future introductions. Because removing this species from trade would probably generate greater costs than benefits, removal would not seem to constitute rational policy.

Management and policy changes are needed not only for the species targeted for sale but also for the species that contaminate them. Gastropods, one of the most common taxa found in our contaminant sampling, are well-known invaders around the world (Cowie and Robinson 2003), including the Great Lakes, where species such as the New Zealand mudsnail (*Potamopyrgus antipodarum*) are already established (Zaranko et al. 1997). Consequently, the transport of large numbers of gastropods and other invertebrates of uncertain origin and taxonomy may pose large risks for future invasions.

For three reasons, we believe the local nursery–water-garden trade may be the most likely source of new invaders from contamination. First, it delivers significantly more contaminants than other trades across a range of plant morphologies. Second, a large proportion of these contaminants are gastropods. Third, the local nursery trade displays most of its plants in outdoor ponds before sale, so contaminants are likely to be adapted to the conditions where they will be released. In contrast, plants used in the local pet trade are kept in heated tanks, and those species are less likely to survive if released. The relative risks posed by Internet pet/nursery sales and by the biological supply trade are more difficult to determine. Although we found few contaminants in samples delivered by these trades, the rapid transport of many species internationally and across continents presents the opportunity for novel introductions.

Determining the exact risks posed by macroinvertebrate contaminants of aquatic plants will require further research. Because of the large number and diversity of contaminants, however, the only effective long-term policy may well be to require contaminant-free domestic and foreign shipments, to conduct more inspections, and to impose penalties for noncompliance. The appropriate inspection procedures will vary, depending on a number of factors, including the practices of the exporter or wholesaler (i.e., has the shipment already been certified free of contaminants?) and the value of the commodity being imported (Batabyal 2006, Batabyal and Lee 2006). Until all products sold are known to be free of undesirable contaminants, a simple and cheap management practice to reduce introductions would be to shake all plants in a tub of water immediately after delivery, and immediately before their sale. This will remove most of the macroinvertebrates, although it will still be necessary to visually check for gastropods. Such a practice could be instituted voluntarily by wholesalers and retailers or mandated by regulation.

Because the Great Lakes are a contiguous water body, the efforts of national and state agencies, as well as trade groups, to reduce the risk of invasions will be most effective when they are coordinated across the region. To illustrate this, we note that although live bighead carp can no longer be sold in Chicago, the species remains available elsewhere in the Great Lakes basin (Rixon et al. 2005), thus constituting an invasion risk to the whole region. For this species and others, our work has shown that the national and state policy goals of preventing the introduction of new invasive species and the spread of established invaders are unlikely to be met unless there are changes in the species sold by the trades in live aquatic organisms, in the ways of determining which species should be in trade, and in the practices regarding contaminants. We have suggested a number of actions that would help to meet these policy goals while causing minimal costs to commerce. In fact, such policies may bring net financial rewards to society (Keller et al. 2007b).

Acknowledgments

Christine Van Loon, Annie Cox, and Sadie Rosenthal assisted with sampling, and Cynthia Kolar provided much useful advice regarding study design. This work was funded by grants from Illinois–Indiana SeaGrant (R/ES-05-01 to D. M. L.) and the Integrated Systems for Invasive Species project, funded by the National Science Foundation (DEB 02-13698 to D. M. L.).

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doi:10.1641/B570509
Include this information when citing this material.