Invasive Aquatic Species in Ontario: A Review and Analysis of Potential Pathways for Introduction

ABSTRACT

We review eight different pathways for invasion by aquatic species into Ontario. These include fish stocking programs, private aquaculture, bait industry, aquarium and ornamental pond industry, live food fish industry, recreational boating, canals and diversions, and commercial shipping. These pathways have been responsible for the introduction of more than 160 invasive aquatic organisms into Ontario. Due to several gaps in policy and legislation, we conclude that the greatest potential pathways for the future introduction and spread of invasive aquatic species are associated with ballast water from the shipping industry, the live food fish industry, and the ornamental pond/aquarium trade. We offer recommendations to reduce the potential for establishment of additional invasive aquatic species. New legislation is required and public awareness programs need to be expanded. Response protocols need to be developed which clearly define roles and responsibilities of different agencies. Finally, a more coordinated effort between stakeholders and various levels of government with regard to invasive aquatic species is needed.

Introduction

Ontario, covering an area of 2.8 million km^2 (1.1 million miles^2), is one of the largest jurisdictions in North America (Figure 1). There are in excess of 250,000 inland lakes, thousands of kilometres of streams and rivers, and waters of 4 of the Laurentian Great Lakes within the province of Ontario. It has been estimated that Ontario accounts for approximately 15% of the world's freshwater. Ontario waters are known to support 165 species of fish, 128 of which are native species (Mandrak and Crossman 1992).

One of the most pressing ecological issues today involves the transfer and spread of non-indigenous species. Non-indigenous species may be defined as plants or animals which are transferred to areas outside of their historic or natural geographic range (Fuller et al. 1999).

Invasive aquatic species can have profound economic and ecological impacts. An estimated $500 million is spent annually by Canada on efforts to control invasive aquatic species in the Great Lakes (Commissioner of the Environment and Sustainable Development 2001). MacIsaac (2003) estimated costs of up to $750 million annually for damage to aquatic ecosystems in Canada. Worldwide, the impact of invasive aquatic organisms is estimated to cost more than $314 billion per year in damage and control costs (Pimentel 2002).

From an ecological perspective, invasive species can often cause major disruptions to native fauna. Native species may be reduced in numbers, driven to extinction directly by competition and predation, or be genetically altered by hybridization with non-indigenous species. Invasive aquatic species are considered to be one of the major threats to fish species at risk in the Great Lakes area (A. Dextrase, Ontario Ministry of Natural Resources, pers. comm.). Even introductions of popular sport fish species such as rainbow trout (*Oncorhynchus mykiss*) and largemouth bass (*Micropterus salmoides*) have had negative impacts on native fish species (see Kerr and Grant 2000). Between the early 1800s and 2001, more than 160

Figure 1. Geographic location of the Laurentian Great Lakes and province of Ontario.

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invasive aquatic organisms were introduced into Ontario (Table 1) (see listing by de Lafontaine and Costan 2002).

Concern over the potential impacts of invasive aquatic species is not a recent phenomena. Over the past 40 years there have been several international workshops and symposia on invasive aquatic species (e.g., Loftus 1968; AFS 1986; Billington and Hebert 1991).

Since eradication of an invasive species is seldom possible, prevention is the key. However, in Canada, most existing regulations were not designed to prevent the transfer, or establishment, of invasive species. Leach and Lewis (1991) concluded that current legislation in Ontario and Canada has not been adequate to prevent the introduction of unwanted invasive species. Recently, renewed concern has been expressed about the lack of effective response protocols at both the national and provincial level to deal with invasive species (Gelinas 2003; Miller 2003).

There is the need to identify species with the potential of having the greatest impact as well as pathways with the greatest likelihood for introducing invasive species. In this article, we examine eight different pathways by which invasive aquatic species may be introduced into Ontario, evaluate legislative and mitigative measures currently in place to prevent unauthorized introductions through these pathways, and make recommendations for action.

Pathways of Introduction

1. Fish Stocking Programs

Authorized introductions, in the form of fish stocking projects, have been identified as a leading vector for the spread of fishes in North America (Crossman and Cudmore 2000b). Benson (2000) reported that over 200 non-indigenous fish species have been stocked in waters of North America. There are several reasons for the intentional stocking of fishes but the most common is to create or enhance a fishery. Historically, there have been several examples of government-sanctioned stocking programs in Ontario (e.g., sockeye [kokanee] salmon *O. nerka*, cherry salmon *O. masou*, and Arctic grayling *Thymallus arcticus*) which, although well intentioned, represented unwarranted ecological risks. Several fish species, including common carp (*Cyprinus carpio*), brown trout (*Salmo trutta*), rainbow trout, coho salmon (*O. kisutch*), and Chinook salmon (*O. tshawytscha*) have become established in the Great Lakes basin as a result of stocking programs (Crawford 2001). Many other species, including smallmouth bass (*Micropterus dolomieu*) and walleye (*Sander vitreus*), have had their Ontario range extended through intentional releases (Dimond and Potter 1996; Lasenby and Kerr 2000).

The province of Ontario and its partners have an active fish stocking program. The Ontario Ministry of Natural Resources (OMNR) operates 10 provincial fish culture stations and releases between 8 and 9 million fishes annually in over 1,400 waters (inland waters and various sites on four Great Lakes). The primary species stocked include lake trout (*Salvelinus namaycush*), brook trout (*S. fontinalis*), brown trout, F1 splake (*S. fontinalis* x *S. namaycush*), rainbow trout, Chinook salmon, coho salmon, and walleye (Table 2). The vast majority of these fishes are reared and released at relatively advanced life stages (e.g., yearlings). In addition, under the Community Fisheries and Wildlife Involvement Program (CFWIP), approximately 12–15 million fishes are reared and stocked in public waters annually by external partners (Kerr 2002). Species stocked include brown trout, rainbow trout, Chinook salmon, and walleye. The majority (>90%) of fishes stocked by partners are released at very early stages of life (e.g., fry).

Private individuals, cottage associations, and interest groups can obtain permission from OMNR to purchase fishes from the private sector for stocking in public waters. Although detailed records are not available, this is not believed to be a major source of fish stocking in the province. While no authorization is required for the purchase of fishes from the private sector for release into private waters, the Ontario Fishery Regulations set out specific criteria that must be met with respect to the source of fishes and the physical characteristics of the receiving water.

All stocking activities in public waters are directed by provincial policy and associated guidelines (OMNR 2002) as well as international agreements on individual Great Lakes. Provincial fish culture facilities also adhere to rigorous fish health standards (GLFC 1993; OMNR 2003b). Fish stocking projects involving introductions or range extensions are subject to the provincial Environmental Assessment Act. Under this act, a stocking project must be screened to evaluate the potential impacts as well as determine the appropriate

Table 1. Invasive aquatic species introduced into the Laurentian Great Lakes and inland waters of Ontario (from Mills et al. 1993 and Riccardi 2001).

Fauna	# Species Introduced
Aquatic plants	56
Fish	26
Algae	25
Mollusks	17
Crustaceans	15
Miscelaneous invertebrates	14
Shoreline trees/shrubs	5
Oligochaetes	3
Diseases/pathogens	3

Stocking programs have resulted in the introduction of several new fish species and extended the range of some native species.

Table 2. Fishes stocked in Ontario waters in 2002 by the Ontario Ministry of Natural Resources.

Fish Species	Great Lakes	Inland Waters	Total Stocked
Atlantic salmon (*Salmo salar*)	208,049	1,656	209,705
aurora trout (*Salvelinus fontinalis timagamiensis*)	0	1,603	1,603
brook trout (*Salvelinus fontinalis*)	0	1,209,369	1,209,369
brown trout (*Salmo trutta*)	162,969	168,998	331,967
Chinook salmon (*Oncorhynchus tshawytscha*)	569,468	0	569,468
coho salmon (*O. kisutch*)	177,881	0	177,881
F_1 splake (*Salvelinus namaycush* x *S. fontinalis*)	0	851,884	851,884
lake trout (*Salvelinus namaycush*)	3,342,598	948,616	4,291,214
lake whitefish (*Coregonus clupeaformis*)	0	141,360	141,360
rainbow trout (*O. mykiss*)	156,705	219,569	376,274
walleye (*Sander vitreus*)	0	61,320	61,320
Total	**4,617,670**	**3,604,375**	**8,222,045**

evaluation and consultation process (OMNR 2003a). Stocking proposals involving non-indigenous species are reviewed using established risk assessment protocols outlined in the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2002). This code was developed to provide a consistent risk analysis procedure for assessing the potential impacts of intentional introductions and transfers of aquatic organisms across Canada.

Currently, risks associated with intentional fish stocking activities in Ontario are believed to be minimal. Some concerns, with respect to the relative absence of disease control standards in fish culture projects involving external partners, need to be addressed. Currently, partnership hatcheries, operated by community interest groups, do not have any requirements for emergency disease reporting. Disease reporting procedures and response protocols need to be developed for fish culture projects sponsored by the provincial CFWIP program.

In some cases, private individuals have illegally moved fishes from one water to another to create a new fishery or enhance the forage base. These are usually isolated occurrences which are difficult to prevent.

2. Private Aquaculture

Aquaculture is currently one of the fastest growing food production sectors in the world and can include both land-based facilities and cage culture operations within natural waterbodies (Office of the Commissioner for Aquaculture Development 2003). Approximately 193 private aquaculture facilities are currently licenced in Ontario (M. Muschett, Ontario Ministry of Natural Resources, pers. comm.). Rainbow trout is the most common species reared in Ontario, accounting for 95% of industry production (OMNR 2004). In 2002, rainbow trout production exceeded 4,500 metric tonnes (Moccia and Bevan 2003). The estimated farm-gate value of production exceeds $16 million (Moccia and Bevan 2003). The bulk of private production is directed to food production with a much smaller proportion being sold to individuals for stocking private waters.

The private aquaculture industry is regulated under the Fish and Wildlife Conservation Act which replaced the Game and Fish Act in 1999. This legislation identifies the species which can be cultured, ensures mandatory reporting of designated emergency diseases, stipulates minimal security standards to prevent escapement, and dictates that escapements must be reported. Other provisions allow immediate intervention to improve security measures if required. Federal import restrictions related to disease certification for salmonid species, regardless of the destination hatchery, and emergency disease reporting requirements for government-operated fish culture stations and all commercial operations are currently in place.

Under provincial policy, all private aquaculture facilities are subject to evaluation, using a short-form risk assessment protocol, to determine if a requested species can be cultured and, if it can, what minimum security measures must be in place. Risk of fish escape is higher in cage culture operations (M. Muschett, Ontario Ministry of Natural Resources, pers. comm.). In Ontario, rainbow trout is the only species currently approved for commercial cage culture in public waters and this must occur only in waters where rainbow trout already exist.

Prior to 1995, only bass (largemouth bass and smallmouth bass) and trout (brook trout and rainbow trout) were eligible for culture in Ontario. With changes to the Game and Fish Act, and subsequent institution of the provincial Fish and Wildlife Conservation Act, the number of species eligible for culture increased substantially. Currently there are 41 aquatic organisms, including 5 species of crayfish and 3 genera of tilapia (*Oreochromis*, *Sarotheradon*, and *Tilapia*) which are eligible for private culture in Ontario (Table 3). Federal legislation prohibits the culture of genetically modified fish in Canada.

While the aquaculture industry is responsible for the introduction of 96 species of fish in North America (Crossman and Cudmore 2000e), few, if any, introductions have been attributed to the Ontario industry. The primary concerns with private aquaculture involve not only the transfer, or escapement, of a species into a new environment but also the transmission of disease (Stewart 1991; Walker et al. 2003). Private aquaculture facilities should continue to be closely monitored to ensure they maintain appropriate facility security measures.

OMNR

Invasive aquatic species can be spread by anglers emptying their bait buckets at the end of a fishing trip.

3. Bait Industry

In Ontario, recreational anglers may collect their own bait or buy commercially-sold live bait. Improper disposal of live baitfish has been attributed as the source of introduction of at least 14 species in Ontario (Litvak and Mandrak 2000).

Ontario's bait industry is regulated through the provincial Fish and Wildlife Conservation Act and the federal Fisheries Act (Ontario Fishery Regulations). The bait industry consists of various species of baitfishes, crayfishes, frogs, and leeches. Baitfish are defined under the Ontario Fishery Regulations to include cisco (*Coregonus artedii*), darters

(Etheostomatinae), minnows (any species of Cyprinidae that is native to Ontario; carp and goldfish are excluded), mudminnows (Umbridae), sculpins (Cottidae), sticklebacks (Gasterosteidae), suckers (Catostomidae), and the trout-perch (*Percopsis omiscomaycus*). The most common species of baitfish in Ontario are emerald shiner (*Notropis atherinoides*), golden shiner (*Notemigonus crysoleucas*), and fathead minnow (*Pimephales promelas*; OMNR and the Bait Association of Ontario [BAO] 2004). The import of live baitfish, crayfish, and salamanders from outside the province, for the purpose of angling, is prohibited.

There are 7,126 bait harvest areas in Ontario that currently support an industry comprised of 696 harvesters and 688 dealers (Table 4).

Litvak and Mandrak (1993) concluded that existing regulations prohibiting release of live baitfish and importation of baitfishes were not effective. However, there have been several new regulations implemented in recent years. A 1999 regulation prohibited the importation of leeches by anglers into Ontario. A complete ban on the importation of leeches, including by commercial operators, should be in place for 2005. New regulations have also recently been passed to prohibit the harvest of species at risk in Ontario. These species will include the gravel chub (*Erimystax x-punctatus*), redside dace (*Clinostomus elongatus*), cutlip minnow (*Exoglossum maxillingua*), lake chubsucker (*Erimyzon sucetta*), and eastern sand darter (*Ammocrypta pellucida*). Finally, there are areas of Ontario (e.g., provincial parks, reclaimed lakes, special fishing areas) where the use or possession of live baitfish is prohibited.

For frog conservation purposes, only the northern leopard frog (*Rana pipiens*) in eastern Ontario may be harvested by the commercial bait industry. However, they may be sold anywhere in the province. There are currently some concerns about transfer of diseases (e.g., Ranavirus) as frogs are moved around the province (Kidd 2004).

Although tight regulations restrict imports of bait from outside the province, there is no control over transfers of bait within the province of Ontario. The BAO is currently working to develop protocols to minimize transfers of some species of baitfish and other organisms (e.g., fellow travellers) associated with holding water.

Another concern is the spread of the rusty crayfish (*Orconectes rusticus*). Rusty crayfish are an aggressive species that can cause a variety of negative environmental and economic impacts when introduced (Gunderson 1999). They are believed to have spread to Ontario and the northern United States by anglers using them as bait. A more thorough examination of Ontario's crayfish industry is currently underway by OMNR and the BAO.

Probably the greatest concern regarding the use of live bait is with the angler who, at the end of a fishing trip, empties the remainder of their bait bucket into the water where they were fishing. This is believed to be how the rudd (*Scardinius erythrophthalmus*) was introduced to Ontario (Crossman et al. 1992). What is most troublesome is that many anglers continue this practice despite knowing of the potential risks involved. Litvak and Mandrak (1993) reported that 41% of anglers released live bait despite provincial regulations that prohibit the release of live fish into a body of water from which they did not originate. In a 1998 survey, Dextrase and MacKay (1999) found that 46% of anglers emptied their bait buckets at the end of their fishing trip. In a similar study, Kulwicki et al. (2003) reported that 36% of anglers in Michigan and Wisconsin released live bait into the water after they were done fishing. Ludwig and Leitch (1996) concluded that drastic policy measures would be required to reduce dispersal of fish via angler's bait buckets. Public education programs should also be used to reduce the number of unauthorized releases, but it is doubtful if this type of activity can ever be eliminated.

Table 3. List of species eligible for culture in Ontario.

Common Name	Scientific Name
American eel	*Anguilla rostrata*
Arctic char*	*Salvelinus alpinus*
Atlantic salmon	*Salmo salar*
black crappie	*Pomoxis nigromaculatus*
bluegill	*Lepomis macrochirus*
bluntnose minnow	*Pimephales notatus*
brook trout	*Salvelinus fontinalis*
brown bullhead	*Ameiurus nebulosus*
brown trout	*Salmo trutta*
channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
common carp	*Cyprinus carpio*
common shiner	*Luxilus cornutus*
crayfish	*Orconectes immunus*
	Orconectes virilis
	Orconectes propinquus
	Cambarus robustus
	Cambarus bartonii
creek chub	*Semotilus atromaculatus*
emerald shiner	*Notropis atherinoides*
fathead minnow	*Pimephales promelas*
finescale dace	*Phoxinus neogaeus*
golden shiner	*Notemigonus crysoleucas*
goldfish	*Carassius auratus*
cisco (lake herring)	*Coregonus artedii*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*
lake whitefish	*Corgonus clupeaformis*
largemouth bass	*Micropterus salmoides*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*
pink salmon	*Oncorhynchus gorbuscha*
pumpkinseed	*Lepomis gibbosus*
rainbow trout	*Oncorhynchus mykiss*
redbelly dace	*Phoxinus eos*
sauger	*Sander canadense*
smallmouth bass	*Micropterus dolomieu*
tilapia*	Genera *Oreochromis, Sarotheradon*
	Tilapia
walleye	*Sander vitreus*
white sucker	*Catostomus commersoni*
yellow perch	*Perca flavescens*

* A high level of facility security is required for culture in all parts of Ontario.

Table 4. 2003 statistics from Ontario's bait industry (OMNR and BAO 2004).

# Bait harvester licences	696
# Bait dealer licences	688
# Bait Harvest Areas	7,126
# Baitfishes harvested (dozen)	5,195,742
# Cisco (lake herring) harvested (dozen)	5,665
# Emerald shiners harvested (dozen)	1,695,578
# Fish species harvested	15–20 major species
# Frogs harvested (dozen)	6,924
# Leeches harvested (dozen)	339,967
# Crayfishes harvested (dozen)	16,726
Value of bait industry	**$19,129,398**

Overall, Ontario's bait industry has embarked on several initiatives designed to reduce the introduction or spread of invasive aquatic species. For example, the BAO, in cooperation with the Ontario Ministry of Natural Resources, recently provided Hazard Analysis and Critical Control Points (HACCP) training sessions for bait harvesters and dealers to identify critical points for preventing the spread of invasive aquatic species and initiate practices to reduce inadvertent transfers. One issue that needs consideration by government and the industry involves the unrestricted movement of bait species and water, which may contain unwanted travellers, within the province. Public education must be increased to reduce the occurrence of bait bucket releases of legal baitfish species. Government and industry must continue to work closely to develop best management practices which reduce the risk of transferring invasive aquatic species across Ontario.

4. Aquarium and Ornamental Pond Industry

The aquarium trade has been identified as one of the most common pathways for introduced aquatic animals (Benson 2000; Crossman and Cudmore 2000c). At least 12 species of exotic plants and animals have been introduced into the Great Lakes basin as a result of aquarium releases (Dextrase and Paleczny 2000). Aquarium fishes such as the pacu (*Colossoma* spp.), oscars (*Astronotus* spp.), and piranha (Characidae) are discovered in Ontario waters each year (Dextrase 2002). Undoubtedly, there are other unreported cases. There are also concerns about the introduction and spread of parasites and diseases (e.g., spring viremia of carp) from ornamental species and their holding water. Although few statistics are available on Ontario's aquarium and ornamental pond industry, it is believed that this sector, particularly water gardening and ornamental ponds, is expanding rapidly. Species such as koi (*Cyprinius carpio*), snakeheads (Channidae), goldfish (*Carassius auratus*), turtles, and snails are commonly maintained in backyard water gardens (B. MacKay, Ontario Ministry of Natural Resources, pers. comm.).

A growing concern involves the release of unwanted aquarium fishes into the wild by their owners who think it is a humane way of disposing of an unwanted pet. In other instances, an individual may release plants or other organisms into local waters when closing their ornamental water pond for the winter. There are also a number of ethnic customs and religious beliefs which involve releasing one fish for each one eaten or releasing a fish into the wild to celebrate a special event.

The unintentional introduction of aquatic plants from aquaria and ornamental water gardens is also believed to be a relatively common occurrence. The fanwort (*Cabomba caroliniana*) and European frog-bit (*Hydrocharis morsus-ranae*) are two recent examples in Ontario. Aquatic plants are routinely ordered and shipped across the continent. In a U.S. study, misidentified aquatic plants were found in 18% of orders, unordered seeds were found in 43% of orders, and 10% of orders contained seeds of noxious weeds or exotic species (Maki and Galatowitsch 2004).

Eight of 22 mollusk species introduced to North America can be attributed to the aquarium trade (Mackie 2000). Potential impacts of introduced mollusks include being vectors for human parasites, competing with native fauna, and impacting navigation and recreational activities (Hebert et al. 1991; Griffiths 1993; Martel et al. 2001).

Control over the aquarium/ornamental pond trade is a joint federal-provincial responsibility but there are currently very few regulations pertaining to this industry. Under the provincial Fish and Wildlife Conservation Act, the aquarium industry is exempted from needing a licence to culture aquatic species within an aquarium. There are few import restrictions and they are also exempt from a licence requirement to buy and sell fishes not found in Ontario waters if the purpose is for the aquarium trade. The Ontario Fishery Regulations prohibit the release of fish into public waters. There are also provisions to restrict the possession and importation of designated species but, to date, this has only been used for ruffe (*Gymnocephalus cernuus*). Only recently, a provincial regulation was passed to ban the live sale of several species of carps, gobies (Gobiidae), and snakeheads for any purpose. It appears that orders of exotic species through the mail or via Internet are on the increase making control even more difficult. MacDonald (2002) concluded that the distribution of responsibilities between various federal and provincial agencies precluded swift and effective action with respect to invasive species associated with the aquarium trade.

Recently, efforts by the Canadian Association of Aquarium Clubs have been initiated to educate aquarium hobbyists of the impacts of releasing pets or plants into the wild. This has included establishing a "Fish Rescue Program" which provides an alternate disposal method to release for unwanted aquarium pets. However, more coordinated programs with industry representatives are required. Because of the relative lack of regulatory control and import restrictions into Ontario, we believe that the aquarium/ornamental pond industry is a pathway with one of the highest risks.

5. Live Food Fish Industry

Live food fish can be defined as any fish, or other aquatic organism, which is imported, or transferred live, for distribution and sale for human consumption. The live food fish industry includes finned fish, shellfish, and crustaceans. Species associated with the food fish industry are an increasing segment of invasive aquatic species introductions (Fuller 2002). Goodchild and Dextrase (2000) identified several species of fishes, plants, and invertebrates whose introduction and spread could be attributed to the live food fish industry.

Ontario's live food fish industry is expanding rapidly, particularly in the Greater Toronto Area (GTA). Based on Canada Food Inspection Agency (CFIA) records, over 700,000 kg of live freshwater fishes and over 1 million kg of live invertebrates and marine species are imported to the GTA annually. Not all imported food fishes are reported to authorities. For example, over 1 million kg of live freshwater fishes were purchased by just 4 of the major wholesalers in the GTA; however, it has been estimated that more than 2 million kg of live freshwater fishes are sold annually (Goodchild 1999a). The major non-indigenous fish species sold are bighead carp (*Hypophthalmichthys nobilis;* approximately 52% by weight), tilapia (23% by weight), and grass carp (*Ctenopharyngodon idella*; 10% by weight; Goodchild 1999b). Other common fishes in the live food fish industry include striped bass (*Morone saxatilis*), eels (Anguillidae), and northern pike.

Bighead carp have already been found in Lake Erie (E. Holm, Royal Ontario Museum, pers. comm.). Grass carp have been documented in Lakes Huron, Erie, and Ontario (Crossman et al. 1987; Crawford and MacKay 2003). The likely source of these carps was from shipments of live fish from the United States to Canada or their release after purchase.

There are several reasons for concern about non-indigenous food fish being introduced into Ontario waters. With few exceptions, fishes can be purchased and taken from the wholesale or retail out-

lets while still alive. Sterility is not a requirement for live food fishes. There are limited restrictions (which are difficult to enforce) on the disposal of holding water which may contain non-target species, pathogens, gametes or fertilized eggs. Unsold fish may be released by the transporter. There is also the potential for disposal of large quantities of dead, or dying, fish into natural waterways. Finally, monitoring of wholesale and retail facilities is limited.

Ontario's live food fish industry is regulated primarily by the federal Fish Inspection Act and monitored by the Canadian Food Inspection Agency. They inspect only a small fraction (2%) of imports and concentrate mainly on proper labelling and the quality of fishes for food (C. Goodchild, Ontario Ministry of Natural Resources, pers. comm.). Many fishes are either misidentified or incorrectly labelled. A wide variety of federal, provincial, and municipal agencies also have an involvement in this industry but the coordination of efforts is difficult.

Based on a review of Ontario's live food fish industry, Goodchild (1999a) identified several potential risks. These included the chance of a invasive fish species being introduced to Ontario waters, a reduction or loss in genetic diversity, and transfer of non-target organisms or pathogens in the water used to hold or transfer fish. Several of these activities are covered by various statutes; however existing legislation is generally inadequate to deal with the threat of unauthorized introductions or transfers from the live food fish industry. Goodchild (1999a) concluded that the overall pathway risk associated with the live food fish industry was high. Despite recent regulations to prohibit the buying or selling of live carps, snakeheads, or gobies, we believe that proactive measures, including development of new legislation, need to be implemented to prevent future undesirable introductions.

OMNR

Recreational boating can serve as a secondary pathway of introduction from the Great Lakes to inland waters of Ontario.

6. Recreational Boating

Receational boating may be defined as public use, and overland transportation, of watercraft including powerboats, yachts, personal watercraft, sailboats, canoes, paddleboats, and associated equipment (e.g., trailers). Recreational boaters represent a potential source of transfer of undesirable organisms from one waterbody to another (MacKay and Rendall 2000). For example, recreational boaters have been identified as the principal source for spreading Eurasian watermilfoil (*Myriophyllum spicatum*) (Crowell et al. 1999). The most common transfers result from water in livewells, or organisms (e.g., zebra mussels, aquatic plants, etc.) attached to the boat hull, motor, or trailer. Dextrase (2002) identified recreational boating as an important secondary invasion pathway for alien species that were originally introduced to the region by some other pathway. For example, recreational boaters using the Rideau Canal were considered to be the source for transferring zebra mussels (*Dreissena polymorpha*) from the Great Lakes to the Rideau River (Martel 1995).

In a 1998 survey of resident anglers (Dextrase and MacKay 1999), 72% of respondents owned boats and 38% reported that they boated, or fished, in waters infested by invasive non-indigenous species. One-half of all boaters reported moving their boats between waterbodies with approximately 15% moving among waterbodies in the same day. Similarly, Gunderson (1994) reported that 16% of boaters in Ohio, Wisconsin, and Minnesota visited two or more waterbodies in the same day. Tournament anglers who regularly transport boats over large geographic distances potentially represent a higher risk as a vector in transfer.

Little, if any, legislation in Ontario directly prohibits the transfer of invasive aquatic organisms by recreational boating. Typically, voluntary precautions taken include draining water from the boat, visual inspections, and the removal of any obvious attachments. Increased public education programs, particularly along some of Ontario's major waterways, will reduce but not eliminate this risk.

7. Canals and Diversions

Canals and channels for shipping and bulk water diversion create artificial connections that allow the free movement of species across physical barriers between (inter-basin) and within (intra-basin) watersheds. Once constructed, the St. Lawrence Seaway provided ready access for invasive species to the Great Lakes (de Lafontaine and Costan 2002; Holeck et al. 2004). Other important artificial waterways include the Chicago Sanitary and Ship Canal, connecting the Mississippi River drainage to the Great Lakes, and the Erie Canal, connecting the Hudson River with Lakes Erie and Ontario (Mills et al. 2000). In Ontario, the Rideau Canal, connecting Lake Ontario and the Ottawa River, and the Trent-Severn Canal, connecting Lake Ontario and Lake Huron, provide major pathways to inland waters from the Great Lakes.

White perch (*Morone americana*) and alewife (*Alosa pseudoharengus*) are both believed to have

invaded Lake Ontario via the Erie Canal (Christie 1972; Smith 1995). Probably one of the most disastrous invasions occurred with the construction of the Welland Canal which circumvented Niagara Falls and allowed sea lamprey (*Petromyzon marinus*) access to the upper Great Lakes (Lawrie 1970). Currently, several species of Asian carp are close to entering the Great Lakes ecosystem from the Mississippi River basin through the Chicago Sanitary and Ship Canal (Moy 2004). This same canal system probably also allowed zebra mussels and round gobies (*Neogobius melanstomus*) to gain access to the Mississippi River basin after becoming established in the Great Lakes (Moore 1991; Blodgett 1992).

One of the largest diversions in Ontario connects the Albany River (Hudson Bay drainage) to lakes Nipigon and Superior. This diversion is probably responsible for several species of fish reaching the Great Lakes from inland waters of northern Ontario (Crossman and Cudmore 2000f).

Mills et al. (2000) concluded that canals and diversions will continue to play a key role in the movement of invasive aquatic organisms in North America. Electric barriers have recently been installed to prevent several carp species from entering the Great Lakes but the effectiveness of these measures have yet to be assessed (Taylor et al. 2003). Low-head barriers have been constructed, with varying degrees of success, to exclude sea lamprey from many Great Lakes tributaries (GLFC 1992). Dams on many tributaries of the lower Great Lakes have probably restricted the movement of other exotic species further inland; however many of these structures have exceeded their lifespan and over the next few years many will either fail or be removed.

Sea lamprey invaded the upper Great Lakes after the Welland Canal allowed them to circumvent Niagara Falls.

OMNR

8. Shipping and Ballast Water

This pathway involves large vessels in the offshore, nearshore, and inland waters of Canada. It includes commercial shipping, naval, fishing, and cruise activities. Since the St. Lawrence Seaway opened in 1959, the role of shipping as an entry vector has increased dramatically. Invasive aquatic species are transported in the ballast water and on the hulls of vessels. The discharge of ballast water from ocean-going vessels has been identified as the foremost pathway for the transfer of invasive aquatic species (Crossman and Cudmore 2000d; Wiley and Claudi 2000). Typically, commercial vessels take on water from their point of origin as they leave port and discharge water when cargo is taken on at another port. Aquatic organisms can thereby be transported and released over great distances.

Globally, at least 100 organisms are believed to have been transported in ballast water and released into new environments (Locke et al. 1993). Of at least 43 non-indigenous species introductions to the Great Lakes, approximately 67% can be attributed to ballast water discharge from commercial vessels (Grigorovich et al. 2003). Some examples of organisms believed to have been introduced from ballast water include fishhook water flea (*Cercopagis pengoi*), quagga mussel (*Dreissena bugensis*), round goby, ruffe, spiny water flea (*Bythotrephes longimanus*), tubenose goby (*Proterorhinus marmoratus*), and zebra mussel.

Canada implemented voluntary ballast water exchange guidelines in 1989 (Wiley 1999). At best, these guidelines serve only to reduce—but not eliminate—the risk of species invasion. Based on a 1990 study involving 525 ocean-going vessels, Locke et al. (1993) reported a voluntary compliance rate of approximately 90%. In 1990, the International Joint Commission (IJC) and the Great Lakes Fishery Commission (GLFC) made a series of recommendations to the governments of Canada and the United States regarding ballast water and invasive species (IJC and GLFC 1990). These included the requirement for all ocean-going vessels to exchange ballast in mid-ocean. Canada is currently developing a national strategy on invasive species but has yet to implement a mandatory ballast water exchange.

Generally, the action taken to date on ballast water discharges is inadequate to safeguard the environment (Gelinas 2003). The ability to regulate ballast water in vessels entering the St. Lawrence-Great Lakes basin would require amendments to several pieces of legislation including the Boundary Waters Act, the Fisheries Act, and the Canada Water Act. Grigorovich et al. (2003) concluded that the Great Lakes remain vulnerable to ship-mediated invasions of aquatic organisms and identified an additional 47 invertebrate species that pose an immediate invasion risk through ballast water discharge.

There is an urgent need for increased research on potential treatment techniques to develop a comprehensive global approach to address this issue and improve the coordination of efforts. Addressing this pathway should be the highest priority as it poses the greatest threat for more introductions to the Great Lakes region.

Discussion

We examined eight of the major potential pathways for the invasion of aquatic species into Ontario waters. Undoubtedly other minor pathways exist. These include extreme weather events, other aquatic organisms (e.g., fishes and birds), barges, and marine aircraft. All of the pathways discussed have resulted in species introductions to Ontario waters. Based on the degree of existing regulatory control, the past role of pathways, and the lack of public education, we conclude that the greatest risks involve ballast water associated with the shipping industry, the live food fish industry, and the aquarium/ornamental pond industry.

The primary goals for any future initiatives must be to keep new invaders from being introduced while making attempts to slow the spread of those invasive species already present. We offer the following recommendations for reducing the risk of any additional invasive aquatic biota from becoming established in Ontario waters.

Policy and Protocols

- Continue to conduct detailed risk analysis for all planned introductions of aquatic species using existing federal and provincial protocols. A precautionary approach is recommended where insufficient information is available to fully evaluate potential impacts.
- Develop criteria to identify "high probability" sites for invasion and the species that could pose the greatest risk.
- Develop and implement suitable protocols and a code of practice for the aquarium and live food fish industries.
- Implement the Hazard Analysis and Critical Control Points protocol for the baitfish, aquarium, and live food fish industries.
- Establish response and detection protocols which clearly define roles and responsibilities of various agencies. This includes developing a "rapid response" capability.
- Develop and implement a ballast water management plan including, but not restricted to, exchange of ballast water and sterilization of residual water and sediments for any ocean-going vessel entering the Great Lakes and connecting waters.
- Coordinate various ongoing efforts regarding invasive species between stakeholders and various levels of government (note: a national strategy is currently under development).
- Expand interprovincial and international cooperative efforts to prevent the spread of exotic species.

Legislation

- Actively enforce existing legislation which prevents the introduction or transfer of invasive aquatic species.
- Amend existing legislation to permit more stringent regulatory control over ballast water discharges.
- Develop new legislation dealing with imports and transfers of species associated with the aquarium trade.
- Implement new legislation to restrict the import of species considered to be high risk for potential impact, prohibit the removal of all live food fishes from a retail outlet, and require triploid certification for live food fishes. New legislation is also required to deal with transfers and introductions of invasive aquatic plants.

Information and Education

- Contribute to a consolidated North American database (e.g., Sea Grant National Aquatic Nuisance Species, Global Invasive Species database) on invasive aquatic species.
- Expand ongoing information and education programs targeting anglers, boaters, pet owners, and ethnic communities about the significant impacts of releasing invasive aquatic species into a natural waterway.

Research and Monitoring

- Foster research initiatives designed to develop and evaluate new control measures.
- Conduct research to evaluate the impacts of various invasive aquatic species.

The future presents many challenges with respect to invasive aquatic species in Ontario. Several species of Asian carp appear poised to enter the Great Lakes from the Mississippi watershed. Tench (*Tinca tinca*) have recently become established in the Richelieu River, a St. Lawrence River tributary, from which they may move upstream through the St. Lawrence Seaway toward Lake Ontario (OMNR 2003c). Known invasive species, such as snakeheads, are already being sold in Ontario pet stores (B. MacKay, Ontario Ministry of Natural Resources, pers. comm.). There are requests to import and stock grass carp for control of aquatic vegetation (M. Muschett, Ontario Ministry of Natural Resources, pers. comm.). Finally, warmer temperatures associated with climate warming may make more Ontario waters suitable for new invasive aquatic species. Mandrak (1989) identified 27 species of fish as potential new invaders to the Great Lakes as a result of climate change. Clearly, the time has come to take more aggressive action to prevent the introduction and spread of undesirable aquatic invaders.

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