# Minnesota Department of Natural Resources AIS CBSM Project

## Literature Scan Research Summary

September 19, 2018

This document is part of the Minnesota Department of Natural Resources (DNR) Invasive Species Program's Community-Based Social Marketing (CBSM) project. The project aims to better promote the adoption of desirable aquatic invasive species (AIS) prevention behaviors and create positive social norms around AIS prevention in Minnesota.

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The goal of the Literature Scan Task is to gather information from published sources to identify research that has been conducted on aquatic invasive species (AIS), particularly behavior-change approaches. The purpose is to outline the anthropogenic sources of AIS relevant to Minnesota; the key Pathways that could contribute to the spread of invasive species, the range of potential target audiences, and interventions undertaken locally and elsewhere. Findings from the Scan will guide subsequent tasks by providing a basis for initial discussions with key experts and will be a resource for more in-depth exploration of best practices, behaviors, barriers, and motivators.

The project team scanned 150+published academic and grey literature, case studies, and technical reports, and summarized the 93 most relevant sources as a means to determine the most important AIS Pathways that could be addressed by a CBSM effort in Minnesota. These selected sources are summarized below in the following categories:

1. Recreational Watercraft (Motorized and Non-Motorized)
2. Recreational Diving
3. Movement of Docks, Lifts, and Equipment (Lake Service Providers)
4. Live Bait Use by Anglers
5. Commercial Bait Trade (Bait Shops, Dealers, Harvesters)
6. Illegal Fish Stocking
7. Aquarium Trade (Stores and Online)
8. Water Garden Trade
9. Live Food Trade
10. Research and Education
11. General Assessment of Pathways

Note: For the purposes of this work, Pathways refers to the mode of transport for an AIS to spread and Sector refers to the group or audience that contributes to the spread of AIS via a Pathway. Pathways may have more than one Sector than can contribute to the spread.

# 1. Recreational Watercraft (Motorized and Non-Motorized)

| Type | Details | Summary |
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| Academic | **Title**: Bilge water as a vector for the spread of marine pests: a morphological, metabarcoding and experimental assessment<br><br>**Authors**: Lauren M. Fletcher, Anastasija Zaiko, Javier Atalah, Ingrid Richter, Celine M. Dufour, Xavier Pochon, Susana A. Wood, Grant A. Hopkins<br><br>**Source**: Biological Invasions, October 2017, Volume 19, Issue 10, pages 2851-2867 | Vessel movements are considered the primary anthropogenic pathway for the secondary spread of marine non-indigenous species. In comparison to the well-studied mechanisms of hull fouling and ballast water, the importance of bilge water for domestic and cross-regional spread of non-indigenous species is largely unknown and has the potential to compromise the overall effectiveness of biosecurity management actions. In this study, the diversity and abundance of biological material contained in bilge water from 30 small vessels (<20 m) was assessed using traditional and molecular identification tools (metabarcoding of the 18S rRNA gene). Laboratory-based studies were also used to investigate the relationship between voyage duration and propagule success. A large taxonomic diversity in organisms was detected, with 118 and 45 distinct taxa identified through molecular and morphological analyses, respectively. Molecular techniques identified five species recognised as non-indigenous to the study region in 23 of the 30 bilge water samples analysed. Larvae and fragments passed through an experimental bilge pump system relatively unharmed. Time spent in the bilge sump was found to affect discharge success, particularly of short-lived and sensitive larvae, but survival for 3 days was observed. Findings show that bilge water discharges are likely to pose a non-negligible biosecurity threat and that further research to identify high-risk vessel operating profiles and potential mitigation measures are warranted.<br>https://link.springer.com/article/10.1007/s10530-017-1489-y |

| Type | Details | Summary |
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| Academic | **Title**: Recreational boats as a vector of secondary spread for aquatic invasive species and native crustacean zooplankton<br><br>**Authors**: Noreen E. Kelly, Kristina Wantola, Erika Weisz, Norman D. Yan<br><br>**Source**: Biological Invasions, March 2013, Volume 15, Issue 3, pages 509–519 | Test of the hypothesis that recreational boats are a vector of secondary spread of AIS among freshwater ecosystems via in-water transport (i.e., while boating between interconnected waterways) in addition to in tow between lakes. Survey conducted of recreational boaters on Lake Simcoe, Ontario. Patterns of boater activities, movements and hygiene habits, suggest recreational boating in the Lake Simcoe region is contributing to the spread of native and invasive species into nearby waterways. Study validates the widespread assumption that recreational boats are an important in-water vector for the secondary spread of both native and invasive zooplankton species. Future management strategies to reduce the spread of AIS should be aimed at increasing awareness of boater hygiene practices, particularly the frequent draining of standing water.<br>https://link.springer.com/article/10.1007/s10530-012-0303-0 |
| Academic | **Title**: Overland Dispersal of Aquatic Invasive Species: A Risk Assessment of Transient Recreational Boating<br><br>**Authors**: Ladd E. Johnson, Anthony Ricciardi, James T. Carlton<br><br>**Source**: Ecological Applications, December 2001, Volume 11, Issue 6, pages 1789-1799 | Predictions of the geographic spread of introduced species are often limited by a lack of data on their mechanisms of dispersal. Study conducted interviews and inspections of boating equipment at public boat launches on Lake St. Clair (Michigan) to assess the potential for the zebra mussel to be dispersed overland to inland waters by transient recreational boating activities. Several mechanisms associated with recreational boating were found to be capable of transporting either larval or adult life stages. Larvae were found in all forms of water carried by boats (i.e., in live wells, bilges, bait buckets, and engines) but were estimated to be 40–100× more abundant in live wells than other locations. Dilution in receiving waters should greatly reduce the risk of establishing new populations by the introduction of larvae. Mussel dispersal from these boat launches did not occur by direct attachment to transient boats. Rather, adult and juvenile mussels were transported primarily on macrophytes entangled on boat trailers and, less frequently, on anchors.<br>Available at: http://www.reabic.net/publ/Johnson_et%20al_2001_biological%20invasions.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Aquatic Invasive Species Transport via Trailered Boats: What is Being Moved, Who is Moving it, and What Can Be Done<br><br>**Authors**: John D. Rothlisberger, W. Lindsay Chadderton, Joanna McNulty, David M. Lodge<br><br>**Source**: Fisheries Magazine, March 2010, Volume 35, Issue 3, pages 121-132 | Study of small-craft boats and trailers to explore type and quantity of aquatic invasive species being transported and effectiveness of management interventions (e.g., inspection crews, boat washing). Surveys of registered boaters and boaters in the field both indicated that more than two-thirds of boaters do not always take steps to clean their boats. Through controlled experiment it was learnt that visual inspection and hand removal can reduce the amount of macrophytes on boats by 88% ± 5% (mean ± SE), with high-pressure washing equally as effective (83% ± 4%) and low-pressure washing less so (62% ±3% removal rate). For removing small-bodied organisms, high-pressure washing was most effective with a 91% ±2% removal rate; low-pressure washing and hand removal were less effective (74% ±6% and 65% ±4% removal rates, respectively). This research supports the widespread belief that trailered boats are an important vector in the spread of aquatic invasive species, and suggests that many boaters have not yet adopted consistent and effective boat cleaning habits and additional management efforts may be appropriate.<br>Available at: https://s3.amazonaws.com/academia.edu.documents/42410780/Aquatic_invasive_species_transport_via_t20160208-14055-ycfpol.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534725510&Signature=2jZCH3GFrCilkHcuRlw67FX7V84%3D&response-content-disposition=inline%3B%20filename%3DAquatic_Invasive_Species_Transport_via_T.pdf |
| Academic | **Title**: Marine boating habits and the potential for spread of invasive species in the Gulf of St. Lawrence<br><br>**Authors**: Emily Darbyson, Andrea Locke, John Mark Hanson, J. H. Martin Willison<br><br>**Source**: Aquatic Invasions, 2009, Volume 4, Issue 1, pages 87-94 | The potential for boating to disperse the clubbed tunicate and green crab in the southern Gulf of St. Lawrence was investigated using interviews with recreational and commercial boaters in eastern Prince Edward Island (PEI) and collecting bilge water and hull scrapings. Recreational boats, nearly half of which were docked outside their home estuary, were a more likely vector of dispersal than commercial fishing boats that tended to return to the same port each night. Northeastern Nova Scotia and the southern coast of PEI were most at risk for the spread of clubbed tunicate, while green crab could be transported to PEI and eastern New Brunswick. The Magdalen Islands, Quebec, were also predicted as a site to which green crabs could spread, and the first green crabs were detected there two years after the study was completed.<br>Available at: http://aquaticinvasions.net/2009/AI_2009_4_1_Darbyson_etal.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Recreational boating: a large unregulated vector transporting marine invasive species<br><br>**Authors**: Cathryn Clarke Murray, Evgeny A. Pakhomov, Thomas W. Therriault<br><br>**Source**: Diversity and Distributions, November 2011, Volume 17, Issue 6, pages 1161-1172 | Hull fouling communities have been recognized to harbour non-indigenous species (NIS), but presence should not be equated with transport. This study characterizes the presence of NIS in hull fouling communities to determine if host vessels transport those species and evaluates the importance of recreational boating as a vector for introduction and spread. Dive surveys were conducted at marinas in coastal British Columbia to record the presence of NIS and to estimate their per cent cover, in addition to boater surveying on common travel and maintenance practices. Results found highly invasive species, even on active and otherwise clean boats. Fouling levels were highly variable amongst individual boats both within marinas and across regions. No relationship was identified with antifouling paint age or travel frequency. The main conclusion is that recreational boating is a major vector contributing to the spread of marine invasive species; recreational boats represent a high-risk vector both for primary introduction and secondary spread of marine NIS.<br>Available at: https://s3.amazonaws.com/academia.edu.documents/40548958/Recreational_boating_A_large_unregulated20151201-6784-18o32w6.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534725651&Signature=YTENpSpG0AMc%2B%2BShLlAt5GDxOVY%3D&response-content-disposition=inline%3B%20filename%3DRecreational_boating_a_large_unregulated.pdf |
| Academic | **Title**: Boats, Pathways, and Aquatic Biological Invasions: Estimating Dispersal Potential with Gravity Models<br><br>**Authors**: Brian Leung, Jonathan M. Bossenbroek, David M. Lodge<br><br>**Source**: Biological Invasions, March 2006, Volume 8, Issue 2, pages 241–254 | Entire pathways for biological invaders should be considered because multiple species are dispersed through the same vectors. The paper uses production-constrained gravity models to describe movement of recreational boaters between lakes – potentially the most important pathway of overland dispersal for many aquatic organisms. Model results were compared observed data based on creel surveys and recreation boater surveys. Four metrics of pathway characteristics were evaluated: boater traffic to individual lakes, distances traveled to reach these lakes, Great Lakes usage and movement from the Great Lakes to inland waters. These factors influence the propagule pressure (hence the probability of establishment of invasive populations) and the rate of spread across a landscape. Study results suggest the ability to capture distances traveled to most but not all lakes, demonstrating that production-constrained gravity models will be generally useful for modeling invasion pathways between non-contiguous locations.<br>Available at: https://www.utoledo.edu/nsm/lec/pdfs/Leung2006.pdf |

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| Academic | **Title**: Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species<br><br>**Authors**: Lucy G. Anderson, Alison M. Dunn, Paula J. Rosewarne, Paul D. Stebbing<br><br>**Source**: Biological Invasions, August 2015, Volume 17, Issue 8, pages 2287–2297 | Watersports equipment can act as a vector for the introduction and spread of invasive non native species (INNS) in freshwater environments. To support advice given to recreational water users under the UK Government's *Check Clean Dry* biosecurity campaign and ensure its effectiveness at killing a range of aquatic INNS, we conducted a survival experiment on seven INNS which pose a high risk to UK freshwaters. The efficacy of exposure to hot water (45 °C, 15 min) was tested as a method by which waters users could 'clean' their equipment and was compared to drying and a control group (no treatment). Hot water had caused 99 % mortality across all species 1 h after treatment and was more effective than drying at all time points (1 h: $\chi^2 = 117.24$, $p < 0.001$; 1 day $\chi^2 = 95.68$, $p < 0.001$; 8 days $\chi^2 = 12.16$, $p < 0.001$ and 16 days $\chi^2 = 7.58$, $p < 0.001$). Drying caused significantly higher mortality than the control (no action) from day 4 ($\chi^2 = 8.49$, $p < 0.01$) onwards. In the absence of hot water or drying, 6/7 of these species survived for 16 days, highlighting the importance of good biosecurity practice to reduce the risk of accidental spread. In an additional experiment the minimum lethal temperature and exposure time in hot water to cause 100 % mortality in American signal crayfish (*Pacifastacus leniusculus*), was determined to be 5 min at 40 °C. Hot water provides a simple, rapid and effective method to clean equipment. We recommend that it is advocated in future biosecurity awareness campaigns.<br>Available at: https://link.springer.com/article/10.1007/s10530-015-0875-6 |
| Academic | **Title**: Preventing the Spread of Aquatic Invasive Species: Boater Concerns, Habits, and Future Behaviors<br><br>**Authors**: Amit Pradhananga, Mae A. Davenport, Erin Seekamp, Darren Bundy<br><br>**Source**: Human Dimensions of Wildlife, 2015,Volume 20, Issue 5, pages 381-393 | Examined the role of value orientations and attitudes toward aquatic invasive species (AIS) on responsible boating behavior to reduce the likelihood of spreading AIS. Mitigation strategies developed to prevent the spread of AIS are most successful when the determinants of boating behaviors are well understood. Data were collected using a self-administered mail survey of a regionally stratified random sample of registered boaters in Illinois. Results provided support for the distinction of attitude into affective and behavioral components. While value orientations were significant predictors of environmental concern and past responsible environmental behavior, these attitude components were good predictors of intentions for future responsible boating behavior. Identifying the most influential predictors of responsible boating behaviors will help resource managers design effective intervention strategies to prevent AIS spread.<br>https://www.tandfonline.com/doi/abs/10.1080/10871209.2015.1030479 |

| Type | Details | Summary |
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| Academic | **Title**: Survival of invasive aquatic plants after air exposure and implications for dispersal by recreational boats<br><br>**Authors**: Lindsey Bruckerhoff, John Havel, Susan Knight<br><br>**Source**: Hydrobiologia, March 2015, Volume 746, Issue 1, pages 113–121 | Recreational boating is widely recognized as an important vector for overland transport of invasive aquatic plants. Since their dominant form of recruitment is vegetative reproduction, entangled fragments on boats and trailers can establish new populations. The effectiveness of recreational boats as transport vectors relies on the resistance of macrophytes to air exposure. Five field experiments in northern Wisconsin to assess air tolerance of Eurasian water-milfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*). Conditions that these plants would experience when ensnared on boats and trailers were simulated by testing viability after drying of single stems, coiled stems, and vegetative buds (turions). Single stems of *M. spicatum* and *P. crispus* were viable for up to 18 and 12 h of air exposure, respectively. Coiling extended the viability of *M. spicatum* to 48 h of air exposure. Turions of *P. crispus* successfully sprouted after 28 days of drying. The fact that recreational boaters in the region typically visit multiple lakes within a few days suggests that most lakes are susceptible to introduction of viable plants, and so lake managers should continue to focus attention on boat cleaning.<br>https://link.springer.com/article/10.1007%2Fs10750-014-1947-9 |
| Academic | **Title**: Modeling the human-induced spread of an aquatic invasive: The case of the zebra mussel<br><br>**Authors**: Levente, Timar, Daniel J. Phaneuf<br><br>**Source**: Ecological Economics, October 2009,<br>Volume 68, Issue 12, pages 3060-3071 | Ecological evidence indicates that transient recreational boating is the principal overland vector of dispersal for several freshwater invasive species. Understanding boating behavior, and how behavior responds to policy changes, is central to understanding the effectiveness of efforts to halt or slow the spread of aquatic invasives. A framework was developed that combines a recreation demand model of boating behavior with a discrete duration model describing the spatial and temporal spread of an aquatic invasive. The integrated approach allows linking invasion risk probabilities directly to boating behavior, policy levers, and behavior changes arising from policy shocks. Applied to zebra mussels in Wisconsin the study shows that explicitly accounting for behavioral responses can dramatically change predictions for the effectiveness of particular policies, in some instances leading to increases in invasions risks at some sites.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.575.5918&rep=rep1&type=pdf |

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| Academic | **Title**: Susceptibility of quagga mussels (Dreissena rostriformis bugensis) to hot-water sprays as a means of watercraft decontamination<br><br>**Authors**: Sean Comeaua, Scott Rainvillea, Wen Baldwinb, Emily Austinb, Shawn Gerstenbergera, Chad Crossa, Wai Hing Wong<br><br>**Source**: Biofouling, March 2011, Volume 27, No. 3, pages 267–274 | The recent spread of dreissenid mussels to various bodies of water in the western US has sparked interest by many state and federal agencies to develop protocols to stop further expansion. Quagga mussels (Dreissena rostriformis bugensis) are of particular importance as they are currently the most widespread dreissenid species in the region. This project examined the susceptibility of quagga mussels to hot-water sprays at different temperatures and durations of spray contact at Lake Mead (Nevada-Arizona, USA). Emersed adult quagga mussels were exposed to hot-water sprays at 20, 40, 50, 54, 60, 70, and 808C for 1, 2, 5, 10, 20, 40, 80, and 160 s. Sprays at 608C for 5 s were shown to be 100% lethal. Sprays of 548C for 10 s, 508C for 20 s, and 408C for 40 s also resulted in 100% mortality. A spray temperature of 608C for 5 s is recommended for mitigating fouling by quagga mussels.<br>https://www.tandfonline.com/doi/abs/10.1080/08927014.2011.564275 |
| Academic | **Title**: Estimating survival rates of quagga mussel (Dreissena rostriformis bugensis) veliger larvae under summer and autumn temperature regimes in residual water of trailered watercraft at Lake Mead, USA<br><br>**Authors**: Wook Jin Choi, Shawn Gerstenberger, Robert F. McMahon,Wai Hing Wong<br><br>**Source**: Management of Biological Invasions, 2013, Volume 4, Issue 1, pages 61–69 | Recreational watercrafts are considered a primary vector for overland dispersal of quagga mussel veliger larvae between water bodies. Effective decontamination of veligers in residual water carried by trailered recreation boats is critical to controlling this species' spread. The survival rate of quagga mussel veligers was measured during exposure to environmental temperature conditions mimicking those experienced in the residual water of trailered vessels in the semi-arid southwestern United States. Under warm summer conditions, quagga mussel veligers survived approximately five days while under cooler autumn conditions they survived 27 days. When tested under autumn temperature conditions veliger survival times increased with increased level of larval development. The results suggested a greater likelihood of veliger transport in the residual water of trailered watercraft during autumn months and that presently recommended vessel quarantine times to kill all externally attached juvenile and adult dreissenid mussels prior to launching in an uninfested water body should be increased to generate 100% veliger mortality in residual water unable to be fully drained from the internal areas of watercraft.<br>Available at: https://core.ac.uk/download/pdf/27178461.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Exploring the efficacy of an aquatic invasive species prevention campaign among water recreationists<br><br>**Authors**: Erin Seekamp, Allie McCreary, Jessica Mayer, Sarah Zack, Patrice Charlebois, Lainey Pasternak<br><br>**Source**: Biological Invasions, June 2016, Volume 18, Issue 6, pages 1745–1758 | Water recreationists regularly engage in behavior that can contribute to the spread of aquatic invasive species (AIS), which can result in costly consequences for managers. As AIS prevention is more cost-effective than response, educational campaigns are implemented as a preventative management strategy. However, little is known about the efficacy of education campaigns in promoting recreationists' knowledge, personal responsibility, and engagement in behaviors that can prevent AIS spread. This study explored the Stop Aquatic Hitchhikers!™ (SAH!) campaign by conducting survey and focus group research with water recreationists' in Illinois and Indiana. Results from the survey research indicate moderate campaign success (55 % were aware of the SAH! campaign), and that awareness is significantly related to increases in knowledge, personal responsibility, and engagement in four of the six recommended control behaviors. Additionally, findings demonstrate that boater-anglers were most aware of the campaign (69 %), most knowledgeable of AIS species, and felt the most personal responsibility for AIS control. However, focus group results demonstrate the need for campaign enhancement, including streamlining campaign messaging and increasing campaign exposure. Policy informed by the recommendations may improve the efficacy of educational campaigns to manage recreation behavior and corresponding environmental impacts among multiple water recreationist groups.<br>https://link.springer.com/article/10.1007/s10530-016-1117-2 |

| Type | Details | Summary |
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| Academic | **Title**: Resistance to desiccation in aquatic invasive snails and implications for their overland dispersal<br><br>**Authors**: John E. Havel, Lindsey A. Bruckerhoff, Meghan A. Funkhouser, Adrienne R. Gemberling<br><br>**Source**: Hydrobiologia, December 2014, Volume 741, Issue 1, pages 89–100 | At least 30 species of nonindigenous freshwater snails have invaded North America. The risk of these snails invading new lakes depends upon their ability to survive overland transport. The study reviewed published laboratory experiments using freshwater snails, which show numerous species are able to tolerate days of air exposure, and then tested tolerance to drying of three species of invasive aquatic snails that are widespread in Wisconsin: Bithynia tentaculata, Cipangopaludina chinensis, and Viviparus georgianus. In a series of seven experiments, boater transport was simulated by placing snails individually in mesh bags, hung outdoors, and confined in a screen tent. The screen roof allowed exposure to both sun and rain, and an on-site weather station recorded temperature, precipitation, and humidity. All three species exhibited high survivorship, with some individuals alive at the end of most experiments: 42 days for B. tentaculata and V. georgianus and 63 days for C. chinensis. Viable young were released by C. chinensis after 54 days of exposure. Overall, results indicate that these invasive snails should readily survive long periods of transport overland, indicating a need for continued vigilance of recreational boaters entering lakes.<br>Available at: https://www.researchgate.net/profile/Meghan_Funkhouser/publication/261795338_Resistance_to_desiccation_in_aquatic_invasive_snails_and_implications_for_their_overland_dispersal/links/0a85e5357d6f725082000000.pdf |
| Other Studies/Research | **Title**: Overland Spread of Aquatic Invasive Species among Freshwater Ecosystems due to Recreational Boating in Canada<br><br>**Authors**: Drake, D. Andrew R<br><br>**Source**: Fisheries and Oceans Canada, Canadian Science Advisory Secretariat (CSAS), Research Document 2017/031 | A literature review was conducted to summarize the overland spread of aquatic invasive species (AIS) among freshwater ecosystems due to recreational boating in Canada. Based on a review of 57 primary publications, factors contributing to overland spread involved heterogeneity in individual boater behaviour, such as differences in trip-taking frequency, the timing between trips, and the spatial distribution of boating locations relative to source populations of AIS. These factors, in addition to measures taken by boaters to remove AIS from boats and related equipment (such as picking visible material from anchors or cleaning hulls) dictate the variety, density, and viability of transported AIS between source and recipient ecosystems, ultimately determining the likelihood of overland spread. Therefore, as with other pathways of AIS introduction and spread within Canada, a subset of human-mediated events pose the majority of invasion risk due to context-dependent environmental and behavioural factors.<br>Available at: http://waves-vagues.dfo-mpo.gc.ca/Library/4061329x.pdf |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Ecological Risk Assessment of Recreational Boating as a Pathway for the Secondary Spread of Aquatic Invasive Species in the Great Lakes Basin<br><br>**Source**: Fisheries and Oceans Canada, Canadian Science Advisory Secretariat (CSAS) Research Document 2017/030 | A model-based assessment was conducted to estimate the ecological risk of recreational boating as a pathway for the secondary spread of aquatic invasive species (AIS) in the Great Lakes basin (GLB). Boater-mediated spread varied across functional groups and was fastest for invasive phytoplankton, with among-lake spread expected in as little as a single year in some scenarios. A relatively robust spatial pattern emerged with the highest rate of spread between neighbouring lakes; however, upstream movement through GLB lock structures and among multiple lake basins was possible with sufficient time (e.g., average modeled estimate of eight years for invasive phytoplankton to spread from the St. Lawrence River to Lake Superior). Two ecological consequences emerged. Boating activity was mostly unlikely to surpass downstream rates of natural dispersal, though in some cases could be exceeded by a period of up to four years. However, for all functional groups of AIS, boating activity was far more likely to lead to new upstream pathways of secondary spread that would otherwise be unlikely to occur through natural dispersal at short timescales (10–20 years). The overall risk of secondary spread was highest for Lake Superior due to the frequent development of upstream pathways. Risk was usually moderate for Lake Michigan, Lake Huron, and Lake Erie, while risk was generally low for Lake Ontario and the St. Lawrence River because boater-mediated rates of spread were consistent with expectations under natural dispersal. Results were sensitive to background estimates of natural dispersal, indicating that the risk of secondary spread would be higher if natural dispersal progressed more slowly than expected. These findings indicate that for certain geographic routes and most functional groups of AIS, increased attention to in-water recreational boating as a pathway of the secondary spread of AIS is warranted.<br>Available at: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2017/2017_030-eng.html |
| Other Studies/Research | **Title**: Voluntary Guidelines to Prevent the Introduction and Spread of Aquatic Invasive Species: Recreational Activities<br><br>**Source**: Aquatic Nuisance Species Task Force, November 2013 | Guidelines revised taking into account new aquatic invasive species (AIS), and new recreational activities and equipment. Guidelines were revised for six recreational activities: anglers, motor boaters, non-motorized boaters, scuba divers and snorkelers, seaplane pilots, and waterfowl hunters. The purpose of these guidelines is to provide a consistent, practical, and effective document to inform outreach efforts geared toward public recreationalists to prevent the spread of AIS, take into account the specific pathways, vectors, and life histories of all AIS, including fish, aquatic plants, invertebrates, and pathogens, and promote voluntary actions to support the national Stop Aquatic Hitchhikers! campaign, as well as statewide efforts such as Clean Boats, Clean Waters.<br>Available at: https://www.anstaskforce.gov/Documents/AIS_Recreation_Guidelines_Final_8-29-13.pdf |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Slowing the lake to lake spread of aquatic invasive species by recreational boaters<br><br>**Source**: Centre for Aquatic Conservation and The Nature Conservancy | Recreational boaters play a major role in the spread of aquatic invasive species (AIS) to inland waters in the Great Lakes region. AIS are transferred on hulls, fishing gear, anchor lines, in live wells, bilge water, and bait buckets. Recreational boaters have likely introduced spiny water flea, zebra mussels, rusty crayfish and Eurasian milfoil to inland lakes across the Great Lakes region. More recently the disease Viral Hemorrhagic Septicemia (VHS) has begun to spread into inland lakes, most likely moved around with contaminated bait and/or live well/bilge water. Efforts to prevent the spread of AIS are underway at many levels and include public awareness and education campaigns (signage, brochures), boat inspections, cleaning stations, and survey and control or eradication programs for some aquatic weeds. This document describes the results of recent research conducted by scientists at the University of Notre Dame (UND) designed to identify the most efficient ways for individuals, lake associations, or other groups to use available resources to slow the spread of AIS.<br>Available at: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5122627.pdf |
| Other Studies/Research | **Title**: Boat Inspection and Decontamination for Aquatic Invasive Species Prevention: Recommendations for the Adirondack Region, 2014 | Report evaluates the concepts of inspection and decontamination and uses existing datasets to inform recommendations for the region. The process involved five steps: 1) reviewing peer-reviewed scientific literature on recreational watercraft as an AIS pathway and the effectiveness of inspections and decontamination in removing AIS, 2) compiling Adirondack AIS distribution and boat access data, 3) compiling Adirondack boat launch steward data, 4) analyzing information in aggregate to understand trends, and 5) developing recommendations appropriate to the region.<br>Available at: http://www.adkwatershed.org/files/boat_decon_report.pdf |
| Other Studies/Research | **Title**: Construction and Integration of Aquatic Invasive Species (AIS) Prevention Areas at Recreational Boating Facilities<br><br>**Source**: States Organization for Boating Access | Guide that expands on many issues discussed during the development and review process undertaken by the SOBA AIS Task Force, SOBA members, and members of the Aquatic Nuisance Species Task Force (ANSTF). Five specific topics are discussed in detail in the Guide as they relate to the development of on-site and off-site AIS control and prevention efforts specifically related to boater access facility enhancement to control the spread of AIS.<br>Available at: http://www.sobaus.org/pdf/Best-Management-Practices.pdf |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Paddler Specific, Aquatic Invasive Species Spread Prevention Sign Project<br>**Source**: Northern Forest Canoe Trail, 2012 | Project to develop paddler specific protocols for road heads and at backcountry portages to educate the non-motorized boating community in how to stop the spread of aquatic invasives. Signage was developed to be simple, clear and effective protocols and graphic images that utilize best known practices while developing an eye catching, easy to read sign with an identifiable brand. A secondary project goal was to test the practicality of using an interactive meeting platform to facilitate workgroup communications.<br>Available at:<br>http://www.northernforestcanoetrail.org/media/NFCT%20Aquatic%20Invasives%20Report%20Final.pdf |
| Other Resources | Ontario Boater Action Plan | https://files.ontario.ca/boater_action_plan_invasivespecies-2017.pdf |
| Other Resources | Alberta Aquatic Invasive Species Quick Facts | http://aep.alberta.ca/recreation-public-use/boating/documents/QF-Invasive-Species-Motorized-Feb2018.pdf<br>http://aep.alberta.ca/recreation-public-use/boating/documents/QF-Invasive-Species-Non-Motorized-Feb2018.pdf |
| Other Resources | Stop Aquatic Hitch Hikers! | http://stopaquatichitchhikers.org/ |
| Other Resources | The 100th Meridian Initiative | http://www.100thmeridian.org/ |
| Other Resources | Be A Hero – Transport Zero Campaign | http://iiseagrant.org/ais/transportzero.php |
| Other Resources | Boater's Guide to Aquatic Nuisance Species (ANS) Inspections | https://cpw.state.co.us/Documents/ANS/BoatersGuideToANS.pdf |

# 2. Recreational Diving

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: The 'killer shrimp' Dikerogammarus villosus (Crustacea, Amphipoda) invading Alpine lakes: overland transport by recreational boats and scuba-diving gear as potential entry vectors?<br><br>**Authors**: Karolina Bacela-Spychalska, Michal Grabowski, Tomasz Rewicz, Alicja Konopacka, Remi Wattier<br><br>**Source**: Aquatic Conservation, August 2013, Volume 23, Issue 4, pages 606-618 | Recently, the species has been reported to invade lakes in the Alps in putative association with overland transport linked with recreational activities. This study provided a method to assess risk associated with this overland transport and an opportunity to set up a rationale for effective preventive conservation management. A field survey of 60 lakes encompassing all the Alpine area has revealed the presence of killer shrimp in 12 lakes. Subsequent multivariate data analysis showed that the occurrence of the amphipod was associated predominantly with large lakes at low altitudes and high recreational boating activity, always inhabited by the invasive zebra mussel. The distribution pattern of killer shrimp was not associated with water conductivity and pH. Laboratory experiments demonstrated that, compared with two other amphipods Gammarus pulex and G. roeselii, killer shrimp seems to attach itself more effectively to ropes used by boaters, as well as diving wetsuits. They remained attached to the ropes even while being strongly shaken for 5 min (mimicking movements associated with overland transport). Moreover, the species is able to survive up to three and a half days out of water, between the layers of diving wetsuits. These results show that even in isolated Alpine lakes there is a high risk of overland spread of killer shrimp by recreational boats and diving wetsuits. https://onlinelibrary.wiley.com/doi/abs/10.1002/aqc.2329 |
| Other Resources | Scuba Divers and Snorkelers Decontamination Guidance | http://www.ndow.org/uploadedFiles/ndoworg/Content/Boat/Aquatic_Invasive_Species/Scuba-Divers-Snorkelers-Gear-Equipment.pdf |
| Other Resources | Tips for Recreational Divers | https://seagrant.psu.edu/sites/default/files/Prevention%20Divers%20FINAL_red.pdf |
| Other Resources | Don't let this happen to your favorite dive location! | https://publications.aqua.wisc.edu/download/scuba-ais-card-pdf/ |
| Other Resources | Scuba Divers Can Help | https://www.michigan.gov/documents/dnr/Scuba_flier_final_365422_7.pdf |
| Other Resources | Invasive Species Biosecurity Guidelines for Scuba Diving | https://www.fisheriesireland.ie/documents/247-invasive-species-biosecurity-guidelines-for-scuba-diving-1/file.html |
| Other Resources | Protect Colorado's Lands and Water | https://cpw.state.co.us/Documents/RulesRegs/Brochure/CPW-ANSAudienceBrochure.pdf |
| Other Resources | Ontario Invading Species Awareness Program | http://www.invadingspecies.com/scuba-diving/ |

# 3. Movement of Docks, Lifts, and Equipment (Lake Service Providers)

| Type | Details | Summary |
|---|---|---|
| Academic | No applicable academic research available | |
| Other Studies/Research | **Title:** Marine Invaders in the Northeast: Rapid Assessment Survey of Non-native and Native Marine Species of Floating Dock Communities, August 2003<br>**Source:** MIT Sea Grant College Program | In his seminal book on The Ecology of Invasions by Animals and Plants, Elton (1958) laid the foundation for the science of biological invasions. He identified the importance of human-mediated vectors as means of transporting organisms to new locations and discussed invasions in the context of ecological impacts and evolutionary consequences. Elton even identified what needed to be done to prevent practical and ecological damages from invaders--keep them out, eradicate them, and if all else fails, manage them at acceptable levels. We have not been vigilant in applying this knowledge to marine ecosystems, although this is changing. Our ability to detect changes in numbers and rate of marine introductions depends on well-documented lists of species in time and space, appropriate identification of non-native species, and careful records that follow changes in nomenclature, distribution, potential vectors, and ecosystem alterations caused by non-native species.<br>Available at: https://dspace.mit.edu/bitstream/handle/1721.1/97032/MITSG_05-3.pdf?sequence=1 |
| Other Studies/Research | **Title:** Spatial coverage and movement of marine anthropogenic structures as a pathway of aquatic invasive species spread<br>**Source:** Fisheries and Oceans Canada, Institute of Ocean Sciences | Presentation regarding aquatic invasive species on moveable, non-propelled structures.<br>Available at: https://static1.squarespace.com/static/5817c391e58c62432bc92186/t/596fb69c1e5b6ce8d190c887/1500493494394/25_Josephine_Iacarella.pdf |
| Other Studies/Research | **Title:** Developing a vector management approach to prevent introduction and spread of marine biofouling invasive species in Newfoundland, Canada<br>**Source:** Fisheries and Oceans Canada, 19th International Conference on Aquatic Invasive Species | Presentation on aquatic invasive species management in Newfoundland.<br>Available at: https://www.icais.org/pdf/2016abstracts/ICAIS%20Monday%20PM%20Session%20C/230_Matheson.pdf |

| Type | Details | Summary |
|---|---|---|
| Other Studies/Research | **Title**: Inspection and Cleaning Manual for Equipment and Vehicles to Prevent the Spread of Invasive Species, Technical Memorandum No. 86-68220-07-05<br><br>**Source**: U.S. Department of the Interior Bureau of Reclamation | Procedures have been developed in this manual to address the transport of invasive species and pests through equipment movement. This manual provides guidance for inspecting and cleaning vehicles and equipment to help prevent the spread of noxious invasive species during Bureau of Reclamation (Reclamation) activities. The general types of equipment described in this manual are: rubber-tired land vehicles, tracked land vehicles, personal use equipment, construction and facility equipment, and watercraft. The spread of invasive species from one location to another has been linked to the use and movement of contaminated equipment. The recent introduction of the invasive zebra and quagga mussel from the Eastern watersheds of the United States into the Western watersheds is thought to be almost entirely by cross country movement of contaminated watercraft and other equipment, and highlights the importance of inspection and cleaning of all types of equipment. As discussed in greater detail later in the manual, the concept of successful prevention is the goal of all equipment inspection and cleaning processes and is the main purpose of this manual. Prevention actions deny the entry of invasive species into uninfested locations. This factor underpins all equipment inspection and cleaning methods to be discussed: through prevention, the spread of invasive species from one place to another can be limited.<br><br>Available at: https://www.usbr.gov/mussels/prevention/docs/EquipmentInspectionandCleaningManual2010.pdf |
| Other Resources | New York State Invasive Species Regulations | https://www.dec.ny.gov/animals/99141.html |
| Other Resources | Inspection and Cleaning Guidelines | https://co.stearns.mn.us/Portals/0/docs/Department%20Files/EnvironmentalSvs/AISBoatingInspectionBooklet.pdf |

# 4. Live Bait Use by Anglers

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Ecology of Freshwater Baitfish Use in Canada and the United States<br>**Authors**: Matthew K. Litvak, Nicholas E. Mandrak<br>**Source**: Fisheries, 1993, Volume 18, Issue 12, pages 6-13 | The study reviews potential impacts of the use of baitfish on the harvested (donor) ecosystem as well as the ecosystem in which the baitfish are used (recipient). Although the number of regulations in both countries has increased since 1956, clearly transport and release of baitfish is still poorly controlled. The listing of 15 baitfish species as vulnerable or threatened and the presence of disjunct populations as a result of bait-bucket transfer of 12 species indicates Ontario baitfish regulations/enforcement have not adequately protected donor and recipient ecosystems. A survey of baitfish practices for customers of four major baitfish dealers in Toronto, Ontario found that almost half of the anglers surveyed released their unused baitfish at their fishing destinations, even though this practice is prohibited by Ontario fishing regulations. Contents of dealers' holding tanks were inspected and plotted the destinations of anglers who bought those baitfish. Eighteen of the 28 species found in the tanks were potentially used outside their known ranges. In light of these findings, a number of recommendations to better manage this economically and ecologically important resource are provided.<br>https://www.tandfonline.com/doi/abs/10.1577/1548-8446(1993)018%3C0006%3Aeofbui%3E2.0.co%3B2 |
| Academic | **Title**: Interbasin Transfer of Aquatic Biota via Anglers' Bait Buckets<br>**Authors**: Herbert R. Ludwig Jr., Jay A. Leitch<br>**Source**: Fisheries Magazine, July 1996, Volume21, Issue7, pages 14-18 | The dispersal and introduction of nonindigenous aquatic species have often been attributed to the release or escape of baitfish and other biota from anglers' bait buckets. Using data obtained through two mail surveys of bait vendors, bait samples from retail locations, vendor interviews, a creel survey, and a literature review, the potential for anglers in North Dakota and Minnesota to contribute to the dispersal of nonindigenous fish from the Mississippi River basin into the Hudson Bay basin is estimated. Specifically, the probability of a single angler on a single angling day in the Hudson Bay basin releasing live bait from the Mississippi River basin is estimated to be 1.2/100. When the cumulative number of trials—19 million angler days per year—was considered, the estimated probability of bait bucket transfer occurring once, 100, or even 10,000 times in 1 year approaches 1.0. In light of these findings, it is concluded that drastic policy measures would have to be undertaken to reduce anglers' potential for contributing to the dispersal of aquatic species.<br>https://onlinelibrary.wiley.com/doi/abs/10.1577/1548-8446(1996)021%3C0014:ITOABV%3E2.0.CO;2 |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Can we predict risky human behaviour involving invasive species? A case study of the release of fishes to the wild<br><br>**Authors**: Dr. Andrew R. Drake, Rebecca Mercader, Tracy Dobson, Nicholas E. Mandrak<br><br>**Source**: Biological Invasions, January 2015, Volume 17, Issue 1, pages 309–326 | Managing risky human behaviour involving invasive species is difficult because the rationale for risk taking is often unknown. To identify factors that increase the likelihood of risky behaviour, social surveys were conducted and perceptions about invasive species, natural resource management, social norms, and outreach initiatives analyzed for live bait anglers in Ontario, Canada and Michigan, USA. Classification trees were used to predict risky behaviour based on patterns of variation in social perceptions. Irrespective of release, respondents generally agreed with (and exhibited strong willingness to pay for) prevention management, despite only moderate consensus that natural resource use had been impacted by invasive species. The most parsimonious model to predict release was based on the convenience of releasing fishes and the (mis)perception that released fishes provide an ecological benefit to natural resources; therefore, perceptions other than those directly involving invasive species strongly increase the likelihood that an individual will release fishes to the wild.<br>https://link.springer.com/article/10.1007/s10530-014-0729-7 |
| Academic | **Title**: Angler awareness of aquatic nuisance species and potential transport mechanisms<br><br>**Authors**: K. K. Gates, C. S. Guy, A.V. Zale, T.B. Horton<br><br>**Source**: Fisheries Management and Ecology, December 2009, Volume 16, Issue 6, pages 448-456 | The role anglers play in transporting aquatic nuisance species (ANS) is important in managing infestations and preventing introductions. The objectives of this study was to: (1) quantify angler movement patterns in southwestern Montana, ANS awareness and equipment cleaning practices; and (2) quantify the amount of soil transported on boots and waders. Mean distance travelled by residents from their home to the survey site was 115 km and mean distance travelled by non-residents was 1738 km. Fifty-one percent of residents and 49% of non-residents reported occasionally, rarely or never cleaning their boots and waders between uses. Mean weight of soil carried on one boot leg was 8.39g. Movement and equipment cleaning practices of anglers in southwestern Montana suggest that future control of ANS dispersal may require restricting the use of felt-soled wading boots, requiring river-specific wading equipment or providing cleaning stations and requiring their use.<br>https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2400.2009.00694.x |
| Academic | **Title**: The role of anglers in preventing the spread of aquatic invasive species in the Great Lakes region<br><br>**Authors**: Nancy A. Connelly, T. Bruce Lauber, Richard C. Stedman, Barbara A. Knuth<br><br>**Source**: Journal of Great Lakes Research, June 2016, Volume 42, Issue 3, pages 703-707 | The spread of aquatic invasive species (AIS) is an ongoing challenge in the Great Lakes region. Anglers play a pivotal role in preventing or contributing to the spread of these organisms. Anglers in the Great Lakes region were surveyed by mail during fall 2013 to assess their AIS-related awareness, knowledge, and concern as well as the actions they took to prevent the spread of AIS. Many anglers were aware of AIS, knowledgeable and concerned about them, and taking some actions to prevent their spread. However, certain actions, such as drying and disinfecting or rinsing equipment with hot water, were more difficult and were reported less frequently. Since many anglers already recognize the importance of taking action to prevent the spread of AIS, future outreach efforts may be able to deemphasize communication about the importance of taking action and focus more on strategies that will enable anglers to take these actions.<br>https://www.sciencedirect.com/science/article/pii/S0380133016300387 |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Biosecurity and Vector Behaviour: Evaluating the Potential Threat Posed by Anglers and Canoeists as Pathways for the Spread of Invasive Non-Native Species and Pathogens<br><br>**Authors**: Lucy G. Anderson, Piran C. L. White, Paul D. Stebbing, Grant D. Stentiford, Alison M. Dunn<br><br>**Source**: PLoS ONE 9(4): e92788. doi:10.1371/journal.pone.0092788 | Freshwater environments are particularly susceptible to invasive non-native species (INNS) invasions as they are exposed to multiple introduction pathways, including non-native fish stocking and the release of boat ballast water. To quantify this biosecurity risk, an online questionnaire with 960 anglers and 599 canoeists was delivered. Results indicate that 64% of anglers and 78.5% of canoeists use their equipment/boat in more than one catchment within a fortnight, the survival time of many of the INNS and pathogens considered in this study and that 12% of anglers and 50% of canoeists do so without either cleaning or drying their kit between uses. Furthermore, 8% of anglers and 28% of canoeists had used their equipment overseas without cleaning or drying it after each use which could facilitate both the introduction and secondary spread of INNS in the UK. Results provide a baseline against which to evaluate the effectiveness of future biosecurity awareness campaigns, and identify groups to target with biosecurity awareness information. Results also indicate that the biosecurity practices of these groups must improve to reduce the likelihood of inadvertently spreading INNS and pathogens through these activities.<br>Available at: http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0092788&type=printable |
| Academic | **Title**: The role of waterfowl and fishing gear on zebra mussel larvae dispersal<br><br>**Authors**: Filipe Banha, Irene Gimeno, Munia Lanao, Vincent Touya, Concha Durán, Miguel A. Peribáñez, Pedro M. Anastácio<br><br>**Source**: Biological Invasions, January 2016, Volume 18, Issue 1, pages 115–125 | Navigation has been considered the primary vector of zebra mussel dispersion and little importance has been given to alternative natural (waterbirds) and other human vectors. Using an experimental approach under field conditions, zebra mussel dispersal potential by fishing gear (waders and keepnets) and mallard ducks (*Anas platyrhynchos*) was evaluated and compared. Adherence and survival rate of zebra mussel larvae on each vector was examined. In addition, the survival of zebra mussel larvae under desiccating conditions (i.e., a set of controlled temperatures and relative humidities) was examined. Larvae adhered to all types of vectors and survived desiccation under both laboratory and field conditions and thus appear able to be dispersed long distances overland by both ducks and fishing gear. Specifically, on a per-event basis, fishing gear has a higher potential to spread zebra mussel larvae than ducks. Survival was three times higher on human vectors and the number of larvae attached to human vectors was over double of that on the ducks. However, findings demonstrate that natural vectors, like ducks, can contribute to the transport of zebra mussel larvae at a local scale. Nevertheless, since vectors related to human activity presented a higher potential for transport, it is imperative to continue campaigns to raise the awareness of anglers and boaters as well as continue the implementation of legislation to reduce the risk of zebra mussel dispersal.<br>Available at:<br>https://dspace.uevora.pt/rdpc/bitstream/10174/18152/1/TESE_Doutoramento_Filipe_Banha.pdf#page=117 |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Bycatch, bait, anglers, and roads: quantifying vector activity and propagule introduction risk across lake ecosystems<br><br>**Authors**: D. Andrew R. Drake, Nicholas E. Mandrak<br><br>**Source**: Ecological Applications, June 2014, Volume24, Issue4, pages 877-894 | To test the role of anglers in propagule transport of invasive species, a social-ecological model was developed quantifying the opportunity for species transport beyond the invaded range resulting from bycatch during commercial bait operations, incidental transport, and release to lake ecosystems by anglers. two patterns of lake-specific introduction risk emerged. Large lakes supporting substantial angling activity experienced propagule pressure likely to surpass demographic barriers to establishment. Small or remote lakes were less likely to receive propagules; however, most risk distributions were leptokurtic with a long right tail, indicating the rare occurrence of high propagule loads to most waterbodies. Infestation simulations indicated that the number of high-risk waterbodies could be as great as 1318 (zero-inflated negative binomial), whereas a 90% reduction in bycatch from baseline would reduce the modal number of high risk lakes to zero. Results indicate that the combination of invasive bycatch and live-bait anglers warrants management concern as a species vector, but that risk is confined to a subset of individuals and recipient sites that may be effectively managed with targeted strategies.<br>Available at: https://pdfs.semanticscholar.org/acd0/0eebcea751bb997f0b3108c34772a937f8df.pdf |
| Academic | **Title**: From bait shops to the forest floor: earthworm use and disposal by anglers<br><br>**Authors**: Keller, R. P., A. N. Cox, C. Van Loon, D. M. Lodge, L.-M. Herborg, J. Rothlisberger.<br><br>**Source**: American Midland Naturalist, 2007, Volume 158, Issue 2, pages 321–328 | Nonindigenous earthworms are causing large and undesirable changes to forests across the U.S. Upper Midwest. Since earthworms have slow rates of natural spread and because their distribution remains patchy in many areas, it would be possible to slow the rate of invasion if vectors of introduction can be identified and controlled. Earthworm populations are often found near lakes, and it has been suggested that anglers discarding unwanted bait are a vector for the establishment of new populations. Surveying of the bait trade and anglers to determine whether bait stores sell known invasive species and whether angler behavior is likely to lead to these species becoming introduced near lakes. All bait stores surveyed sold known invasive species and 44% of anglers who purchase bait dispose of unwanted bait on land or in trash. The study concludes that the bait trade and subsequent disposal of worms by anglers constitute a major vector for earthworm introductions and thus, slowing the spread of invasive earthworms will require efforts to change the species sold at bait stores and/or efforts to change angler behavior.<br>Available at: https://www.researchgate.net/profile/Leif-Matthias_Herborg/publication/232690592_From_Bait_Shops_to_the_Forest_Floor_Earthworm_Use_and_Disposal_by_Anglers/links/0deec5318e92e967d0000000.pdf |

| Type | Details | Summary |
|---|---|---|
| Other Studies/Research | **Title**: Bait Management Review<br><br>**Source**: Ontario Ministry of Natural Resources, Fisheries Policy Section, Biodiversity Branch, June 2012 | Assembled information on the live bait industry in Ontario prior to a policy review of live bait management in the province. Various types of live bait are described and the feasibility of aquaculture for different bait species is investigated. Licence sales, reported harvests, and economics are provided for the Ontario bait industry. Management of the Ontario bait industry is reviewed. Results of a North American jurisdictional scan on bait policies and management practices are presented. Finally, problems and issues currently facing the bait industry are identified. An emphasis has been placed on ecological issues associated with the use of live bait. More than 370 citations have been provided as additional reference material.<br>Available at: https://www.ontario.ca/page/bait-management-review |
| Other Studies/Research | **Title**: A review of bait use and harvest in Ontario's provincial parks and conservation reserves<br><br>**Source**: Parks and Protected Areas Policy Section, Natural Heritage, Lands and Protected Spaces Branch, Ministry of Natural Resources | This report has been prepared to provide a summary of information on the use of bait for recreational fishing and commercial bait harvest in provincial parks and conservation reserves in support of a policy review. Existing policies are summarized, current bait use and harvest activities in these protected areas are reviewed and key policy issues are discussed. According to a 2011 survey of visitors to operating parks, artificial lures (47%) and earthworms (41%) were the most popular types of bait used by park anglers, while about 7% used live baitfish and 2% used leeches. Depending on the type of bait that was used, approximately 7% to 33% of park anglers disposed of it in the water. This suggests that angling with live bait may pose a risk to park fisheries and ecosystems due to the potential for this behaviour to introduce or spread invasive species. Provincial parks and conservation reserves comprise about 8% of the area available for commercial bait harvest in the province. The extent of commercial bait harvest in protected areas is unknown because annual harvest reports do not include the waterbody where the bait was caught. The use and harvest of live bait is a threat to the ecological integrity of protected areas since it is a pathway for the introduction of invasive species and diseases, which imperils fisheries and aquatic ecosystems. Existing protected area policies include some measures to reduce these risks; however, policy direction is fragmented and inconsistent, resulting in a complex management regime that has been challenging to implement.<br>Available at: http://www.ontla.on.ca/library/repository/mon/29006/330918.pdf |

| Type | Details | Summary |
|---|---|---|
| Other Studies/Research | **Title**: National Risk Assessment of Recreational Boating as a Vector for Aquatic Invasive Species<br><br>**Source**: Fisheries and Oceans Canada, Science Advisory Report 2017/025 | This science advisory report is intended to provide advice on recreational boating as a vector for aquatic nonindigenous species (NIS) in Canada. This work dealt with three aspects of this vector (marine, freshwater – Great Lakes Basin, and freshwater overland movement) separately, and for the first time, assessed the risk of recreational boating in terms of introduction and secondary spread of NIS at the national level. Primary introductions and secondary spread of known, high impact NIS via recreational boating are possible in Canadian waters. Both the freshwater and marine portions of this risk assessment work demonstrate the large magnitude of recreational boating activity in their respective environments. A conservative estimate for the magnitude of inland freshwater boating trips outside of the GLB is 24.7 M per year. This enables rare, per boat events with high consequence to occur. The riskiest boats are a small subset of all recreational boats in both marine and freshwater environments. Factors identified that influenced boat infestation status included maintenance, voyage history, and boat type. Boats from areas with greater NIS loads that travel extensively and have poor maintenance or extended in-water periods are of greatest risk. Final Ecoregion Invasion Risk scores were greater for the Pacific region than the Atlantic region. These regional differences are largely influenced by seasonality of boating activities (time in water, maintenance, boating activity) and the sheer number of boats.<br>Available at: http://waves-vagues.dfo-mpo.gc.ca/Library/4061489x.pdf |
| Other Studies/Research | **Title**: The Introduction and Spread of Aquatic Invasive Species through the Recreational Use of Bait: A Literature Review<br><br>**Source**: Ontario Ministry of Natural Resources, 2014 | Summary of information related to the introduction and spread of aquatic invasive species in Ontario through the recreational use of live bait. Literature on the recreational use of bait as a pathway for the spread of aquatic invasive species is examined. Various pathways are reviewed and evaluated. These pathways include accidental release, escape from holding containers, fellow travellers in holding water and packaging materials, illegal dumping of bait and the commercial sale/use of aquatic invasive species. Impacts of aquatic invasive species may be direct or indirect. Potential impacts are many and varied including interspecific competition, predation, transmission of disease and parasites, habitat alteration, genetic impacts, displacement of native species, community alteration, and adverse effects on recreational and commercial fisheries. The use of live bait provides a pathway for the introduction and spread of aquatic invasive species which can potentially result in significant ecological and economic impacts.<br>Available at: http://www.ontla.on.ca/library/repository/mon/28012/328831.pdf |

| Type | Details | Summary |
|---|---|---|
| Other Studies/Research | **Title**: Do Live Marine Products Serve as Pathways for the Introduction of Nonindigenous Species?<br><br>**Source**: Marketing and Shipping Live Aquatic Products, University of Alaska Sea Grant, AK-SG-01-03, 2001, pages 243-247 | Two kinds of nonindigenous species are associated with the trade in live products. One type is the live products themselves and the other is non-target or hitchhiking species that are pests, pathogens, and other species of unknown status that might come along with the product. They come in the packing material, the water, or the packaging. They may also be attached to or living in the target species, as with disease organisms. This suggests that, in addition to the product and its handling, the handling and disposal of packaging has potential for bringing these unintentional introductions. Research focuses on human activities during the transport stage. The study looks at scientific specimens, live seafood, and live bait in more depth. From a live bait perspective, main pathways identified included local bait shops that import bait for retail sale, recreational users who increasingly can order directly from the Internet, users who transport from out of state, and suppliers who stock bait vending machines. Extensive survey work in Washington determined that the majority of bait shops did not carry live bait at all. They were marine oriented and were carrying frozen bait. Those who carried live bait got it from a local source (no suppliers supply live bait to Washington). Those who imported bait got it from Oregon, which were actually earthworms. No imported marine bait was being brought in. It looks to us like people do not ship live bait from Maine for use in marine waters in Washington. Study of live bait illustrates how the protocol of defining a pathway as provisionally closed might work. Available at: https://pdfs.semanticscholar.org/d4d7/31a65880b78b810771552c6b7b250af01244.pdf#page=252 |
| Other Resources | Wyoming AIS Angler Brochure | https://wgfd.wyo.gov/WGFD/media/content/PDF/Fishing/AIS_ANGLERS_BROCHURE.pdf |
| Other Resources | Ontario Angler Action Plan | https://files.ontario.ca/angler_action_plan_invasivespecies-2017.pdf |

# 5. Commercial Bait Trade (Bait Shops, Dealers, Harvesters)

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: An assessment of angler education and bait trade regulations to prevent invasive species introductions in the Laurentian Great Lakes<br><br>**Authors**: Lucas R. Nathan , Christopher L. Jerde, Margaret McVeigh, Andrew R. Mahon<br><br>**Source**: Management of Biological Invasions, 2014, Volume 5, Issue 4, pages 319–326 | The commercial bait trade is one pathway for aquatic invasive species (AIS) introductions, as non-target bait species can be accidentally sold to anglers who either inadvertently or intentionally release them while fishing or as excess bait. Prevention of AIS introductions via the bait trade requires a two-tiered management approach, which includes both regulation of the bait industry and angler education. Retail bait shops may offer opportunities for public education regarding AIS, however it is unknown how often shops are targeted for such purposes and how viable this method of angler education is on a temporal scale. Research goals were to 1) quantify the current distribution of AIS signage in retail bait shops in the Great Lakes region and 2) estimate the long term viability of using retail bait shops as platform for angler education. Of the 525 bait shops visited in 2012 and 2013, 22% displayed some form of AIS educational materials or signage. Additional signs were distributed during initial visits and, during revisits after one calendar year, 54% of shops still displayed the provided signage. Review of bait regulations for Great Lakes jurisdictions indicates multiple discrepancies across the region, which may hinder successful management strategies. Future management goals should consider additional methods of angler education and coordinating regulations across the Great Lakes to improve upon AIS prevention.<br>Available at:<br>https://www.researchgate.net/profile/Lucas_Nathan/publication/274253795_An_assessment_of_angler_education_and_bait_trade_regulations_to_prevent_invasive_species_introductions_in_the_Laurentian_Great_Lakes/links/5519f2a90cf26cbb81a2b599/An-assessment-of-angler-education-and-bait-trade-regulations-to-prevent-invasive-species-introductions-in-the-Laurentian-Great-Lakes.pdf |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: The use of environmental DNA in invasive species surveillance of the Great Lakes commercial bait trade<br><br>**Authors**: Lucas R. Nathan, Christopher L. Jerde, Michelle L. Budny, Andrew R. Mahon<br><br>**Source**: Conservation Biology, April 2015, Volume 29, Issue 2, pages 430-439 | One potential pathway for non-native species introductions is the commercial bait trade; unknowing or unconcerned anglers commonly release unused bait into aquatic systems. Previous surveillance efforts of this pathway relied on visual inspection of bait stocks in retail shops, which can be time and cost prohibitive and requires a trained individual that can rapidly and accurately identify cryptic species. Environmental DNA (eDNA) surveillance can be used to efficiently detect species at low abundances. The study collected and analyzed 576 eDNA samples from 525 retail bait shops throughout the Laurentian Great Lake states to screen samples for multiple aquatic invasive species that could be transported in the bait trade, including bighead and silver carp, round goby, tubenose goby, Eurasian rudd, and goldfish. Twenty-seven samples were positive for at least one target species (4.7% of samples), and all target species were found at least once, except bighead carp. Despite current regulations, the bait trade remains a potential pathway for invasive species introductions in the Great Lakes region. Alterations to existing management strategies regarding the collection, transportation, and use of live bait are warranted.<br>Available at:<br>https://s3.amazonaws.com/academia.edu.documents/46556738/The_Use_of_Environmental_DNA_in_Invasive20160616-12477-ptcmsl.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534731173&Signature=C1mxqH1%2BBEchNuNtJ%2BarmHhQiu8%3D&response-content-disposition=inline%3B%20filename%3DThe_use_of_environmental_DNA_in_invasive.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Meta-genomic surveillance of invasive species in the bait trade<br><br>**Authors**: Andrew R. Mahon, Lucas R. Nathan, Christopher L. Jerde<br><br>**Source**: Conservation Genetics Resources, September 2014, Volume 6, Issue 3, pages 563–567 | There are a number of different pathways by which invasive species can enter aquatic ecosystems, including the relatively unstudied live bait trade. Through contaminated stocks, the bait trade vector has the potential to distribute species widely, and unknowingly, across a wide geographic area. Reliable techniques for monitoring for invasive species remains challenging, particularly due to a lack of taxonomic expertise by those using live bait. The study shows that non-target species (i.e., rare; not intended to be purchased) can be detected based on environmental DNA (eDNA) collected in water samples from commercial bait vendors. Utilizing high-throughput DNA sequencing, water samples collected from six different commercial bait shops were analyzed, screening the resulting sequence data for presence of non-target, and potentially invasive species of fish. Findings show that DNA from multiple non-target species was present in the collected samples, including DNA from at least one potentially harmful invasive species. Additionally, this work supports the use of eDNA surveillance for screening the bait shop vector for rare and potentially harmful aquatic invasive species.<br>Available at: https://s3.amazonaws.com/academia.edu.documents/46556735/Meta-genomic_surveillance_of_invasive_sp20160616-26659-1cd9g5z.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534731266&Signature=u%2FWv0pXQYOd3fibGgXtISQw%2Bloo%3D&response-content-disposition=inline%3B%20filename%3DMeta-genomic_surveillance_of_invasive_sp.pdf |
| Academic | **Title**: Ecological Risk of Live Bait Fisheries: A New Angle on Selective Fishing<br><br>**Authors**: D. Andrew, R. Drake, Nicholas E. Mandrak<br><br>**Source**: Fisheries, 2014, Volume 39, Issue 5 | The use of live baitfish is a cultural norm in many jurisdictions across North America. Since baitfish are often harvested from mixed stocks in the wild, the potential for bycatch exists, leading to the inadvertent relocation of nontarget species via distribution networks and anglers; therefore, like many fisheries, core issues revolve around selective fishing. The study assesses selectivity of bait fisheries in Ontario, focusing on the prevalence of bycatch within the commercial supply chain and the propensity for nontarget species introductions by anglers. Selection for target stocks was strong; however, species assemblages in retail tanks and angler purchases included game, imperiled, invasive, and other nontarget species. The combination of bycatch, a large volume of angling trips, and risky angler behavior results in high probabilities of introducing the suite of nontarget species contained incidentally. Pathway approaches to management provide opportunities to increase selectivity, manage the risk of species introductions, and sustain the integrity of bait operations throughout North America.<br>Available at: https://fisheries.org/docs/wp/AFS-Fisheries-May-2014.pdf#page=12 |

| Type | Details | Summary |
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| Academic | **Title**: An assessment of a bait industry and angler behavior as a vector of invasive species<br><br>**Authors**: Jay V. Kilian, Ronald J. Klauda, Sarah Widman Michael Kashiwagi, Rebecca Bourquin, Sara WegleinJohn Schuster<br><br>**Source**: Biological Invasions, July 2012, Volume 14, Issue 7, pages 1469–1481 | The use of live bait by anglers is an important vector of both aquatic and terrestrial invasive species. A telephone survey of bait shops and a mail survey of anglers were conducted to obtain information on the trade and use of bait in Maryland, USA. The bait shop survey confirmed that this industry is a source of non-native and invasive species in Maryland, documenting at least six non-native bait species for sale in the state. Release of unused bait by anglers varied with bait type; anglers more readily released aquatic than terrestrial baits. The surveys indicated that any non-native, potentially invasive species imported into the state via the bait industry is likely to be released by anglers into Maryland's aquatic and terrestrial ecosystems. Many of these species have the potential to become established in the state. Results illustrate the need for greater oversight of the bait industry, development of consistent regulations on bait use, and a region-wide education campaign aimed at changing anglers' behavior regarding bait use and its disposal. Specific management actions are recommended that, if implemented, would greatly reduce further bait-bucket introductions and provide protection against invasive bait species in Maryland and the Mid-Atlantic region.<br>https://link.springer.com/article/10.1007/s10530-012-0173-5 |
| Academic | **Title**: The Bait Industry as a Potential Vector for Alien Crayfish Introductions: Problem Recognition by Fisheries Agencies and a Missouri Evaluation<br><br>**Authors**: Robert J. DiStefano, Mary E. Litvan, Paul T. Horner<br><br>**Source**: Fisheries Magazine, December 2009, Volume 34, Issue 12, pages 586-597 | "Bait-bucket introductions" related to the fishing bait industry are the suspected primary cause of alien (non-indigenous) crayfish introductions that have damaged North American aquatic ecosystems. Our 2008 survey of U.S. and Canadian fisheries agencies revealed that 49% of respondents reported aquatic resource problems that were believed to have been caused by bait-bucket introductions of alien crayfishes. Most respondents reported existing regulations designed to address those problems; however, only 4% prohibited the use of live crayfish bait. Our 2002–2007 examination of Missouri bait shops revealed sales of illegal and invasive alien crayfishes by bait shop proprietors who could not identify the species they were selling. Fisheries agencies should consider more effective bait regulations and education to prevent negative impacts to aquatic biodiversity, habitat, and fisheries that can result from alien crayfish introductions.<br>Available at:<br>http://www.mostreamteam.org/Documents/Research/AquaticInverts/Pages%20from%20DiStefano_et_al._Fisheries_12-09.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Harvest models and stock co-occurrence: probabilistic methods for estimating bycatch<br><br>**Authors**: Drake, D. A. R., and N. E. Mandrak<br><br>**Source**: Fish and Fisheries, 2014, Volume 15, Issue 1, pages 23–42 | A primary goal of ecosystem-based fishery management is to reduce non-target stock impacts, such as incidental harvest, during targeted fisheries. Quantifying incidental harvest has generally incorporated fishery-dependent catch data, yet such data may be biased by gear non-retention, observation difficulties, and non-random harvest patterns that collectively lead to an impartial understanding of non-target stock capture.. To illustrate application of the framework, simulation models were based on fishery-independent data from a freshwater fishery in Ontario, Canada. Harvest simulations of empirical stock data indicated that greatest species-specific capture values were over 4000 times more likely than for species with lowest values, indicating highly variable capture probabilities because of the combined influence of stock heterogeneity and harvest dynamics. Estimated bycatch–effort relationships will allow forecasting incidental harvest on the basis of effort to evaluate future shifts in fishing activity against specific ecosystem-based fishery management objectives, such as reducing the overall probability of bycatch while maintaining target landings.<br>https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12005 |
| Academic | **Title**: Bait worm packaging as a potential vector of invasive species<br><br>**Authors**: Christina L. Haska, Charles Yarish, George Kraemer, Noreen Blaschik, Robert Whitlatch, Huan Zhang, Senjie Lin<br><br>**Source**: Biological Invasions, February 2012, Volume 14, Issue 2, pages 481–493 | Vectors of invasive species introductions are often unclear. This project evaluated the potential for the brown seaweed (Hauck) Reinke, packaged with bait worms harvested from the coast of Maine, as a vector of invasive marine fauna and flora. Often, the seaweed and contents of the bait boxes are discarded into the water by recreational fishermen after using the bait worms, and any included non-native species may then be introduced. Bait boxes were purchased from several commercial vendors in Connecticut and New York over a two-year period. Subsamples of the seaweed were placed in laboratory culture and the growth of associated macro- and microalgae was monitored. Marine invertebrate species present in the samples were also identified and quantified. Results indicated 13 species of macroalgae and 23 species of invertebrates were associated with baitboxes. Among the highly diverse microbial assemblage detected, two species of potentially toxic marine microalgae were found both prior to and after incubation at various temperatures, indicating these harmful algae are brought to and can survive in receiving waters. These findings highlight the need to consider alternative choices of bait box packaging materials or appropriate disposal methods of the seaweed in order to minimize the transport of species which are not native to the receiving coastal waters.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.875.3588&rep=rep1&type=pdf |

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| Other Studies/Research | **Title**: Reducing the Spread of Aquatic Invasive Species and Fish Pathogens in the Great Lakes: The Role of Bait Dealers<br><br>**Authors**: Nancy A. Connelly, T. Bruce Lauber, Richard C. Stedman<br><br>**Source**: HDRU Series No 14-8, Human Dimensions Research Unit, Department of Natural Resources, Cornell University (2014) | Study aim was to assess: (1) how bait dealers in the Great Lakes region have responded to regulations regarding the sale and transport of baitfish; (2) how their responses to regulations are related to their knowledge and awareness of and concern about pathogens, and constraints on their compliance; and (3) if they were aware of and concerned about AIS, and if they engaged in any efforts to educate their customers about them. A mail survey was conducted of bait dealers in the Great Lakes region. Bait dealer license records were obtained from each of the six states and provinces selected for the study (Indiana, Michigan, New York, Ohio, Ontario, and Wisconsin). The questionnaire included sections on awareness and knowledge of AIS and fish pathogens and the related regulations, behavioral responses to the presence of AIS and fish pathogens, concern about AIS and fish pathogens, sources used to obtain information about the regulations, factors potentially influencing compliance with the regulations, opinions about the regulations, and bait dealer business and owner characteristics.<br>https://ecommons.cornell.edu/bitstream/handle/1813/40356/HDRUReport14-08.pdf;sequence=2 |
| Other Studies/Research | **Title**: Preventing Aquatic Invasive Species through Vector Management: Live Bait Vector as a Model in the Mid-Atlantic Region<br><br>**Source**: Maryland Sea Grant and the Mid-Atlantic Panel on Aquatic Invasive Species, 2009 | Maryland Sea Grant hosted a workshop in 2009 in Baltimore, Maryland that focused on examining and controlling exotic species vectors. The workshop, sponsored in partnership with the Mid-Atlantic Panel on Aquatic Invasive Species, drew experts from throughout the region and beyond. Participants detailed specific research, management, and education and outreach actions for the major AIS vectors, or pathways, in the Mid-Atlantic.<br>Available at: https://www.mdsg.umd.edu/sites/default/files/files/AIS2009Report.pdf |
| Other Studies/Research | **Title**: Investigations into the introduction of non-indigenous marine organisms via the cross-continental trade in marine baitworms<br><br>**Authors**: Cohen AN, Weinstein A, Emmett MA, Lau W, Carlton JT<br><br>**Source**: A report for the US Fish and Wildlife Service, San Francisco Bay Program (2001) | Two species of marine polychaetes, Nereis virens Sars ("pileworms") and Glycera dibranchiata Ehlers ("bloodworms"), are imported into California in large numbers from the U.S. East Coast to be sold as fishing bait. The worms arrive by air freight, in shallow cardboard boxes packed with Atlantic coastal seaweeds, primarily Ascophyllum nodosum (Linnaeus) Le Jolis. Other living algae, fungi, invertebrates and protozoans from the Atlantic coast have been found in these boxes after their arrival in California, and a significant portion of these exotic organisms are regularly released into the California marine environment, where a few have apparently become established. The goal of this project is to provide a qualitative and quantitative assessment of the diversity and abundance of non-indigenous marine organisms imported and released into San Francisco Bay via the trade in marine baitworms.<br>https://www.sfei.org/sites/default/files/2001-Baitworms357.pdf |

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| Other Studies/Research | **Title**: DON'T DUMP BAIT: marine bait worms as a potential vector of non-native species<br>**Source**: Connecticut Sea Grant Publication (2009) | Researchers from the University of Connecticut and SUNY Purchase completed a study that reinforces concerns that live marine bait, such as bait worms, and more particularly, the seaweed or other material they are packed in, can serve as a vector or pathway by which organisms from one region can be introduced into another.<br>Available at: http://web2.uconn.edu/seagrant/whatwedo/ais/btwrms.pdf<br>http://longislandsoundstudy.net/wp-content/uploads/2010/02/Yarish.summary.20-Jan-09.pdf |
| Other Resources | Protect Our Fisheries | https://www.mdsg.umd.edu/sites/default/files/files/AIS%20Bait%20Worm%20Project/Bait%20sticker_Sea%20Grant(1).pdf<br>https://www.mdsg.umd.edu/sites/default/files/files/AIS%20Bait%20Worm%20Project/Brochure_baitworm_Delaware_rev.pdf |
| Other Resources | Bait Worm Study | https://www.mdsg.umd.edu/topics/aquatic-invasive-species/bait-worm-study |

# 6. Illegal Fish Stocking

| Type | Details | Summary |
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| Academic | **Title**: Are We Doing All We Can to Stem the Tide of Illegal Fish Stocking?<br>**Authors**: Brett M. Johnson, Robert Arlinghaus, Patrick J. Martinez<br>**Source**: Fisheries, 2009, Volume 34, Issue 8, pages 389-394 | The unauthorized, intentional release of aquatic animals to facilitate a fishery, which is referred to as "illegal stocking", is a global problem and yet there appears to be little collaboration across jurisdictions to seek solutions. Within North America it appears to be more prominent in regions with fewer native gamefish species: west of the continental divide and in the northern and northeastern regions. The paper contends that the fisheries profession can and must do a better job of preventing illegal fish stocking through strategic education programs, proactive regulatory policy, universally sever penalties, an international reward pool, and inter-jurisdictional collaboration.<br>https://onlinelibrary.wiley.com/doi/abs/10.1577/1548-8446-34.8.389 |

# 7. Aquarium Trade (Stores and Online)

| Type | Details | Summary |
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| Academic | **Title**: Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems<br>**Authors**: Dianna K. Padilla, Susan L. Williams<br>**Source**: Frontiers in Ecology and the Environment, April 2004, Volume2, Issue3, pages 131-138 | Although ballast water has received much attention as a source of aquatic invasive species, aquariums and trade in aquarium and ornamental species are emerging as another important source for species likely to invade aquatic habitats. These species are spread throughout the world in a generally unregulated industry. The recent focus on the aquarium trade as a possible mechanism for environmentally sustainable development poses an especially dangerous threat, although this has so far escaped the attention of most environmentalists, conservationists, ecologists, and policy makers.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.461.5665&rep=rep1&type=pdf |
| Academic | **Title**: The aquarium and horticultural industry as a pathway for the introduction of aquatic invasive species—outreach initiatives within the Great Lakes basin<br>**Authors**: Emily Funnell, Mark Heaton, Francine MacDonald, Beth Brownson<br>**Source**: Biodiversity, December 2011, Volume 10, Issue 2-3, pages 104-112 | The aquarium and horticultural industry is increasingly being recognized as a significant avenue for the introduction of non-indigenous aquatic species, a pathway which is increasing in risk due to steady growth in these industries. Some of the world's worst AIS have been associated with aquarium or horticultural release and at least 12 exotic species have been introduced into the Great Lakes basin via this route. Ongoing public education initiatives throughout the Great Lakes basin documented over 250 stores selling known AIS. Most commonly, the invasive Goldfish, Koi, and Cabomba were observed, respectively occurring 80%, 62%, and 49% of the time. The direct release of aquarium and horticultural organisms is not well regulated in Canada and surveys have found that individuals admit to disposing of unwanted plants and animals into the wild. With few regulations controlling the importation and sale of non-indigenous species, and in considering their widespread availability, intentional or unintentional release by the public is inevitable. The relatively unrestricted movement of exotic plants and animals through international markets necessitates a more coordinated national, regional, and international approach to identifying risks posed by non-indigenous species and actions to control their introduction and spread.<br>https://www.tandfonline.com/doi/abs/10.1080/14888386.2009.9712852 |

| Type | Details | Summary |
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| Academic | **Title**: The Aquarium Trade as an Invasion Pathway in the Pacific Northwest<br><br>**Authors**: Angela L. Strecker, Philip M. Campbell, Julian D. Olden<br><br>**Source**: Fisheries, 2011, Volume 36, Issue 2, pages 74-85 | Report on the first investigation of the ornamental pet trade as an invasion pathway in the Pacific Northwest region of the United States, where a moderate climate and a large human population present ample opportunities for the introduction and establishment of aquarium trade species. Results from a regional survey of pet stores found that the number of fish (n=400) and plant (n=124) species currently in the aquarium trade is vast. Pet stores import thousands of fish every month, the majority of which (58%) are considered to pose an ecological threat to native ecosystems. Our propagule pressure model suggests that approximately 2,500 fish (maximum 21,000 individuals) are likely released annually to the Puget Sound region by aquarists, and that water temperatures in many parts of Washington are suitable for establishment of populations. The study concludes that the aquarium trade may be a significant source of past and future invasions in the Pacific Northwest and recommendations are to enhance public education programs, greater regulate the aquarium industry, and improved legislation of nonnative species in the ornamental trade.<br>Available at: https://www.tandfonline.com/doi/pdf/10.1577/03632415.2011.10389070 |
| Academic | **Title**: Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes<br><br>**Authors**: Rixon CAM Duggan IC Bergeron NMN Ricciardi A Macisaac HJ<br><br>**Source**: Biodiversity and Conservation, 2005, 14, pages 1365 - 1381 | International trade is an important mechanism for global non-indigenous species introductions, which have had profound impacts on the biodiversity of aquatic ecosystems including the Laurentian Great Lakes. The best-documented vector by which non-indigenous species have entered the Great Lakes is ballast water discharged by transoceanic ships. A variety of potential alternative vectors exist, including the intentional release of aquarium or food organisms. To assess whether these vectors pose a significant invasion risk for the Great Lakes, research surveyed fish sold live in markets and fish, mollusks and macrophytes sold in pet and aquarium stores within the Great Lakes watershed. Evaluation was conducted of invasion risk using information on species' thermal tolerance, history of invasion elsewhere, and potential propagule loads as indicated by frequency of occurrence in shops. The research suggests that both the aquarium industry and live fish markets represent potential sources of future invaders to the Great Lakes, including several aquarium fishes and macrophytes, as well as Asian carp species sold in fish markets. Currently, few regulatory mechanisms exist to control these potential vectors.<br>Available at: http://redpath-staff.mcgill.ca/ricciardi/Rixon.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Thousands introduced annually: the aquarium pathway for non-indigenous plants to the St Lawrence Seaway<br><br>**Authors**: Jill Cohen, Nicholas Mirotchnick, Brian Leung<br><br>**Source**: Frontiers in Ecology and the Environment, December 2007, Volume5, Issue10, pages 528-532 | Non-indigenous species are both economically and ecologically costly. Invasions are occurring at an accelerating rate worldwide and therefore present a critical challenge to natural resource managers. The aquarium trade is commonly recognized as a pathway for non-indigenous plants, but few regulations exist to curb such introductions. In addition, very few studies have attempted to quantify the number of propagules introduced through the aquarium trade each year, probably because it is difficult to directly measure the number of propagules introduced. The study uses a novel approach to quantify propagule numbers by analyzing each step in the path to introduction and synthesizing this information to calculate propagule pressure for each species. The aquarium plant trade in Montreal, Quebec, Canada, was used as the study system and found that thousands of non-indigenous plant propagules are introduced to the St Lawrence Seaway each year, through the Montreal aquarium trade alone. Two known invaders are among those species with the highest measured propagule pressure.<br>Available at: http://biology.mcgill.ca/faculty/leung/articles/Cohen_etal_thousands.pdf |
| Academic | **Title**: Tackling aquatic invasions: risks and opportunities for the aquarium fish industry<br><br>**Authors**: Andrew L. Chang, Judah D. Grossman, Teresa Sabol Spezio, Heidi W. Weiskel, Julia C. Blum, Jennifer W. Burt, Adrianna A. Muir, Jonah Piovia-Scott, Kari E. Veblen, Edwin D. Grosholz<br><br>**Source**: Biological Invasions, April 2009, Volume 11, Issue 4, page 773–785 | The aquarium trade is an important and rapidly growing vector for introduced species in the United States. The study examined this vector by surveying pet stores in the San Francisco Bay–Delta region to compile a list of aquarium fish species commonly stocked. Species that might be able to survive in the Bay–Delta, and investigated store representatives' knowledge and attitudes about biological invasions were identified. In the more restrictive analysis, three national retail chains stocked significantly more potentially invasive species than independent aquarium stores, but there was no difference in the more inclusive analysis. A significantly higher percentage of fish taxa were easily identifiable and well-labeled in chain stores than in independent stores. Most aquarium store representatives indicated willingness to take action to reduce the threat of trade-related introductions, although chain store employees were more willing to assign responsibility for reducing this threat to the aquarium industry than were independent store employees. Management efforts for this vector should focus on (a) improving labeling and identification of fish species in stores, (b) expanding the often spotty data on fish physiological tolerances, especially for saltwater species, (c) educating customers and store employees about the risks posed by pet release, and (d) providing better options for responsible disposal of unwanted fish.<br>Available at: https://link.springer.com/content/pdf/10.1007%2Fs10530-008-9292-4.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Quantifying invasion pathways: fish introductions from the aquarium trade<br><br>**Authors**: Erin Gertzen, Oriana Familiar, Brian Leung<br><br>**Source**: Canadian Journal of Fisheries and Aquatic Sciences, 2008, Volume 65, Issue 7, pages 1265-1273 | Introduced species can cause economic and environmental harm. Researchers have developed risk assessment models for exotic species based on biological characteristics; however, few have quantified propagule pressure despite its relevance for establishment. Both are needed to identify invasion risk. The study focused on fishes introduced via the aquarium trade, because this pathway transports thousands of species throughout the world. An approach to estimate propagule pressure was developed by (*i*) identifying and quantifying aquarium fishes sold, (*ii*) determining fish owner behavior and disposal practices, and (*iii*) quantifying uncertainty, using the St. Lawrence Seaway as the model system. Only one non-established species (Tanichthys albonubes, 117 per year) had the propagule pressure and environmental tolerances to likely invade this region. However, overall, more than 10 000 fishes were released annually from Montréal (Quebec, Canada) alone. The implication of the observed propagule pressures is that the aquarium trade should be a very important pathway in other warmer habitats and should be explicitly assessed. Knowledge of the numbers introduced of each species will be useful for population models to estimate the probability of establishment.<br>Available at:<br>https://www.researchgate.net/profile/Brian_Leung2/publication/237153292_Quantifying_invasion_pathways_Fish_introductions_from_the_aquarium_trade/links/00463529bd416e7ae5000000.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Opportunities for Public Aquariums to Increase the Sustainability of the Aquatic Animal Trade<br><br>**Authors**: Michael F. Tlusty, Andrew L. Rhyne, Les Kaufman, Michael Hutchins, Gordon McGregor Reid, Chris Andrews, Paul Boyle, Jay Hemdal, Frazer McGilvray, Scott Dowd<br><br>**Source**: Zoo Biology, 2013, Volume32, Issue1, pages 1-12 | The global aquatic pet trade encompasses a wide diversity of freshwater and marine organisms. While relying on a continual supply of healthy, vibrant aquatic animals, few sustainability initiatives exist within this sector. Public aquariums overlap this industry by acquiring many of the same species through the same sources. End users are also similar, as many aquarium visitors are home aquarists. It is posited that this overlap with the pet trade gives aquariums significant opportunity to increase the sustainability of the trade in aquarium fishes and invertebrates. Improving the sustainability ethos and practices of the aquatic pet trade can carry a conservation benefit in terms of less waste, and protection of intact functioning ecosystems, at the same time as maintaining its economic and educational benefits and impacts. The relationship would also move forward the goal of public aquariums to advance aquatic conservation in a broad sense. For example, many public aquariums in North America have been instrumental in working with the seafood industry to enact positive change toward increased sustainability. The actions include being good consumers themselves, providing technical knowledge, and providing educational and outreach opportunities. These same opportunities exist for public aquariums to partner with the ornamental fish trade, which will serve to improve business, create new, more ethical and more dependable sources of aquatic animals for public aquariums, and perhaps most important, possibly transform the home aquarium industry from a threat, into a positive force for aquatic conservation. Available at: https://docs.rwu.edu/cgi/viewcontent.cgi?article=1140&context=fcas_fp |
| Academic | **Title**: Loopholes in the regulation of invasive species: genetic identifications identify mislabeling of prohibited aquarium plants<br><br>**Authors**: Ryan A. Thum, Amanda T. Mercer, Dustin J. Wcisel<br><br>**Source**: Biological Invasions, May 2012, Volume 14, Issue 5, pages 929–937 | Numerous invasive aquatic species introductions can be traced to the aquarium trade. Many potentially harmful aquarium species may be difficult to identify based on morphology alone. As such, some prohibited or invasive species may be available for purchase if they are mislabeled as species without restrictions. A comparison is conducted of molecular identifications to internet vendors' identifications for accessions of a popular genus of aquarium plants that are difficult to distinguish morphologically (Myriophyllum; watermilfoils). Specifically, the extensive mislabeling of M. heterophyllum was identified—an invasive species in the northeastern and western US. Furthermore, genotypes of M. heterophyllum found in our aquarium survey have also been found in invasive populations, suggesting their potential introduction through escape from aquaria, water gardens, or nurseries. Two additional taxa were sold under incorrect names. Finally, the survey revealed that Myriophyllum taxa present in the aquarium trade generally have poorly known distributions and ecologies, and therefore their invasive potential is unknown. The study confirms that molecular identification methods can provide a valuable tool to survey commercial pathways for potentially harmful species that are otherwise difficult to identify. https://link.springer.com/article/10.1007/s10530-011-0130-8 |

| Type | Details | Summary |
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| Academic | **Title**: The freshwater aquarium trade as a vector for incidental invertebrate fauna<br><br>**Authors**: Ian C. Duggan<br><br>**Source**: Biological Invasions, November 2010, Volume 12, Issue 11, pages 3757–3770 | The aquarium trade has a long history of transporting and introducing fish, plants and snails into regions where they are not native. However, other than snails, research on species carried "incidentally" rather than deliberately by this industry is lacking. The study samples invertebrates in the plankton, and from water among bottom stones, of 55 aquaria from 43 New Zealand households. 55 incidental invertebrate taxa were recorded, including six known established non-indigenous species, and eight others were not previously recorded from New Zealand, demonstrating the aquarium trade continues to pose an invasion risk for incidental fauna. A variety of behaviours associated with the set-up and keeping of home aquaria were recorded (e.g., fish and plants in any home were sourced from stores, wild caught, or both, and cleaning methods varied), which made prediction of "high risk" behaviours difficult. However, non-indigenous species had a greater probability of being recorded in aquaria containing aquatic plants and in those that were heated. Methods for disposal of aquarium wastes ranged from depositing washings on the lawn or garden (a low risk for invasion) to disposing of water into outdoor ponds or storm-water drains (a higher risk). The study recommends that aquarium owners be encouraged to pour aquarium wastes onto gardens or lawns—already a common method of disposal—as invasion risk will be minimised using this method.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.718.827&rep=rep1&type=pdf |
| Academic | **Title**: E-commerce and Caulerpa: unregulated dispersal of invasive species<br><br>**Authors**: Linda J. Walters, Katherine R. Brown, Wytze T. Stam, Jeanine L. Olsen<br><br>**Source**: Frontiers in Ecology and the Environment, March 2006, Volume 4, Issue 2, pages 75-79 | Professional aquarists and hobbyists are thought to be the source of invasions of the aquarium strain of the green macroalga Caulerpa taxifolia in the Mediterranean, southern California, and Australia. The US Department of Agriculture, Animal and Plant Health Inspection Service (USDA–APHIS) restricted interstate commerce and importation of the Mediterranean clone of C taxifolia prior to the California invasion and is currently deciding if it should strengthen regulation of this genus as more species of Caulerpa are being described as invasive. The importance of e-commerce as a mode of dispersal for many species of Caulerpa in the United States is documented in this study. Caulerpa was purchased from 30 internet retailers and 60 internet auction sites representing 25 states and Great Britain. Twelve different Caulerpa species were confirmed using DNA sequencing. Only 10.6% of sellers provided the correct genus and species names with their shipments. Thirty purchases of "live rock" provided four species of Caulerpa, as well as 53 additional marine species. Results confirm the extensive e-commerce availability of this invasive genus and its high dispersal potential via postal services and hobbyists. We recommend that both eBay and the USDA maximize regulation of Caulerpa.<br>Available at: https://www.rug.nl/research/gelifes/green/_pdf/2006/2006-waltersfee.pdf |

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| Academic | **Title**: Mail Order, the Internet, and Invasive Aquatic Weeds<br><br>**Authors**: Stratford H, Kay, Steve T. Hoyle<br><br>**Source**: Journal of Aquatic Plant Management, 2001, Volume 39, pages 88-91 | Aquatic and wetland weeds pose serious threats to the freshwater resources of the United States. Essentially unregulated sale of plants for aquarium and ornamental pool use has resulted in the recent introduction and spread of several highly invasive weeds, including giant salvinia. This problem has been exacerbated during the past few years by mail-order and e-commerce. The objective of this study was to examine mail order and the internet as sources for sale of invasive aquatic weeds, with primary emphasis on the Internet. An online search was conducted using the search engine Yahoo™. Data were collected on twelve of the most common and highly invasive weeds sold by the industry. The data from the first 100 hits were grouped into regulatory, educational, commercial, hobbyist, and foreign sites. Essentially every aquatic or wetland plant listed in the United States as either a Federal Noxious Weed or as a noxious weed in one or more states was found. Twelve highly invasive plants intentionally sold by the wetland nurseries and water garden dealerships were found listed for sale by sites throughout the United States and internationally. This study shows that stronger enforcement of laws and regulations and an intensive education and outreach effort are needed to prevent further introductions of invasive weeds through the aquatic and wetland plant industry.<br>Available at: http://www.apms.org/wp/wp-content/uploads/2012/10/v39p88.pdf |
| Academic | **Title**: Revealing the Appetite of the Marine Aquarium Fish Trade: The Volume and Biodiversity of Fish Imported into the United States<br><br>**Authors**: Andrew L. Rhyne, Michael F. Tlusty, Pamela J. Schofield, Les Kaufman, James A. Morris Jr, Andrew W. Bruckner<br><br>**Source**: PLoS ONE, 2012, 7(5): e35808. doi:10.1371/journal.pone.0035808 | The aquarium trade and other wildlife consumers are at a crossroads forced by threats from global climate change and other anthropogenic stressors that have weakened coastal ecosystems. While the wildlife trade may put additional stress on coral reefs, it brings income into impoverished parts of the world and may stimulate interest in marine conservation. To better understand the influence of the trade, we must first be able to quantify coral reef fauna moving through it. Herein, we discuss the lack of a data system for monitoring the wildlife aquarium trade and analyze problems that arise when trying to monitor the trade using a system not specifically designed for this purpose. To do this, we examined an entire year of import records of marine tropical fish entering the United States in detail, and discuss the relationship between trade volume, biodiversity and introduction of non-native marine fishes. Our analyses showed that biodiversity levels are higher than previous estimates. Additionally, more than half of government importation forms have numerical or other reporting discrepancies resulting in the overestimation of trade volumes by 27%. While some commonly imported species have been introduced into the coastal waters of the USA (as expected), we also found that some uncommon species in the trade have also been introduced. This is the first study of aquarium trade imports to compare commercial invoices to government forms and provides a means to, routinely and in real time, examine the biodiversity of the trade in coral reef wildlife species<br>Available at: http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0035808&type=printable |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Reducing Invasive Organisms in Trade in Great Lakes Watersheds<br><br>**Source**: Bureau of Science Services Wisconsin Department of Natural Resources | This report describes grant-funded work undertaken by the Wisconsin Department of Natural Resources to reduce the availability of invasive species in the live aquatic plant trade in Wisconsin. We: 1) surveyed aquatic plant retailers to assess attitudes towards invasive species and knowledge of the invasive species regulations, and to identify barriers to selling non-invasive alternatives; 2) surveyed Wisconsin aquatic plant retailers' stock to locate regulated species for sale; 3) conducted educational visits and provided educational materials to retailers; and 4) surveyed small water bodies to assess the landscape risk from aquatic invasive plants sold in the live plant trade.<br>Available at: https://dnr.wi.gov/files/PDF/pubs/ss/SS1144.pdf |
| Other Studies/Research | **Title**: Best Practices in Pre-Import Risk Screening for Species of Live Animals in International Trade (Expert Workshop on Preventing Biological Invasions, 2008)<br><br>**Source**: Global Invasive Species Program | Proceedings of an expert workshop was organised entitled, 'Preventing Biological Invasions: Best Practices in Pre-Import Risk Screening for Species of Live Animals in International Trade', which focused on 'best practices' to address the risks associated with imports of live animals (and their parasites and pathogens) in international trade. Such species are imported primarily for the pet, aquarium/terrarium, aquaculture/mariculture, live bait, game farming, fur farming and live food industries, and include terrestrial, aquatic, vertebrate and invertebrate species. Participants at the expert workshop on preventing biological invasions: best practices in pre-import risk screening for species of live animals in international trade, considered the issues under eight key themes are follows: i. Risk assessment and decision-making; ii. Progression of biological invasion and risk assessment approach; iii. Concepts and technical tools for risk assessment of live animal species; iv. Gaps in the international regulatory framework; v. National implementation, strategic approaches, capacity; vi. Subnational and regional risk assessments; vii. Awareness and stakeholder involvement; and viii. Information requirements and sharing.<br>Available at: http://www.gisp.org/publications/policy/workshop-riskscreening-pettrade.pdf |
| Other Studies/Research | **Title**: Pets, Aquarium, and Terrarium Species: Best Practices for Addressing Risks to Biodiversity, CBD Technical Series No. 48, 2010<br><br>**Source**: Secretariat of the Convention on Biological Diversity | Documents some of the problems resulting from invasive alien species introduced via the pet and aquarium trade, provides examples of risk assessment and regulatory practices employed by some Parties, and presents measures to prevent further invasions of species which pose a significant risk. This information is relevant to importers/exporters operating in large markets, pet owners, and decision-makers considering appropriate control measures for invasive alien species. Facts are presented in a format accessible to all readers, ranging from the local to global levels, to take appropriate actions with regard to invasive alien species introduced as pets, aquarium and terrarium species.<br>Available at: https://www.cbd.int/doc/publications/cbd-ts-48-en.pdf |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Aquatic Invasive Organisms in Trade - Marketing & Outreach Plan<br>**Source**: Michigan Department of Agriculture and Rural Development | Invasive organisms available through trade can reach Michigan's waterways via a number of pathways, including intentional release of pets or plants purchased via retail outlets, and escape from private ponds and water gardens during floods or other disturbances. Communication between the Michigan Department of Agriculture and Rural Development, the public, and the businesses involved with organisms in trade is imperative to the success of the RIPPLE (Reduce Invasive Pet and PLant Escapes) campaign. Its purpose is to establish and foster mutual understanding, promote public involvement, and influence the behaviors, attitudes and actions of consumers and retailers in the pond and pet store industry. Through RIPPLE, the public and retail establishments will see a unified message regarding containment and disposal of aquatic plants and organisms commonly acquired through pet store and pond retail businesses. The RIPPLE campaign strives to build a unified understanding of the harmful impacts aquatic invasive species have on Michigan's waterways and promote the proper containment and disposal of potentially invasive organisms by creating and distributing visual materials and developing partnerships with leading environmental organizations and businesses to provide consistent information about organisms in trade to the public.<br>Available at:<br>https://www.michigan.gov/documents/invasives/RIPPLE_Marketing_and_Outreach_Plan_2015_516671_7.pdf |
| Other Resources | Habitattitude Project | http://www.habitattitude.net/ |
| Other Resources | Aquatic Pests Introduced from Aquariums and Water Gardens | https://bugwoodcloud.org/mura/gist/assets/File/pubs/aquatics.pdf |
| Other Resources | Recommended Voluntary Guidelines Aquarium Industry | http://www.ridnis.ucdavis.edu/May05Wrkshp/FnlIndGlines.pdf |

# 8. Water Garden Trade

| Type | Details | Summary |
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| Academic | **Title**: Species Invasions from Commerce in Live Aquatic Organisms: Problems and Possible Solutions<br><br>**Authors**: Reuben P. Keller, David M. Lodge<br><br>**Source**: BioScience, May 2007, Volume 57, Issue 5, pages 428–436 | 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. The study 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. Study 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. Five retail trades were identifed 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. Available at: https://academic.oup.com/bioscience/article/57/5/428/221808 |

| Type | Details | Summary |
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| Academic | **Title**: Evaluating stakeholder awareness and involvement in risk prevention of aquatic invasive plant species by a national code of conduct<br><br>**Authors**: Laura N.H. Verbrugge, Rob S.E.W. Leuven, Johan L.C.H. van Valkenburg, Riyan J.G. van den Born<br><br>**Source**: Aquatic Invasions, 2014, Volume 9, Issue 3, pages 369–381 | Dutch stakeholders signed a voluntary agreement between the government and horticulture sector (i.e. plant nurseries and retailers) to ban the sale of invasive species and to increase public awareness and stakeholder involvement in measures to prevent new introductions of potential invaders. Public outreach campaigns included flyers and posters displayed in stores and labelling of non-native plant species with warning logos and messages on harmful effects and appropriate disposal. The study evaluates several measures by conducting by performing ex ante and ex posterior surveys and interviews with relevant stakeholder groups. Compliance of retailers and producers concerning species on sale and proper labelling was monitored annually by the Netherlands Food and Consumer Product Safety Authority. Interviews with aquarists and water gardeners provided the first quantitative evidence in the Netherlands that 2–3% of these hobbyists deliberately introduced non-native aquatic plants in surface water. A survey of retail professionals identified limited availability of information and lack of salesman's knowledge on the species lists issued in the code of conduct as major impediments for their engagement. Furthermore, low frequency of meetings and lack of guidance were major obstacles identified by the partners assembled in the code of conduct. Overall, compliance to species bans showed promising results, however, problems were identified with correct labelling of species. The study concludes by listing opportunities to improve voluntary regulations for preventing non-native species introductions.<br>Available at: https://repository.ubn.ru.nl//bitstream/handle/2066/130194/130194pub.pdf |
| Academic | **Title**: Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade<br><br>**Authors**: Kristine Maki, Susan Galatowitsch<br><br>**Source**: Biological Conservation, July 2004, Volume 118, Issue 3, pages 389-396 | The extent to which invasive aquatic plants move via accidental inclusion in aquatic plant orders or sale of prohibited species is unknown. Forty orders were placed to 34 aquatic plant vendors across the US between May and September 2001 to determine the prevalence of movement into Minnesota via horticultural trade. Federal noxious weeds or Minnesota prohibited exotic species were acquired 92% of the time they were ordered and included *Alternanthera sessilis*, *Butomus umbellata*, *Hydrocharis morsus-ranae*, *Potamogeton crispus*, and *Lythrum salicaria*. Ninety three percent of orders received from aquatic plant vendors contained a plant or animal species not specifically requested; 10% of these purchases contained federal noxious weeds or Minnesota exotic species. *Lemna minor* was the most common incidental receipt found per taxa and per purchase, although *Hydrilla verticillata*, *Lythrum salicaria*, *Salvinia molesta*, and *Potamogeton crispus* (all prohibited taxa) were also found. Misidentified plants were found in 18% of the orders; unordered seeds in 43%. The sale and transport of prohibited aquatic plants likely presents the greatest risk associated with the aquatic plant trade. Other important factors include misidentification leading to the unintentional sale of invasive plants and the incidental inclusion of species during translocation.<br>https://www.sciencedirect.com/science/article/pii/S0006320703003835 |

| Type | Details | Summary |
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| Academic | **Title**: Minnesota horticultural industry survey on invasive plants<br><br>**Authors**: William L. Peters, Mary Hockenberry, Meyer, Neil O. Anderson<br><br>**Source**: Euphytica, March 2006, Volume 148, Issue 1–2, pages 75–86 | Horticultural commerce of ornamental plants has been the source of many of our most troublesome plant invaders worldwide. The purpose of the research was to document the knowledge gap of industry perspectives and knowledge of invasive ornamental crops by surveying industry professionals in the Midwest region of the U.S. (primarily in the state of Minnesota). An invasive plant survey was created to assess this information and was mailed to *n* = 500 individuals and companies randomly chosen from the Minnesota Nursery and Landscape Association (MNLA) membership, which included wholesale/retail nurseries, landscape design, installation & maintenance firms, and retail garden centers. A total of *n* = 167 surveys (33.4%) were returned and analyzed. A majority of respondents, 62%, felt that the invasive plant issue was very important and 89% tried to direct their customers away from potentially invasive plants. Many respondents, 76%, indicated that they were responsible for educating their customers about invasive ornamental plants. Sixty-nine percent said that they would not sell a plant if it was potentially invasive; however, 57% indicated that this would be true if a competing business was selling the plant. Respondent's knowledge about specific invasive plants varied from 75% to 89% on the identification of three terrestrial invasive plant crops. Far less, 20% and 21%, were able to identify *Butomus umbellatus* and *Salvinia molesta,*respectively, two invasive aquatic species. When asked about regulation of invasive ornamental crops, 43% preferred national, state, or USDA regulation while 22% felt industry self-regulation was best, and 21% approved of private regulation. Opportunities exist for educating horticulture industry professionals about invasive plants and providing information to the public through commercial businesses.<br>https://link.springer.com/article/10.1007/s10681-006-5942-8 |

| Type | Details | Summary |
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| Academic | **Title**: Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes<br><br>**Authors**: Jennifer G. Howeth, Crysta A. Gantz, Paul L. Angermeier, Emmanuel A. Frimpong, Michael H. Hoff, Reuben P. Keller, Nicholas E. Mandrak, Michael P. Marchetti, Julian D. Olden, Christina M. Romagosa, David M. Lodge<br><br>**Source**: Diversity and Distributions, February 2016, Volume 22, Issue 2, pages 148-160 | Impacts of non-native species have motivated development of risk assessment tools for identifying introduced species likely to become invasive in the Laurentian Great Lakes region. The study developed trait-based models for the establishment and impact stages of freshwater fish invasion, and use them to screen non-native species common in international trade. We also determine which species in the aquarium, biological supply, live bait, live food and water garden trades are likely to become invasive. Screening outcomes suggest the water garden trade poses the greatest risk of introducing new invasive species, followed by the live food and aquarium trades. Analysis of historical patterns of introduction pathways demonstrates the increasing importance of these trades relative to other pathways. Comparisons among trades reveal that model predictions parallel historical patterns; all fishes previously introduced from the water garden trade have established. The live bait, biological supply, aquarium and live food trades have also contributed established non-native fishes.<br>Available at: http://depts.washington.edu/oldenlab/wordpress/wp-content/uploads/2013/01/DiversityDistributions_2016.pdf |
| Other Studies/Research | **Title**: Summary of a survey of water garden owners in Canada, 2009<br><br>**Source**: Canada. Department of Fisheries and Oceans | The “Great Canadian Water Garden Survey” was led by the Ontario Federation of Anglers and Hunters (OFAH) along with partner organizations, both as an online and paper questionnaire to determine the origin and fate of aquatic invasive species in the water garden trade. A total of 752 surveys were completed, of which 359 respondents (48%) indicated they had a water garden. In the survey was a list of water garden plant and animal species used by respondents, including eight aquatic invasive plant species and two aquatic invasive animal species, all of which were added to water gardens by multiple respondents. Analyses of the purchase locations and water garden locations indicated relatively small mean travel distances (mean Euclidean distances were 39.49 km for plants and 33.52 km for animals), but were notable for high variability and extreme right-skewness signifying rare, long-distance travel distances within both the plant and animal surveys. The survey results indicate that the water garden trade should not be overlooked as a vector for aquatic invasive species into Canadian freshwaters.<br>Available at: http://waves-vagues.dfo-mpo.gc.ca/Library/339424.pdf |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Invasive aquatic plants and the aquarium and ornamental pond industries<br><br>**Source**: Azan, Shakira Stephanie Elaine Thesis Dissertation | The purpose of the research was to clarify the common traits of a successful aquatic invasive plant. The biological traits of aquatic plans sold by aquarium and ornamental pond stores in the Greater Toronto Area, Ontario were analysed using logistic regression analysis (LRM). The multinomial LRM successfully predicts group identify 63% of the time, clearly differentiating native invasive and native non invasive from alien invasive (AI) but not alien non invasive (ANI) from AI. In contract, the binomial LRM effectively discriminates ANI from AI taxa 77% of the time. The variables that best discriminated between AI and ANI are type of propagation strategies, number of propagation strategies used, number of dispersal mechanism used, minimum temperature, and sales volume of aquatic plans as a proxy for introduction. Recognizing the common traits of successful invaders allows for the identification of ANI taxa that have the potential to become invaders, prior to introduction, thus preventing future invasions.<br>Available at: http://digital.library.ryerson.ca/islandora/object/RULA:1220/datastream/OBJ/view |
| Other Resources | Michigan RIPPLE: Reduce Invasive Pet and PLant Escapes | https://www.michigan.gov/invasives/0,5664,7-324-68000_75850---,00.html |
| Other Resources | Smart water gardening to prevent the spread of aquatic invasive species | http://msue.anr.msu.edu/uploads/234/68325/lsli_2013_session_1/Session2_SmartGardeningAIS.pdf |
| Other Resources | Recommended Voluntary Guidelines Aquatic Horticulture Industry | http://www.ridnis.ucdavis.edu/NovWrkshp/FnlIndGlns.pdf |
| Other Resources | Keeping Aquatic Plants In Their Place: Common Sense Tips to Protect Lakes and Rivers | http://www.ridnis.ucdavis.edu/Docs/HCrossonArtcle..pdf |
| Other Resources | Aquatic Gardens, Not Aquatic Pests: How to Practice Responsible Water Gardening | https://anrcatalog.ucanr.edu/pdf/8369.pdf |

# 9. Live Food Trade

| Type | Details | Summary |
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| Academic | **Title**: Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes<br><br>**Authors**: Rixon CAM Duggan IC Bergeron NMN Ricciardi A Macisaac HJ<br><br>**Source**: Biodiversity and Conservation, 2005, 14, pages 1365 - 1381 | International trade is an important mechanism for global non-indigenous species introductions, which have had profound impacts on the biodiversity of aquatic ecosystems including the Laurentian Great Lakes. The best-documented vector by which non-indigenous species have entered the Great Lakes is ballast water discharged by transoceanic ships. A variety of potential alternative vectors exist, including the intentional release of aquarium or food organisms. To assess whether these vectors pose a significant invasion risk for the Great Lakes, research surveyed fish sold live in markets and fish, mollusks and macrophytes sold in pet and aquarium stores within the Great Lakes watershed. Evaluation was conducted of invasion risk using information on species' thermal tolerance, history of invasion elsewhere, and potential propagule loads as indicated by frequency of occurrence in shops. The research suggests that both the aquarium industry and live fish markets represent potential sources of future invaders to the Great Lakes, including several aquarium fishes and macrophytes, as well as Asian carp species sold in fish markets. Currently, few regulatory mechanisms exist to control these potential vectors.<br>Available at: http://redpath-staff.mcgill.ca/ricciardi/Rixon.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Assessing the risk of introducing exotic species via the live marine species trade<br><br>**Authors**: Weigle SM, Smith LD, Carlton JT, Pederson J<br><br>**Source**: Conservation Biology, 2005, Volume 19, Issue 1, pages 213 - 223 | Although the shipping industry has received considerable attention as a dispersal mechanism for aquatic nuisance species, many invasions have been linked to other mechanisms of transfer. The threat posed to coastal ecosystems by these alternative mechanisms, however, remains largely unquantified. An assessment was conducted on the potential risks of introducing marine and estuarine species associated with seven mechanisms of transfer: seafood companies, aquaculture operations, bait shops, stores that sell marine ornamental species, research and educational organizations, public aquariums, and coastal restoration projects. For each, we compiled a comprehensive database of organizations in coastal Massachusetts. We then designed and administered a survey to a subset of organizations that inquired about (1) their proximity to saltwater and methods of handling live imports; (2) the type and quantity of marine species being imported; and (3) the organization's familiarity with marine invasions. Respondents in five of the seven categories acknowledged importing nonlocal live marine species to the area. Seafood companies handled the majority of individuals but relatively few taxa. This mechanism of transfer also had the most complex trade patterns and the greatest number of operations located near saltwater. In contrast, the other transfer mechanisms each had simpler trade pathways and fewer operations but varied in the quantity and taxonomic diversity of their imports. Significantly, no single mechanism of transfer stood out as presenting a primary risk. Rather, each had characteristics or used handling practices at different points in the importation process that could facilitate introductions. To prevent future marine invasions, better reporting requirements for live species imports are needed, and best-management practices and outreach strategies specific to the transfer mechanism should be developed and implemented.<br>Available at: http://seagrant.mit.edu/media/publications/MITSG_05-01J.pdf |

| Type | Details | Summary |
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| Academic | **Title**: Live Seafood Species as Recipes for Invasion<br>**Authors**: John W. Chapman, Todd W. Miller, Eugene V. Coan<br>**Source**: Conservation Biology, October 1003, Volume 17, Issue 5, pages 1386-1395 | A global market in seafood disperses many live organisms to distant locations. These organisms can be released into environments of the new locations, where they can establish reproductive populations. The risks of such introductions remain poorly resolved. Bivalves (oysters, mussels, and clams) that are commercially available as seafood in the western United States were surveyed. Twenty-four of the 37 available marine and estuarine bivalve species are nonindigenous. Eleven of these 24 nonindigenous species have established, self-sustaining populations in northeast Pacific environments. Three of the remaining 13 nonindigenous species have been introduced outside their natural ranges elsewhere in the world. We estimated the risks of some of these species being introduced by performing binomial probability analyses on these data. Results suggest that there is a significant risk of introducing live seafood species into northeast Pacific ecosystems. Efforts to warn distributors and consumers to screen imported seafood species for invasiveness, to monitor estuaries and coastal ecosystems for early detection, and to develop rapid-response plans for containing new invaders are warranted.<br>https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1523-1739.2003.01016.x |
| Academic | **Title**: Aquaculture: A gateway for exotic species<br>**Authors**: Naylor RL Williams SL Strong DR<br>**Source**: Science, 2001, 294, pages 1655 - 1656 | Aquaculture is a fast-growing segment of the world food economy and a leading vector of aquatic invasive species in the United States and abroad. Surprisingly, little national or international oversight exists even for deliberate introductions of exotic species in aquaculture. The authors of this [Policy Forum] propose a policy agenda on exotic introductions as aquaculture expands that includes scientific risk assessment for all nonnative introductions and single-agency oversight for the prevention, containment, and monitoring of ecologically harmful species.<br>Available at: https://www.researchgate.net/publication/11634627_Aquaculture--A_Gateway_for_Exotic_Species |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Do Live Marine Products Serve as Pathways for the Introduction of Nonindigenous Species?<br><br>**Source**: Marketing and Shipping Live Aquatic Products, University of Alaska Sea Grant, AK-SG-01-03, 2001, pages 243-247 | Two kinds of nonindigenous species are associated with the trade in live products. One type is the live products themselves and the other is non-target or hitchhiking species that are pests, pathogens, and other species of unknown status that might come along with the product. They come in the packing material, the water, or the packaging. They may also be attached to or living in the target species, as with disease organisms. This suggests that, in addition to the product and its handling, the handling and disposal of packaging has potential for bringing these unintentional introductions. Research focuses on human activities during the transport stage. The study looks at scientific specimens, live seafood, and live bait in more depth. For the pilot study, two shipments of scientific specimens (fucus, or rockweed, and mixed algae) were ordered and tree shipments of Maine lobster were ordered through contacts found over the Internet. The fauna and flora present in the shipments were classified. In addition to the target taxa, which for animals were the lobsters, there were numerous nontarget taxa found in all these shipments. Most of them were isopods, some were amphipods, and a few were worms. Among the flora, there were between three and six nontarget species. Overall, 21 or 22 multicellular species were found in the scientific specimens, and between five and eleven species in the live seafood. These species were found largely in the packing material. Available at: https://pdfs.semanticscholar.org/d4d7/31a65880b78b810771552c6b7b250af01244.pdf#page=252 |

| Type | Details | Summary |
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| Other Studies/Research | **Title**: Evaluating transfers of harvested shellfish products, from the west to the east coast of Vancouver Island, as a potential vector for European Green Crab<br><br>**Source**: Fisheries and Oceans Canada Science Branch, Canadian Science Advisory Secretariat (CSAS) Research Document 2015/014 | The transfer of live seafood and aquaculture products has long been thought to be one of the primary vectors of many well established and notorious NIS around the world. However, there is little to no primary evidence of the potential of this particular vector to entrain and transport NIS to new areas. This has become particularly relevant given the arrival of the European Green Crab on Vancouver Island in the late 1990s as well as the recent transfer of regulatory authority of the aquaculture sector from the provincial government of British Columbia to the Pacific branch of the federal Department of Fisheries and Oceans and the continued growth of shellfish aquaculture in British Columbia. The potential for NIS entrainment on shellfish was investigated through a long-term experimental study carried out along the west coast of Vancouver Island in waters that were known to be infested with European Green Crab. Mid-way through the experimental study, a short-term observational study was also conducted using shellfish product as it arrived at processing facilities. The entrainment potential of six NIS on shellfish was investigated and was confirmed for the European Green Crab at two different life stages and four other NIS. Five NIS, not including the Green Crab, were also found on shellfish products that had been transported to processing facilities. They included three well known NIS tunicate species as well as two non-indigenous bryozoans. After an extensive review of the literature, we confirmed that none of the existing or experimentally tested mitigation methods to remove NIS from products was 100% effective at removing NIS prior to product transport. We also identified several areas of potential improvement of the current shellfish aquaculture license conditions which culminated in the development of a conceptual framework model to reduce the risk of spreading NIS at each stage of the shellfish transfer process. Available at: http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2015/2015_014-eng.html |
| Other Resources | Live and Fresh Seafood: Into the pan and not into the wilds | https://massbay.mit.edu/seafood/english.pdf |
| Other Resources | Live and Fresh Seafood Industry | https://massbay.mit.edu/exoticspecies/seafood/index.html |

# 10. Research and Education

| Type | Details | Summary |
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| Academic | **Title**: Unintentional dispersal of aquatic invertebrates via footwear and motor vehicles in a Mediterranean wetland area<br><br>**Authors**: Aline Waterkeyn, Bram Vanschoenwinkel, Sanne Elsen, Maria Anton-Pardo, Patrick Grillas, Luc Brendonck<br><br>**Source**: Aquatic Conservation, July/August 2010, Volume 20, Issue 5, pages 489-604 | Several human activities, such as actions for nature conservation, research and recreational activities, are closely associated with inland aquatic habitats that are usually considered as isolated island habitats. In this study, the possibility of unintentional dispersal of aquatic invertebrates among water bodies via footwear and motor vehicles was investigated. Mud samples collected from boots and from the tyres and wheel cases of cars used for field work by biologists (Camargue, Southern France) were hatched under laboratory conditions and also checked for the presence of unhatched propagules. A large number of organisms hatched and invertebrate propagules from a wide range of taxa were encountered. The results also demonstrated that different research groups tend to transport the aquatic invertebrates typical for their respective study systems. This study provides evidence that dispersal via footwear and motor vehicles may result in frequent dispersal of aquatic invertebrates on a local scale, and we presume also occasionally over longer distances.<br>Available at: https://s3.amazonaws.com/academia.edu.documents/30936356/Waterkeyn_et_al._2010_-_aquatic_conserv_-_Human_mediated_dispersal.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534732380&Signature=fhmG6%2FRIcv212djV9vItT9%2FgtA0%3D&response-content-disposition=inline%3B%20filename%3DUnintentional_dispersal_of_aquatic_inver.pdf |
| Academic | **Title**: Do schools and golf courses represent emerging pathways for crayfish invasions?<br><br>**Authors**: Eric R. Larson, Julian D. Olden<br><br>**Source**: Aquatic Invasions, 2008, Volume 3, Issue 4, pages 465-468 | Prevention is frequently promoted as the most desirable management strategy for biological invasions. Crayfish introductions are typically associated with aquaculture and bait bucket releases, but this study reports two alternate pathways that may be responsible for the recent invasion of Procambarus clarkii (Girard, 1852) and Orconectes virilis (Hagen, 1870) in Washington State, U.S.A. Using distributional data and personal interviews identified (1) school science programs, which use crayfish as laboratory organisms, as a likely pathway of introductions, and (2) golf courses bordering lakes, in which ponds have been constructed and are suspected to be stocked with O. virilis to control aquatic macrophytes. Particularly concerning, it was found that highly invasive crayfish Orconectes rusticus (Girard, 1852) in use as a laboratory organism at multiple schools, although this species is not known to be established in the region. Vector management is critical for interrupting the transfer of invasive species; the study has identified two emerging pathways that require greater research attention and stricter regulation.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.556.8381&rep=rep1&type=pdf |

| Type | Details | Summary |
|---|---|---|
| Other Resources | Preventing the Spread of Aquatic Invasive Species: Decontamination Steps for Field Equipment | https://www.michigan.gov/documents/invasives/AISDecontaminationModule_NoQuiz_ADA_622958_7.pdf |
| Other Resources | Handling and Disposal of Non-Native Aquatic Species and their Packaging | https://wsg.washington.edu/wordpress/wp-content/uploads/Handling-Disposal-Non-Native-Aquatic-Species.pdf |
| Other Resources | Adopting a Classroom Pet Pledge Form | https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/sgpubs/onlinepubs/e11011-accessible.pdf |
| Other Resources | Schoolyard Habitat | https://www.fws.gov/chesapeakebay/schoolyd.htm |

# 11. General Assessment of Pathways

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Invasive Aquatic Species in Ontario: A Review and Analysis of Potential Pathways for Introduction<br><br>**Authors**: Steven J. Kerr, Christopher S. Brousseau, Mark Muschett<br><br>**Source**: Fisheris, 2005, Volume 30, Issue 7, pages 21-30 | Eight different pathways for invasion by aquatic species into Ontario are reviewed, including 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. Recommendations are offered 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.<br>https://www.tandfonline.com/doi/abs/10.1577/1548-8446(2005)30%5B21%3AIASIO%5D2.0.CO%3B2 |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions<br><br>**Authors**: Mills EL Leach JH Carlton JT Secor CL<br><br>**Source**: Journal of Great Lakes Research, 1993, Volume 19, Issue 1, pages 1 - 54 | Through literature review, introductions of non-indigenous aquatic flora and fauna into the Great Lakes basin were documented since the early 1800s, focusing on the origin, probable mechanism(s) of introduction, and the date and locality of first discovery of Great Lakes exotic species. Since the 1800s, 139 non-indigenous aquatic organisms have become established in the Great Lakes. The bulk of these organisms has been represented by plants (59), fishes (25), algae (24), and mollusks (14). Most species are native to Eurasia (55%) and the Atlantic Coast (13%). As human activity has increased in the Great Lakes watershed, the rate of introduction of exotic species has increased. Almost one-third of the organisms have been introduced in the past 30 years, a surge coinciding with the opening of the St. Lawrence Seaway in 1959. Five categories of entry mechanisms were identified: unintentional releases, ship-related introductions, deliberate releases, entry through or along canals, and movement along railroads and highways. Entry mechanisms were dominated by unintentional releases (29%) and ships (29%). Unintentional releases included escapees from cultivation and aquaculture, bait, aquarium, and other accidental releases. Ship-related introductions included ballast water (63%), solid ballast (31%), and fouling. Introductions via canals represent a small percentage of entries into the Great Lakes. As long as human activities provide the means through which future species can be transported into the Great Lakes basin, the largest freshwater resource in the world will continue to be at risk from the invasion of exotic organisms.<br>Available at: https://pdfs.semanticscholar.org/7733/9297fef64eaedbe0ccdd22b5cec2c7b944d1.pdf |
| Academic | **Title**: A management framework for preventing the secondary spread of aquatic invasive species<br><br>**Authors**: M. Jake Vander Zanden, Julian D. Olden<br><br>**Source**: Canadian Journal of Fisheries and Aquatic Sciences, 2008, Volume 65, Issue 7, pages 1512-1522 | Biological invasions continue to accelerate, and there is a need for closer integration between invasive species research and on-the-ground management. The paper describes recent advances in forecasting the secondary spread of aquatic invasive species and presents a framework for assessing vulnerability of inland waters based on explicit assessment of three distinct aspects of biological invasions: colonization, site suitability, and adverse impact. In many cases, only a fraction of lakes on the landscape are vulnerable to specific invasive species, highlighting the potential application of this type of research for improving invasive species management. Effective application to on-the-ground resource management will require that research aimed at assessing site vulnerability be translated into management tools.<br>Available at: http://www.nrcresearchpress.com/doi/pdf/10.1139/F08-099 |

| Type | Details | Summary |
|---|---|---|
| Academic | **Title**: Assessing the global threat of invasive species to marine biodiversity<br><br>**Authors**: Jennifer L Molnar, Rebecca L Gamboa, Carmen Revenga, Mark D Spalding<br><br>**Source**: Frontiers in Ecology and the Environment, November 2008, Volume 6, Issue 9, pages 485-492 | Although invasive species are widely recognized as a major threat to marine biodiversity, there has been no quantitative global assessment of their impacts and routes of introduction. Here, we report initial results from the first such global assessment. Drawing from over 350 databases and other sources, we synthesized information on 329 marine invasive species, including their distribution, impacts on biodiversity, and introduction pathways. Initial analyses show that only 16% of marine ecoregions have no reported marine invasions, and even that figure may be inflated due to under-reporting. International shipping, followed by aquaculture, represent the major means of introduction. Our geographically referenced and publicly available database provides a framework that can be used to highlight the invasive taxa that are most threatening, as well as to prioritize the invasion pathways that pose the greatest threat.<br>Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.909.7219&rep=rep1&type=pdf |
| Academic | **Title**: The future of species invasions in the Great Lakes-St. Lawrence River basin<br><br>**Authors**: Katie S. Pagnuccoa, George A. Maynard, Shannon A. Ferac, Norman D.Yand, Thomas F.Nalepae, Anthony Ricciardi<br><br>**Source**: Journal of Great Lakes Research, 2015, Volume 41, Supplement 1, pages 96-107 | Review the invasion history of the basin and identify future invasion threats by considering trends and potential scenarios in changing vectors and pathways. Whereas most non-native species discovered since the opening of the St. Lawrence Seaway in 1959 were attributable to ballast water discharge from transoceanic vessels, recent regulations have apparently reduced the threat of this vector. Nevertheless, non-native species may continue to be introduced through poorly-regulated vectors, particularly those associated with trade in live organisms. The spread and impact of current and future invaders are expected to be exacerbated by interactions with other anthropogenic stressors that are increasing in frequency and spatial extent. Live trade is predicted to eclipse ballast water as the dominant vector of future invaders.<br>Available at: https://s3.amazonaws.com/academia.edu.documents/45575545/The_future_of_species_invasions_in_the_G20160512-77494-3bf7kk.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534732077&Signature=LPZpKS9kvJn4j5%2Fx8K%2BmrO4poP0%3D&response-content-disposition=inline%3B%20filename%3DThe_future_of_species_invasions_in_the_G.pdf |

| Type | Details | Summary |
|---|---|---|
| Other Studies/Research | **Title**: Focus Group Conference Report And Pathways Ranking Guide<br><br>**Source**: NISC Prevention Committee Pathways Work Team, National Invasive Species Council (NISC) and Aquatic Nuisance Species (ANS) Task Force | The Invasive Species Pathways Work Team was established in June 2002 by the Invasive Species Advisory Committee to accomplish discreet tasks contained within the National Invasive Species Management Plan. Assignment scope extended to addressing issues related to unintentional introductions of invasive species. This document represents the second version of a guide and process for pathway definition, analysis and prioritization. It is essential that these considerations be brought to the forefront for future decision-making efforts. The Pathways Work Team strongly supported the position that policy decides the direction to take (with human health, commerce, then ecosystems being the priorities for ranking), but science must maintain the focus.<br>Available at: https://www.anstaskforce.gov/Documents/2006%20Pathways%20Guide.pdf |
| Other Studies/Research | **Title**: Closing the Pathways of Aquatic Invasive Species across North America: Overview and Resource Guide<br><br>**Source**: Commission for Environmental Cooperation | This paper provides an overview of the status and trends of IAS and their pathways of invasion into the marine and freshwater systems of North America. It is not intended to serve as thorough scientific review, but to provide participants in the CEC's activities with sufficient background to: 1) understand the cause and consequences, as well as status and trends, of biological invasion in North America's aquatic and marine systems; 2) understand the need for bi- and tri-lateral cooperation to prevent and manage introductions of IAS; 3) identify opportunities for such cooperation; and 4) contribute to and support well-informed policy decisions that will help minimize the spread of IAS into and within North America.<br>Available at: http://www3.cec.org/islandora/en/item/2068-closing-pathways-aquatic-invasive-species-across-north-america-en.pdf |
| Other Resources | AIM: Aquatic Invaders in the Marketplace | http://takeaim.org/how/ |