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Science Advisory Report 2017/025

NATIONAL RISK ASSESSMENT OF RECREATIONAL BOATING AS A VECTOR FOR AQUATIC INVASIVE SPECIES

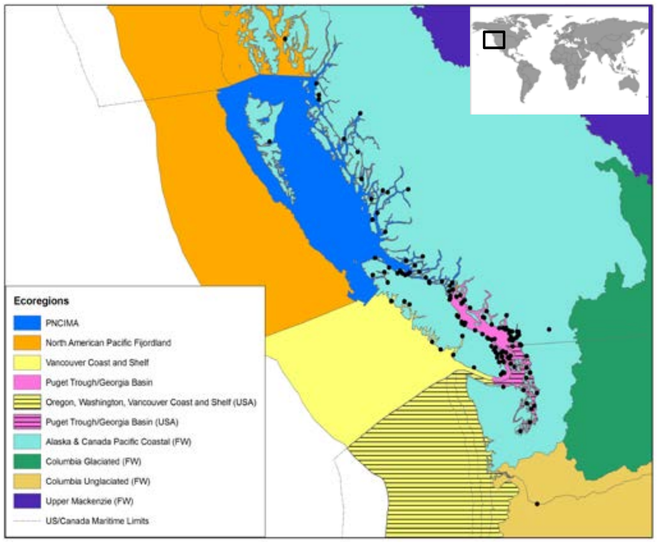

Figure 1. Pacific ecoregions using the Marine Ecoregion Of the World (MEOW) classification (Spalding et al. 2007) with further subdivision of the Pacific North Coast Integrated Management Area (PNCIMA ecoregion, [PNCIMA initiative](#)), Freshwater Ecoregions of the World (FEOW, Abell et al. 2008) classification and visited and home marinas of the Pacific Region mentioned in boater questionnaires (black dots).

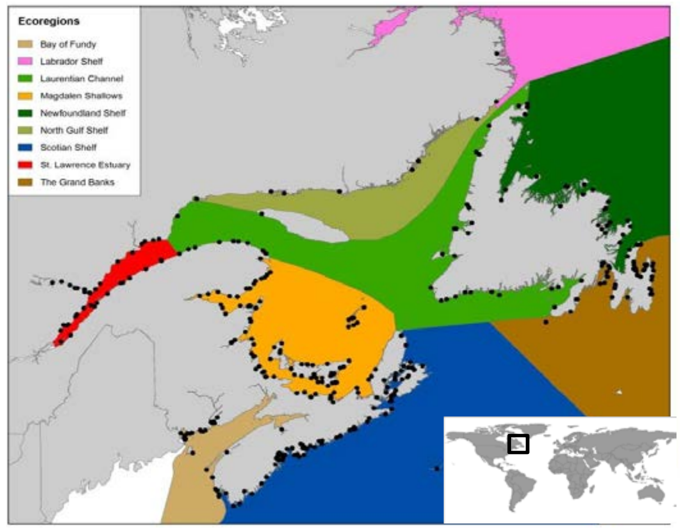

Figure 2. Atlantic ecoregions using the Parks Canada biogeographic classification (Harper et al. 1993) and visited and home marinas of the Atlantic Region mentioned in boater questionnaires (black dots).

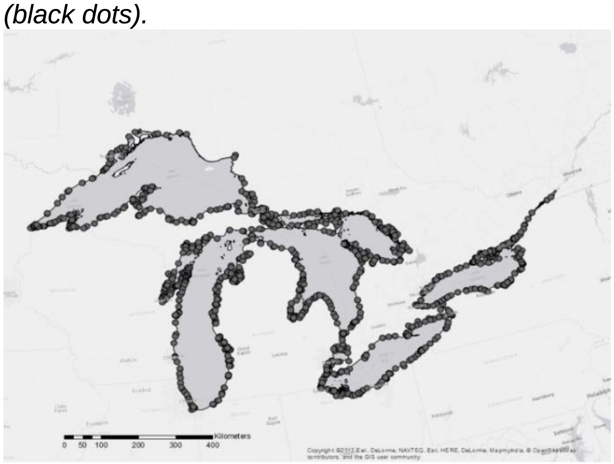

Figure 3. Distribution of the 1717 recreational access points distributed throughout the Great Lakes Basin. 487 recreational access points were contained in Canadian waters, 1230 were contained in U.S. waters.

Context:

Aquatic invasive species (AIS) pose a significant threat to Canadian fresh, estuarine, and marine waters, and recreational boating is an important vector for their introduction and spread. In response to a request for science advice from the National Aquatic Invasive Species Committee, a national risk assessment was performed to assess the risk posed by recreational boating in Canada in terms of the introduction and spread of AIS. This risk assessment also contributes to the overall body of knowledge of AIS vectors and pathways in Canada.

This Science Advisory Report summarizes the results of the December 8-11, 2015 "National Risk Assessment for Recreational Boating as a Vector for Aquatic Invasive Species" meeting. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- 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. In the marine environment there are an estimated 4.02 M trips per year on the east and west coasts. In the freshwater environment there are an estimated 11.88 M yearly recreational boating events in the Great Lakes Basin (GLB), of which an estimated 3.8 M originate from Canadian recreational access sites. 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.
- High connectivity exists within and among all marine ecoregions, as well as within the waters of the GLB. Nonindigenous species-infested recreational boats from highly connected marinas are very likely to transport NIS to other marinas.
- Natural and anthropogenic barriers exist in both freshwater (i.e. watersheds) and marine (i.e. ecoregions) environments, but recreational boats breach these barriers in both environments and facilitate the movement of NIS within and across these boundaries in both systems. For example, when an invasive species is introduced to the GLB, modelling indicates that on-water boating activity can increase the rate of spread of species to new locations compared to natural dispersal.
- In both marine and freshwater environments, trips that cross physical or ecological barriers, regardless of distance travelled, pose a greater risk than trips that do not cross barriers. In both marine and freshwater environments, long distance spread of NIS via the recreational boating vector is possible. Both environments have a higher frequency of shorter trips than longer trips.
- 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.
- An important next step will involve comparing the recreational boating vector to other vectors of NIS introduction and spread.

INTRODUCTION

Aquatic invasive species (AIS) pose a significant threat to Canadian fresh, estuarine, and marine waters. An important vector for their introduction and spread is recreational boating, yet the magnitude of this vector and its ecological risk in Canada are largely unknown. In response to a request for science advice from the National Aquatic Invasive Species Committee, a federal-provincial-territorial committee that reports to the Canadian Council of Fisheries and Aquaculture Ministers, Fisheries and Oceans Canada led a national risk assessment to assess the risk posed by recreational boating as a vector for AIS in freshwater and marine systems in Canada.

In contrast to other historically important vectors for the introduction and spread of AIS, such as shipping and aquaculture, there is no national management strategy aimed at limiting the introduction and spread of nonindigenous species (NIS) by the recreational boating vector. Despite the lack of national regulation of this vector, results and advice presented here can be used by various jurisdictions and may help inform future targeted research, the locations for boater-specific monitoring activities, potential policy or regulatory changes, and the overall management of this vector.

The scope of this risk assessment is national; however, the assessments for marine and freshwater systems were conducted using varied approaches, and as such, this Science Advisory Report has been divided into three parts. The marine portion of this risk assessment (Part I) uses information gathered from the West and East coasts of Canada (Figures 1 and 2, respectively).The freshwater portions of this risk assessment use information gathered from the Great Lakes Basin (Part II, Figure 3), as well as information from a comprehensive review of the literature pertaining to the overland spread of NIS among freshwater ecosystems in the rest of Canada due to recreational boating (Part III).

RISK ASSESSMENT

Part I – Marine

The marine portion of this risk assessment characterized the movement patterns of recreational boats in Canadian marine waters within and between 12 ecoregions: 3 on the Pacific coast (Figure 1) and 9 on the Atlantic coast (Figure 2). The relative risk that recreational boating posed in each ecoregion in terms of primary introduction and secondary spread of biofouling (i.e. aquatic organisms that accumulate on wet surfaces) NIS was estimated. A combination of data generated from boater and marina manager questionnaires, visual surveys of boats for NIS, statistical models, existing monitoring programs, directed sampling, expert opinion, and the literature were used. Data on NIS present in marinas, boat infestation probability, recreational boating traffic, and environmental conditions in source and recipient marinas were compiled separately for each transient recreational boat.

The Final Ecoregion Relative Invasion Risk was estimated for each ecoregion by combining information on regional background levels of NIS, the probability that a given recreational boat will be fouled (involving boat and boater characteristics), the probability that a boat will arrive in a given ecoregion (based on transient boat traffic data), the probability that a fouling NIS will survive and establish there (based on climate and salinity match between source and recipient marinas), and by scaling up based on estimates of the overall annual transient recreational boat traffic in each visited ecoregion (Figure 4). Uncertainty was assigned for each variable of the risk assessment, per ecoregion, based on quality and type of information used for each variable. The highest level of uncertainty assigned to any of the steps of the assessment was retained as the uncertainty associated with the Final Ecoregion Relative Invasion Risk.

Relative Invasion Risk scores per ecoregion were also predicted over a 10-year period. The greater number of boats over this larger time-scale allowed for a better overall estimate of rare boats/boating trips with highest relative risk scores within each ecoregion.

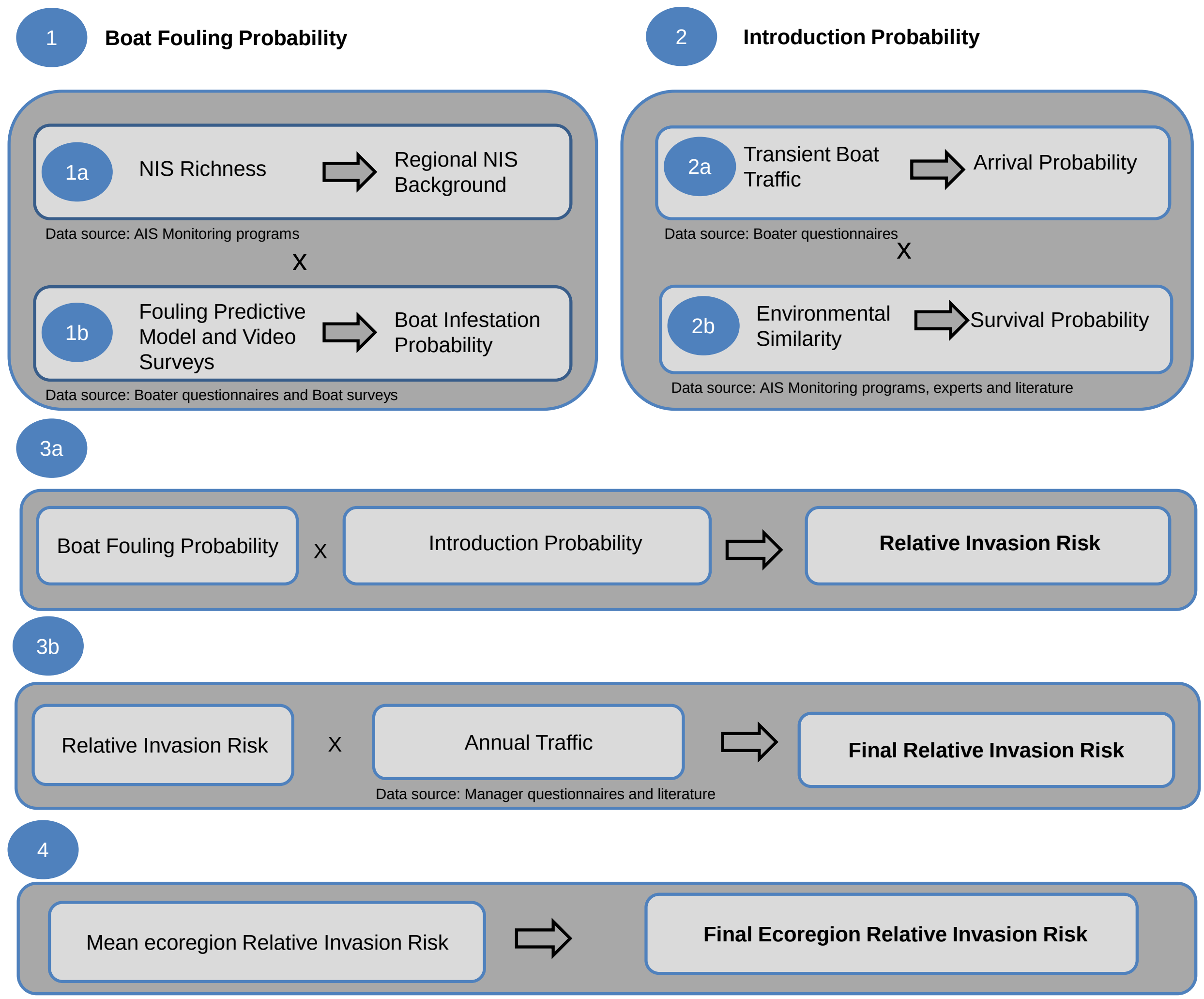

Figure 4. Flow chart illustrating steps used in the marine portion of the recreational boating risk assessment. Reproduced from Simard et al. 2017.

Assumptions and Sources of Uncertainty

The marine portion of the risk assessment considered mostly sessile, biofouling NIS (e.g. tunicates), it did not consider mobile taxa such as crabs or shrimp. It was assumed that sessile, biofouling organisms were the most likely type of NIS to be transported by the recreational boating vector and that more mobile taxa wouldn't typically have the necessary refugia on recreational boats needed for effective transport compared with larger refugia (ballast or sea chests) that are more common on larger ships.

It was also assumed that the biofouling on each transient boat was associated with the NIS present in their home ecoregion, and not from all ecoregions visited before arriving at a marina in a Canadian ecoregion. This could have influenced results of the risk assessment, particularly for boats that spent several days outside of their home marina or ecoregion before arriving in a given location. Linear increases in the number of NIS on hulls were also assumed, but it is possible that certain NIS could facilitate others to attach more quickly/easily than they would otherwise.

Models that were used to predict the probability that a transient boat would be infested were somewhat ineffective at predicting whether or not boats would be fouled on either coast, especially in the Atlantic region where the model predicted substantially fewer fouled boats than were actually recorded. This discrepancy could have been due in part to the absence of certain variables from the model that could have influenced Boat Infestation Status, such as the degree of fouling on boats, which could have impacted the final results and possibly led to an underestimation in overall risk. Certainty would be improved with a better understanding of the factors that predict fouling on boats on the Atlantic coast.

Conclusions

In the marine environment there are an estimated 4.02 M recreational boating trips per year on the east and west coasts. Primary introduction and secondary spread of NIS may result from recreational boating in all Canadian marine ecoregions, however, only a small proportion of boats have an intermediate, high, or highest risk (Table 1). Although most marine ecoregions have lower risk, they may still receive transient boats with high absolute risk. High connectivity exists among marinas within each of the marine ecoregions as well as among ecoregions. When NIS exist in the surrounding environment, boats from these highly connected marinas are very likely to transport NIS to other marinas. Some Atlantic ecoregions have marinas that are also well connected to international marinas, but this international connectivity is less for marinas in the Pacific based on the subsample surveyed. This smaller degree of connectivity (“small” in terms of proportion of boats but “large” in terms of the number of boats) with U.S. marinas introduces the risk of “stepping stone” introductions into Canada.

Table 1. Percentage (%) of transient boats with complete boater questionnaires that obtained each risk category in each ecoregion, before combining with annual traffic (see Step 3a in Figure 4). Reproduced from Simard et al. 2017. Risk categories correspond to percentage ranges as follows: Lowest = 0-5%; Low = 5-40%; Intermediate = 40-60%; High = 60-95%; Highest = 95-100% (modified from Mandrak et al. 2012). I.D. = Insufficient data.

Visited ecoregion	# Transient boats	Lowest (%)	Low (%)	Intermediate (%)	High (%)	Highest (%)
Bay of Fundy	37	94.6	5.4	0	0	0
Labrador Shelf	3	I.D.	I.D.	I.D.	I.D.	I.D.
Laurentian Channel	90	96.7	3.33	0	0	0
Magdalen Shallows	374	94.7	5.3	0	0	0
Newfoundland Shelf	20	95	5	0	0	0
North Gulf Shelf	18	100	0	0	0	0
Scotian Shelf	305	79.7	20.3	0	0	0
St. Lawrence Estuary	168	98.2	1.8	0	0	0
The Grand Banks	21	100	0	0	0	0
Vancouver Coast and Shelf	35	71.4	28.6	0	0	0
PNCIMA	155	69.1	29.7	0.6	0.6	0
Puget Trough/Georgia Basin	385	34.3	62.9	1.8	0.8	0.2

Recreational boating traffic in Canadian Pacific waters was an order of magnitude greater than on the Atlantic coast and was typically greater in more southern ecoregions than northern ones.

Final Ecoregion Invasion Risk scores were greater for the Pacific region than the Atlantic region, and highest for the Puget Trough/ Georgia Basin ecoregion (Table 2). These regional differences are greatly influenced by seasonality of boating activities (time in water, maintenance, boating activity) and the sheer number of recreational boats in the Pacific region; with the west coast having year-round recreational boating traffic while the east coast generally has a more restricted boating season. Year-round boating on the Pacific coast results in recreational boats there spending a greater length of time in the water compared to those on the Atlantic coast. Statistical models showed that the incidence of long trips taken and the age of antifouling paint on the boat hull were important factors that predicted whether or not a boat would be fouled in the Pacific ecoregions, whereas the number of days in the water was a key predictor of fouling in the Atlantic ecoregions.

Table 2. Mean Final Relative Invasion Risk and level of uncertainty for each ecoregion and percentage (%) of transient boats in each risk category after taking into account annual boat traffic (see Steps 3b and 4 in Figure 4). Adapted from Simard et al. 2017. Risk categories correspond to percentage ranges as follows: Lowest = 0-5%; Low = 5-40%; Intermediate = 40-60%; High = 60-95%; Highest = 95-100% (modified from Mandrak et al. 2012). I.D. = insufficient data.

Visited ecoregion	# Transient boats	Lowest risk (%)	Low risk (%)	Intermediate risk (%)	High risk (%)	Highest risk (%)	Mean Final Relative Invasion Risk	Level of Uncertainty
Bay of Fundy	37	100	0	0	0	0	Lowest	Moderate
Labrador Shelf	3	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.	Highest
Laurentian Channel	90	100	0	0	0	0	Lowest	Moderate
Magdalen Shallows	374	100	0	0	0	0	Lowest	Moderate
Newfoundland Shelf	20	100	0	0	0	0	Lowest	Moderate
North Gulf Shelf	18	100	0	0	0	0	Lowest	Moderate
Scotian Shelf	305	100	0	0	0	0	Lowest	Moderate
St. Lawrence Estuary	168	100	0	0	0	0	Lowest	Moderate
The Grand Banks	21	100	0	0	0	0	Lowest	Moderate
Vancouver Coast and Shelf	35	100	0	0	0	0	Lowest	Moderate
PNCIMA	155	94.2	5.8	0	0	0	Lowest	Moderate
Puget Trough/Georgia Basin	385	34.3	62.9	1.8	0.8	0.3	Highest	Moderate

The Pacific region has the greatest overall and maximum within-marina NIS richness, while some Atlantic ecoregions have greater mean NIS richness. There are overall trends of greater NIS richness in the south relative to the north and for NIS richness to be concentrated around high-volume ports and/or marinas. Predicted Relative Invasion Risk scores over a 10 year period suggest that transient boats with greater risk scores would be found in ecoregions on both the Pacific and Atlantic coasts and, although uncommon, such boats represent a considerable absolute risk when considering cumulative arrivals over a 10 year period (Table 3). These trends have implications in light of global change and for stepping stone processes.

Table 3. Predicted percentages of transient boats in each risk category per ecoregion using bootstrapped data over a period of 10 years. Adapted from Simard et al. 2017. Risk categories correspond to ranges of probabilities as follows: Lowest = 0-5%; Low = 5-40%; Intermediate = 40-60%; High = 60-95%; Highest = 95-100% (modified from Mandrak et al. 2012). I.D. = Insufficient data.

Visited ecoregion	# Transient boats	Lowest risk (%)	Low risk (%)	Intermediate risk (%)	High risk (%)	Highest risk (%)
Bay of Fundy	35,111	100	0	0	0	0
Labrador Shelf	I.D.	I.D.	I.D.	I.D.	I.D.	I.D.
Laurentian Channel	27,130	98.80	1.09	0.0405	0.0332	0.0332
Magdalen Shallows	145,520	99.62	0.3793	0	0	0
Newfoundland Shelf	15,770	99.94	0.0571	0	0	0
North Gulf Shelf	9,620	100	0	0	0	0
Scotian Shelf	296,690	98.11	1.89	0	0	0
St. Lawrence Estuary	69,010	99.74	0.2536	0.00145	0	0
The Grand Banks	7,540	100	0	0	0	0
Vancouver Coast and Shelf	350,100	93.02	6.93	0.0377	0.0143	0.00371
PNCIMA	990,850	89.11	10.67	0.1268	0.0589	0.0305
Puget Trough/Georgia Basin	3,718,843	70.53	29.43	0.0328	0.00204	0.0000538

Other Considerations

The final ecoregion invasion risk scores obtained for each marine ecoregion are relative to the risk scores in the other ecoregions, and as such, a low score does not represent low absolute risk. Only certain NIS were observed in this study through standardized sampling programs across all ecoregions. Therefore results obtained for NIS richness likely underestimate the true number of NIS present in each marine ecoregion.

Trailered recreational boats and their overland movement were not explicitly included in the marine portion of the risk assessment. Such boats could pose a different type of risk; for example, entanglement may be more likely on trailer equipment or fouling could be possible in different types of niche spaces on trailers (see also Part III). Boats purchased from one ecoregion and moved to another were not included. There was also insufficient data to determine the relative risk due to recreational boating in the Labrador Shelf ecoregion and the Arctic was not addressed.

The spread of NIS by recreational boats was not compared to spread by other vectors or to natural rates of dispersal in the marine portion of this work. No measure of impact was used, however, tunicates were found in most ecoregions on both coasts and are known to cause substantial ecological and economic impacts (Therriault and Herborg, 2007).

Part II – Freshwater (Great Lakes Basin)

The freshwater portion of this risk assessment was performed in two sections. The first section involved the ecological risk of secondary spread of NIS within the Great Lakes Basin (GLB) due to on-water boat movement (presented here in Part II), while the second section involved the secondary spread of NIS, overland, among Canada's inland freshwater ecosystems (presented in Part III).

In the first section, a model based approach was used to estimate the ecological risk of recreational boating as a vector for the secondary spread of NIS within connected waterbodies in the GLB (Figure 5). A statistical boater-movement dispersal kernel was developed based on boater questionnaires to quantify recreational boat movement patterns. Nonindigenous species infesting recreational boats were classified into three main groups based on their functional fouling characteristics: plankton and other organisms with planktonic stages (typically transported in live wells, bilge water); organisms that can attach directly to hulls or trailers (i.e. freshwater molluscs); and organisms with indirect fouling potential that typically entangle on trailers and accessories such as anchor lines (i.e. aquatic plants, benthic invertebrates). The likelihood of these different functional groups of NIS becoming fouled on boats was combined with the statistical dispersal kernel in the propagule pressure component of the model (see Step 1 in Figure 5). Propagule pressure was then combined with the likelihood that functional groups of NIS would establish reproducing populations to determine the boater-driven timelines of secondary spread of NIS throughout the GLB.

Boater-mediated spread timelines for the various functional groups of NIS were predicted up to a maximum period of 10 years. The expected rates of boater-mediated spread were compared with baseline estimated rates of natural dispersal to determine the overall risk, relative to natural dispersal. The ecological risk of recreational boating in the GLB is therefore a function of how likely boater activity is to surpass (i.e. quicken) the rates of natural dispersal of NIS, the consequence (i.e. magnitude) of faster spread attributed to boating relative to the natural dispersal baseline, and the uncertainty that is inherent in the model-based assessment.

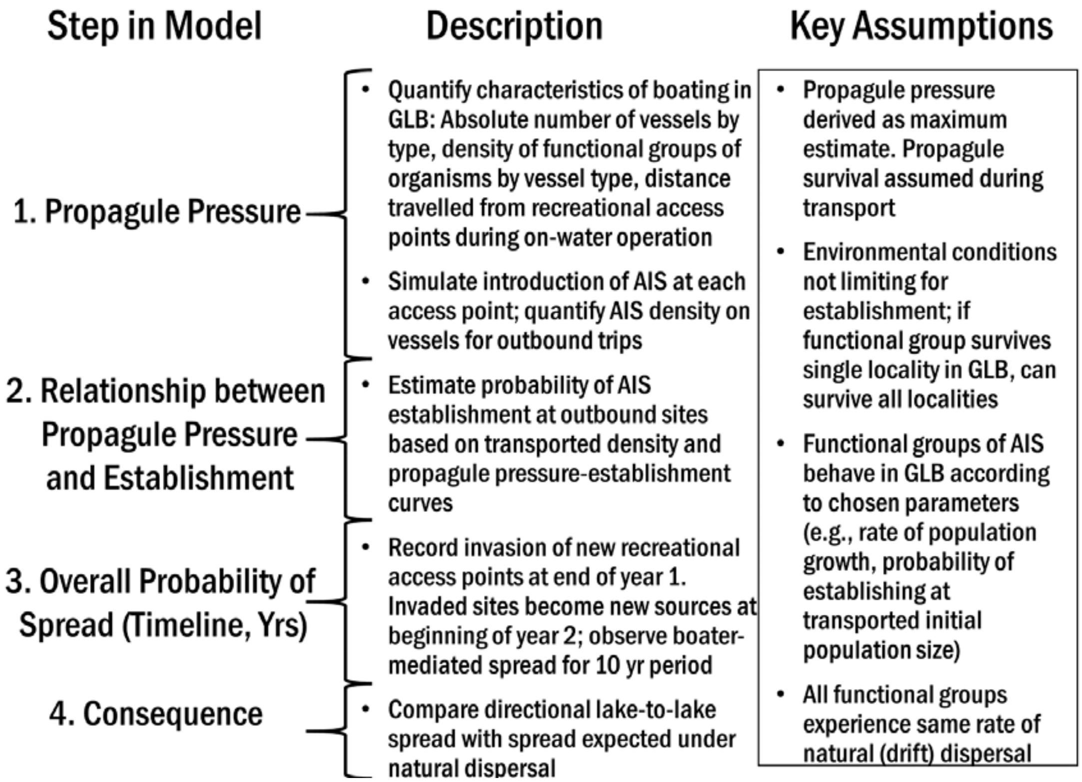

Figure 5. Overview of the model-based approach and key assumptions used in the freshwater (Great Lakes Basin) portion of the recreational boating risk assessment. Reproduced from Drake et al. 2017.

Assumptions and Sources of Uncertainty

Key assumptions used in this model-based approach are highlighted in Figure 5 and their influence on the estimates of ecological risk was tested through sensitivity analyses.

The proportion of recreational boats owned in Canadian provinces that border the GLB (i.e. Ontario and Quebec) that are used in the Great Lakes proper, rather than exclusively in smaller nearby lakes, is not known. Therefore, the proportion was assumed to be the same as that for U.S. states bordering the GLB when estimating the total number of Canadian boats used in the Great Lakes in a given year.

The use of a single dispersal kernel to quantify recreational boat movement in the model likely overestimated the distances travelled by manually-driven boats (e.g. canoes); however, these boats had a disproportionately low propagule pressure compared to other types of boats, so the error associated with using a single dispersal kernel was assumed to be low.

The model was very sensitive to changes in the assumed natural dispersal rates of the different functional groups of NIS. Therefore uncertainty regarding the ecological risk posed by recreational boats in freshwater could be reduced by refining knowledge of how the different functional groups of NIS naturally move through large lake basins. Certainty would also be improved with a better understanding of the assumptions that were made about propagule pressure. For example, further investigation regarding the ability of high densities of NIS to be transported and survive long distances in niche spaces such as engine cooling water and livewells would be useful.

There was also a lack of data describing the fouling behavior of benthic species, such as isopods and freshwater shrimp, which could be spread by anchor sediments. The rate of spread for this group of organisms is uncertain and this functional group was not included in this section of the freshwater risk assessment.

Conclusions

A total of 11.88 M recreational boating trips are estimated to occur in the GLB each year, 3.8 M of which originate from Canada and 8.01 M originate from the U.S. The sheer volume of recreational boater activity allows for effective boater-mediated spread of NIS in the GLB.

When an invasive species is introduced to the GLB, modelling indicates that on-water boating activity can increase the rate of spread of species to new locations compared to the baseline rate of natural dispersal. In some cases, this leads to new pathways of dispersal (i.e. to upstream locations) that would otherwise be unlikely to occur in the GLB, with a presumed high ecological impact. The species-specific scale and rate of natural dispersal of NIS within the GLB influences the presumed consequences of spreading these species via boating activity, such that the risk of secondary spread is higher for NIS with slower natural dispersal rates, given that they can be transported by boating.

The overall risk of secondary spread was found to be highest to Lake Superior due to the frequent development of upstream pathways via recreational boating. 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 boat-mediated rates of spread were typically consistent with the expected rate of natural dispersal. Figures 6, 7, and 8 illustrate these findings using the parthenogenetic zooplankton (i.e. reproduces asexually, offspring are clones of parent) functional group of NIS as an example. Functional groups of organisms generally displayed similar spread patterns and consequences. See Drake et al. 2017 for detailed results for other NIS functional groups.

Through standard operation, recreational boats can become infested with native and nonindigenous species, some of which may be invasive. Freshwater invasive species of concern, such as the Fishhook Waterflea, have been found on recreational boats operating within the GLB. The recreational boat structures associated with fouling species include livewells, engine cooling systems, bilge areas, anchor lines, and other boating accessories. Direct attachment of molluscs to hulls can also occur for the subset of boats that are stored in water.

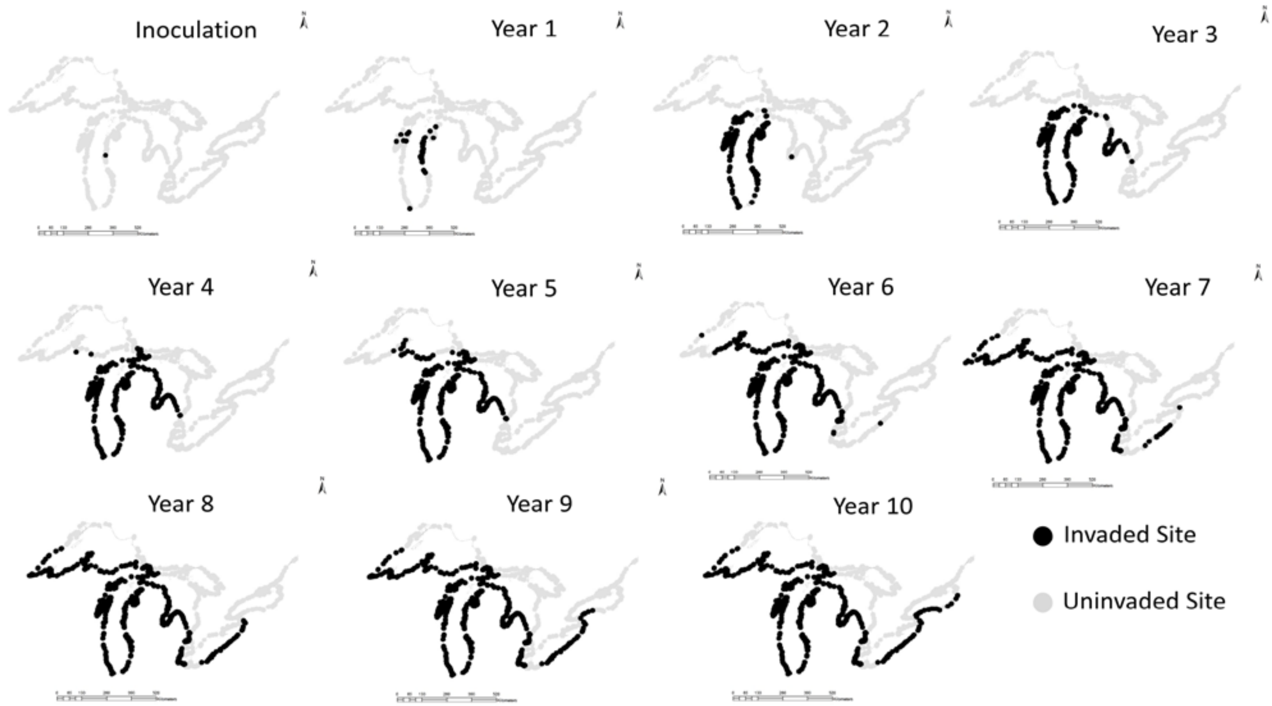

Figure 6. Example of a 10-year iteration of recreational boat-mediated spread of a parthenogenetic zooplankton when introduced to a recreational site in Lake Michigan near Manistee, Michigan. Reproduced from Drake et al. 2017.

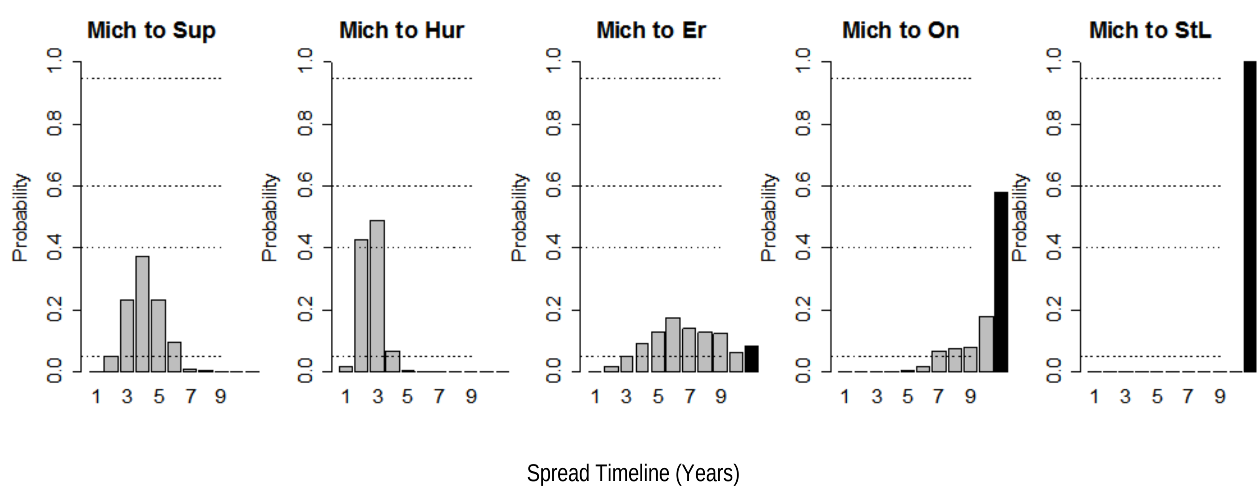

Figure 7. Example of timelines (years) of secondary spread of the parthenogenetic zooplankton functional group due to recreational boating activity in the GLB over the 10-year model period. Grey vertical bars represent spread occurring between pairs of lakes over a 1 to 10 year period. Black vertical bars represent a value of 11 or more years, signifying a failure of spread to occur within the 10 year model period. Lake-to-lake spread is labelled at the top of each graph (e.g. leftmost panel shows spread from an inoculation in Lake Michigan to Lake Superior). Dotted horizontal lines represent the boundaries of likelihood categories, corresponding to the following ranges of probabilities: very unlikely = 0-0.05; low = >0.05-0.40; moderate = >0.40-0.60; high = >0.60-0.95; very likely = >0.95-1.0 (from Mandrak et al. 2012). Reproduced from Drake et al. 2017.

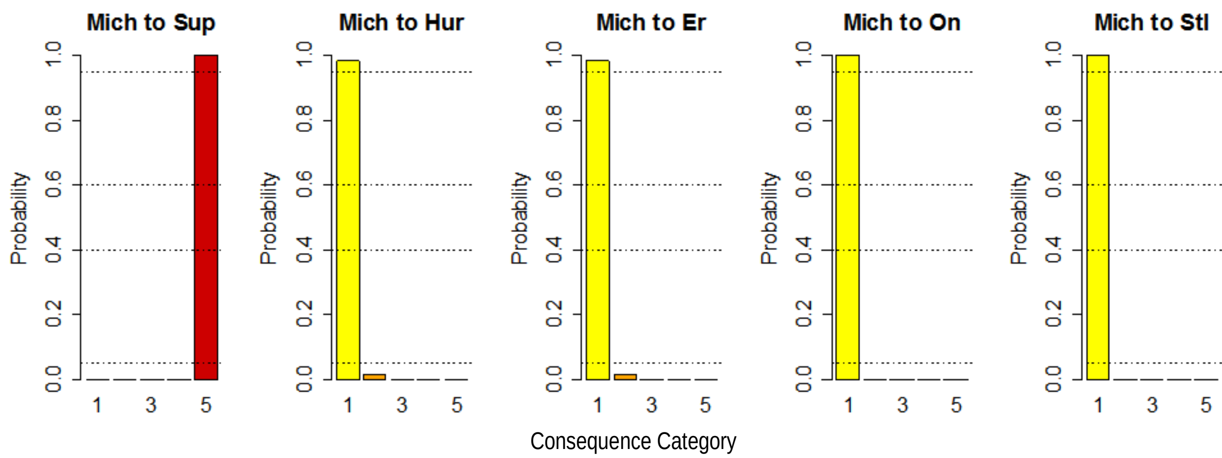

Figure 8. Example of the ecological risk of secondary spread of the parthenogenetic zooplankton functional group due to recreational boating in the GLB, shown as the change in boater-mediated secondary spread relative to natural dispersal rates. Consequence categories (x-axis labels) are as follows: (1) very low = no change in rate of spread relative to natural dispersal, or reduction of <1 year attributed to recreational boating (yellow); (2) low = reduction of 1-2 years attributed to recreational boating; (3) moderate = reduction of 3-4 years attributed to recreational boating; (4) high = reduction of 5 years attributed to recreational boating; (5) very high = reduction of >5 years attributed to recreational boating, or development of a new upstream pathway where natural dispersal would otherwise be unlikely to occur (red). Lake-to-lake spread is labelled at the top of each graph (e.g. leftmost panel shows spread from an inoculation in Lake Michigan to Lake Superior). Dotted horizontal lines represent the boundaries of likelihood categories, corresponding to the following ranges of probabilities: very unlikely = 0-0.05; low = >0.05-0.40; moderate = >0.40-0.60; high = >0.60-0.95; very likely = >0.95-1.0 (from Mandrak et al. 2012). The sample size for each graph is equal to the number of access points (and inoculation events) in each origin lake. Reproduced from Drake et al. 2017.

Other Considerations

The difference in the time it takes for NIS to spread via the recreational boating vector compared to the time needed for spread under natural conditions was used here as the measure of ecological impact of recreational boating. Spread due to recreational boating was not compared to any other vectors in the GLB, though the modeled timelines of NIS spread could be compared to similar timelines derived for other vectors, such as the ballast of commercial vessels moving within the Laurentian Great Lakes, i.e. Lakers (e.g. Drake et al. 2015).

While this portion of the risk assessment dealt explicitly with in-water movement of NIS due to recreational boating in the GLB, results may be more broadly applicable to other large Canadian lake ecosystems such as Lake Winnipeg and Lake Winnipegosis, Great Bear, and Great Slave Lake, Lake Athabasca, and others that are spatially and ecologically similar to the GLB. As with results derived for the GLB, the ecological risk of secondary spread within Canada's other large lake ecosystems will be conditional on the initial introduction of NIS to those waterways via several different pathways of primary and secondary introduction.

Part III – Freshwater (Overland Movement)

In the second section of the freshwater risk assessment a literature review was performed to summarize the research to date on the overland spread of NIS among freshwater ecosystems due to recreational boating in Canada. Specifically, it focused on the overland movement of recreational boats to and from smaller inland waterbodies outside of the GLB by trailering. See appendix 1 in Drake 2017 for a list of primary publications reviewed and their key findings.

Based on the literature reviewed, estimates of fouling rates, NIS survival potential during overland transport, and propagule pressure for different functional groups of NIS were obtained. As in Part II, the NIS infesting recreational boats were classified into three main groups based on their functional fouling characteristics including plankton, molluscs, and aquatic macrophytes (plants). Using data from Ontario, a first–order estimate of the number of inland boaters and inland boating trips was derived for all of Canada. These estimates were then used to simulate per boating trip probabilities of NIS introduction events and to characterize the overall probability of NIS introduction associated with this vector.

Assumptions and Sources of Uncertainty

By extrapolating boat ownership and trip frequency data derived from an Ontario boater survey to the rest of Canada it was assumed that the Ontario data were representative of a national average. This assumption was necessary as there was a lack of data for each province and territory regarding the number of active resident boaters. Therefore, the proportion of the Ontario resident population owning at least one recreational boat (4.2%) was applied to the entire population of Canada. This extrapolation could have resulted in an overestimation of freshwater trips at the national scale, as coastal provinces likely experience relatively less inland freshwater boating than marine boating. Alternatively, underestimation of the scale of recreational boating trips in Canada could have occurred if more rural provinces actually have proportionately higher rates of boat ownership than the largely urban resident population of Ontario. Future research to obtain more complete information about the number of active boaters residing in each province and territory could provide a more refined national estimate of the scale of recreational boating activity among inland freshwater ecosystems.

Uncertainty exists around the frequency of trailered recreational boats moving across the Canada-U.S. border and across provincial and territorial borders. Many boats are travelling overland from American infested waters to Canadian lakes each year, but this was not addressed in the risk assessment. Despite being a management priority for many provinces, there is also a lack of detailed information regarding patterns of long distance boat-mediated spread among the various provinces and territories.

Conclusions

There is extensive literature pertaining to overland movement of NIS by freshwater recreational boats. Four themes emerged from the literature:

1. Contamination of boats with aquatic species,
2. Predicting the ecosystems at greatest risk of invasion,
3. Survival of species during overland transport (including the effectiveness of physical decontamination techniques to remove species and/or reduce survival), and
4. The link between boater behaviors, educational campaigns, and spread management.

A large number of boating trips occur that involve the overland, trailered movement of recreational boats among freshwater ecosystems in Canada each year (estimated to be at least 24.7 M/year). As a result of this large number of trips, even low per-trip probabilities of introduction can lead to a high number of NIS introduction events in a short period. For example, even when the chance that any given boating trip will introduce an NIS is only 1 in 10,000, at least 1,000 introduction events are predicted to occur per year based on the millions of boating events in freshwater ecosystems in Canada.

Compared to in-water boat movements, overland movements have a much greater potential to move NIS, including across watershed boundaries. For example, in Ontario, recreational boats have led to establishment of NIS at distances of 100 to 200 km overland. In the U.S., recreational boat-mediated movements have led to the establishment of NIS across major watershed boundaries at distances of up to 1500 km. Several modeling techniques exist to accurately predict the spread of NIS across the landscape.

A subset of recreational boaters have the greatest potential to transport and introduce NIS through their trip-taking behaviour. These boaters take frequent trips among multiple water bodies in short timeframes and also exhibit a lack of boat maintenance and cleaning practices. Shorter times between recreational boating trips, coupled with lack of cleaning, could result in an associated NIS, having less desiccation time between source and recipient waterbodies, potentially leading to more viable propagules being released at the new location.

The species groups that are transported overland through recreational boating activity are typically plankton, molluscs, and aquatic plants, which vary widely in their ability to survive overland trips depending on species and individual boater behavior. The overland movement of recreational boats has led to the spread of several high-impact NIS among Canada's inland freshwater ecosystems, including the Spiny Waterflea, Fishhook Waterflea, and Zebra and Quagga Mussels (predominantly transported as veligers, the planktonic stage). It is also the suspected vector of spread for Eurasian Watermilfoil and Bloody Red Shrimp.

Other Considerations

Although information presented in this review has been summarized from publications across North America, the focus of this portion of the risk assessment was to review the science of, and management implications for, the inland recreational boating pathway in Canada.

This work did not address the potential for recreational boating to spread species that are native to some parts of Canada to other parts of Canada, but it is likely that any species fitting into the three functional categories identified are being transported to new areas of Canada via the overland movement of recreational boats.

Knowledge Gaps Surrounding the Risk Posed by Recreational Boating as a Vector for NIS in Canada

A number of knowledge gaps exist regarding the recreational boating vector. A key gap is information about the cross-border movement of recreational boats, which was not included in this risk assessment. Identification of specific high risk access points or marinas would also be useful information to support monitoring and enforcement of this vector.

In Canadian marine waters, there is a paucity of data for the vector in the Labrador shelf marine ecoregion and in the Arctic, and as such, these areas were not included in this risk assessment. There is also a lack of data pertaining to the overland movement of marine recreational boats, which was not covered by this work. In Canadian freshwater systems there is generally a lack of data about the overland movement of recreational boats outside of Ontario, as well as the movement of recreational boats that are being sold and moved overland.

The natural dispersal mechanisms of NIS need to be better understood. Accordingly, the marine portion of this risk assessment did not compare the recreational boat-mediated spread of NIS with the natural rates of dispersal of already introduced NIS. There is a deficiency of data pertaining to the background NIS abundance and distribution in Canadian freshwater environments. Empirical data about fouling rates of recreational boats in freshwater systems are missing and there is a lack of data on the infestation rates for some functional groups in the marine environment.

Sources of Uncertainties

Boater surveys were used as a starting point for both the marine and freshwater portions of this risk assessment work. The majority of these surveys were self-reporting which have inherent uncertainties, such as respondents not understanding questions or answering questions untruthfully. These studies were also based on the underlying assumption that recreational boaters who completed surveys were a representative sample of the broader recreational boating population.

This work used current projections of recreational boating activity, but such projections could change in the future. It should also be noted that the pristineness of ecoregions or the existence of empty niches is of concern in some areas that have currently been identified as having a low relative risk from recreational boating (e.g. Newfoundland). This has management implications and highlights opportunities for preventative management.

CONCLUSIONS

The scale of recreational boating activity was established in both marine (estimated 4.02 M trips per year on east and west coast) and freshwater environments (estimated 11.88 M boating events in the GLB and at least 24.7 M inland trips per year outside of the GLB). The probability of introduction of an NIS per boating trip is extremely low and the riskiest boats represent a small subset of all the recreational boats in both environments, but given the high number of boating trips in both environments, NIS introductions are predicted to occur. In both environments, there is a higher frequency of shorter trips and a lower frequency of longer trips, but regardless of distance, trips that cross natural barriers (such as watersheds or ecoregions) pose a greater risk. Scenarios where very few high risk boats make only a few trips, or where many intermediate risk boats are combined with high boater traffic, both lead to increased risk.

Similar functional groups of NIS are of concern in both marine and freshwater systems in Canada, including fouling organisms with direct attachment potential, planktonic species, and entangling macrophytes. Although this assessment did not directly address ecosystem impacts of NIS, it is known that high-impact NIS are being transported by recreational boating in Canada. For example, Zebra Mussels fouled on recreational boats are currently being intercepted, well outside of their current range, by Alberta watercraft inspectors during routine roadside inspections. Known high-impact tunicates, such as the Golden Star Tunicate and Violet Tunicate, were observed during this study on the hulls of recreational boats in the marine environment. Survival potential is species-dependent, but there is evidence that species can survive trips to new locations, and long distance spread of NIS is possible via recreational boating in both marine and freshwater systems. Further species-specific variability in the potential for long distance spread exists in the marine environment (e.g. European Green Crab dispersal follows a stepping stone process).

Factors identified that influence boat infestation status include boat maintenance, voyage history, and boat type. There is also strong variation in travel and boat cleaning behaviours. Risk is confined to a subset of boaters due to behavioural and trip heterogeneity, but rare, high risk boating activities are very important (such as long distance travel with no cleaning, or ineffective cleaning behaviours). Boats from areas with greater NIS loads that travel extensively and have poor maintenance or extended in-water periods pose greatest risk. Day-use boats are generally less risky than those in the water for longer timeframes, and as such, differences in risk are greatly influenced by seasonality of boating activities.

Management opportunities exist that can be informed by characteristics of risky boats. For example, high risk boat types could be identified to undergo proactive cleaning behaviours, or could be controlled to limit outbound, infested movements. For example, a review of anti-biofouling practices in marine environments in New Zealand and Australia, where efforts are already being made to manage this vector, indicates potential management options could include: the application of effective antifouling coating, boat inspection, promoting effective cleaning behaviour, and boater logbooks. Management activities aimed at reducing propagule pressure could target identified high risk boat types and high risk access points or marinas.

Recommendations

There was consensus among meeting participants that marine and freshwater assessors should work towards the initial goal of a unified national recreational boating risk assessment protocol that would include similar endpoints, thereby allowing for direct comparisons among freshwater and marine ecosystems and the prioritization of high risk ecoregions in Canada. Methods applied in GLB portion of this risk assessment work, including comparisons made to the natural rate of spread of NIS, could also be applied to marine systems in the future if information on natural spread in that environment becomes available. Methods used in the marine portion of the risk assessment work could also be applied to the GLB, but additional data for the GLB would be required. Standardized methodology for data acquisition and survey techniques are recommended to advance the application of a common risk assessment protocol for recreational boating across Canadian waters. Refer also to the knowledge gaps identified above.

A national system of registering and tracking recreational boats and/or recreational boat trailers is recommended; such a system would better inform any future recreational boating risk assessment work while also decreasing uncertainty in the scale of pathway activity. Increased future collaboration with jurisdictions on recreational boating-mediated invasive species issues is recommended, along with collaboration with border services organizations to gather data on, and to track, cross-border movement of recreational boats.

Considering the risk posed by recreational boating in Canadian marine waters on both west and east coasts, management of recreational boats as a vector for marine NIS should be strongly considered in Canada. Similar management measures should be considered to address the overland movement of recreational boats among freshwater ecosystems. Management measures may also be warranted for in-water movements within the GLB in some cases, such as upstream dispersal routes.

Finally, an important next step would be to compare the risk of the recreational boating vector with other vectors of NIS introduction and spread, such as commercial shipping.

SOURCES OF INFORMATION

This Science Advisory Report is from the December 8-11, 2015 National Risk Assessment of Recreational Boating as a Vector for Aquatic Invasive Species. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S. C., Bussing, W., Stiassny, M. L. J., Skelton, P., Allen, G. R., Unmack, P., Naseka, A., NG R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Hebeil, t. J., Wikrmanayake, E., Olson, E., Lopez, H. L., Reis, R. E., Lundberg, J. G., Pérez, M. H. S., and Petry, P. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. BioScience, 58(5): 403-414.

Anonymous. 1996. Generic non-indigenous aquatic organisms risk analysis review process. Report to the Risk Assessment and Management Committee of the U. S. Aquatic Nuisance Species Task Force. 21 p.

Drake, D.A.R., S. A. Bailey, and M.E. Mandrak. 2015. Predicting the secondary spread of aquatic invasive species through ballast water and recreational boating in the Great Lakes Basin. Completion Report submitted to the Great Lakes Fishery Commission. Sept 2015. 45 pp.

Drake, D.A.R., Bailey, S.A., and Mandrak, N.E. 2017. Ecological Risk Assessment of Recreational Boating as a Pathway for the Secondary Spread of Aquatic Invasive Species in the Great Lakes Basin. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/030. v + 84 p.

Drake, D.A.R. 2017. Overland Spread of Aquatic Invasive Species among Freshwater Ecosystems due to Recreational Boating in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/031. v + 37 p.

Floerl, O., and Inglis, G.J. 2005. Starting the invasion pathway: the interaction between source populations and human transport vectors. Biol. Invasions 7: 589-606.

Harper, J.R., Christian, J., Cross, W.E., Firth R., Searing G., and Thompson, D. 1993. A Classification of the marine regions of Canada – Final Report. Coastal and Oceans Resources Inc, 77 p.

Lockwood, J.L., Cassey, P.,and Blackburn, T. 2005. The role of propagule pressure in explaining species invasions. Trends in Ecology and Evolution 20:223-228.

Lockwood, J.L., Cassey, P., and Blackburn, T. 2009. The more you introduce the more you get: the role of colonization pressure and propagule pressure in invasion ecology. Diversity and Distributions 15: 904-910.

Mandrak, N.E., Cudmore, B and Chapman, P.M. 2012. National detailed-level risk assessment guidelines: assessing the biological risk of aquatic invasive species in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/092. vi + 15 p.

Simard, N., Pelletier-Rousseau, M., Clarke Murray, C., McKindsey, C.W., Therriault, T.W., Lacoursière-Roussel, A., Bernier, R., Sephton, D., Drolet, D., Locke, A., Martin, J.L., Drake D.A.R., and McKenzie, C.H. 2017. National Risk Assessment of Recreational Boating as a Vector for Marine Non-indigenous Species. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/006. vi + 95 p.

Spalding, M.D., Fox, H.E., Allen, G. R., Davidson, N., Ferdeña, Z.A., Finlayson, M., Halpern, B. S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., MacManus, E., Molnar, J., Recchia, C.A., and Robertson, J. 2007. Marine Ecoregions of the World: A bioregionalization of coastal and shelf areas. BioScience 57 (7): 573-583.

Therriault, T.W., and Herborg, L.M. 2007. Risk assessment for two solitary and three colonial tunicates in both Atlantic and Pacific Canadian waters. Can. Sci. Advis. Sec. Res. Doc. 2007/063: 64 p.

APPENDIX – GLOSSARY OF TERMS

Colonization pressure: Total number of species introduced or released to a single location (Lockwood et al*.* 2009).

Impact: An adverse (harmful) effect of such significance that it affects not just individual organisms, but the health of a population of organisms (Mandrak et al*.* 2012).

Nonindigenous species (NIS): A species of plant, animal or micro-organism occurring outside its natural past or present distribution as a result of human actions (Anonymous 1996 in Mandrak et al. 2012).

Pathway: One or more routes by which an invasive species is transferred from one geographic area to another (Mandrak et al. 2012).

Primary introduction: Vessel-mediated introduction and establishment of NIS among ecoregions.

Propagule pressure: A composite measure of the number of individuals released into a region to which they are not native. It incorporates propagule number – number of discrete introduction events; and propagule size – number of individuals released in an introduction event (Lockwood et al*.* 2005, 2009).

Risk assessment: The process of determining the value of risk, either in qualitative or quantitative terms. For NIS, it is the determination of the likelihood of introduction and the estimation of the extent of biological consequences (Mandrak et al. 2012).

Secondary spread: Vessel-mediated introduction and establishment of NIS within ecoregions, or within the Great Lakes Basin.

Sensitivity analyses: An analysis of how sensitive outcomes are to changes in data and/ or assumptions (Mandrak et al. 2012).

Stepping stone process: Process by which a NIS spreads from its endemic area to other areas (marinas), which then become the origin for further spread via a vector (Floerl and Inglis 2005).

Transient boat: Boats that visit non-home marinas (overnight).

Uncertainty: There are three basic types of uncertainty: stochasticity, which refers to the inherent randomness of the system being studied and can be described and estimated but not reduced; imperfect knowledge; and, human errors (Skider et al. 2006 in Mandrak et al. 2012).

Vector: The physical means by which a species is transported from one area to another, usually referring to transport by humans (Mandrak et al. 2012).

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