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Using a Novel Spatial Tool to Inform Invasive Species Early Detection and Rapid Response Efforts

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Abstract Management of invasive species has increasingly emphasized the importance of early detection and rapid response (EDRR) programs in limiting introductions, establishment, and impacts. These programs require an understanding of vector and species spatial dynamics to prioritize monitoring sites and efficiently allocate resources. Yet managers often lack the empirical data necessary to make these decisions. We developed an empirical mapping tool that can facilitate development of EDRR programs through identifying high-risk locations, particularly within the recreational boating vector. We demonstrated the utility of this tool in the Great Lakes watershed. We surveyed boaters to identify trips among water bodies and to quantify behaviors associated with high likelihood of species transfer (e.g., not removing organic materials from boat trailers) during that trip. We mapped water bodies with high-risk inbound and outbound boater movements using ArcGIS. We also tested for differences in high-risk behaviors based on demographic variables to understand risk differences among boater groups. Incorporation of boater behavior led to identification of additional high-risk water bodies compared to using the number of trips alone. Therefore, the number of trips itself may not fully reflect the likelihood of invasion. This tool can be broadly applied in other geographic contexts and with different taxa, and can be adjusted according to varying levels of information concerning the vector or species of interest. The methodology is straightforward and can be followed after a basic introduction to ArcGIS software. The visual nature of the mapping tool will facilitate site prioritization by managers and stakeholders from diverse backgrounds.

Keywords Biological invasion · GIS · Great lakes · Macrophyte · Monitoring · Nonindigenous species · Recreational boating · Site prioritization

Introduction

From gulls to golf courses, there are many potential vectors for the transfer of aquatic nonindigenous species (ANS) (Larson and Olden 2008; Tøttrup et al. 2010). Of these, recreational boating is recognized as one of the most significant vectors (Johnstone et al. 1985; Johnson et al. 2001). Dispersal via this vector does not follow classical diffusion models, but is complex, often 'leap-frogging' between widely distributed water bodies, and therefore difficult to predict (Buchan and Padilla 1999).

Efforts to describe the recreational boating vector include surveys, models, and expert judgment. Surveys specific to this vector generally aim to understand attitudes, knowledge, and behaviors of boaters (e.g., Padilla et al. 1996; Buchan and Padilla 1999). Models are an approach specifically used to predict long-distance species spread based on boater movements. Gravity models are based on the attractiveness and distance of a destination (e.g., Bossenbroek et al. 2001; MacIsaac et al. 2004). Less common are random utility models (e.g., Timar and Phaneuf 2009) and boosted regression tree models (e.g.,

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Compton et al. 2012). Expert judgment can be used to elicit invasion risk for different habitats (Acosta et al. 2010).

While gravity modeling has had some success in predicting boater movement related to species transfer (e.g. Chivers and Leung 2012 found a gravity model explained 58 % of trip variations), it has several limitations. Rothlisberger and Lodge (2011) found gravity models performed no better than a random selection of water bodies in identifying 10 water bodies most likely to be colonized by Eurasian watermilfoil. Gravity models performed particularly poorly during the early stages of an invasion, due to the large number of vacant sites that may be colonized (Rothlisberger and Lodge 2011). Treating all boaters as equal-risk has been criticized for the resulting inability to capture key differences in boater behavior (Johnson et al. 2001; Rothlisberger and Lodge 2011; but see, e.g., MacIsaac et al. 2004; Jerde et al. 2012). Third, gravity models often assume travel to recipient lakes is based on proxies for lake attractiveness such as lake area (e.g., Bossenbroek et al. 2001). While these proxies can explain variability in boat traffic, they may not correlate with the potential for transfer of species. For example, Reed-Andersen et al. (2000) used the number of boats on a lake as a proxy for attractiveness but did not discriminate between transient and residential boats. Differentiating these two types of boaters is important when attempting to predict the transfer of species, as only transient boaters that move between water bodies have the potential to transfer species. Finally, the use of species-specific parameters in predicting likelihood of transfer can result in predictions limited to a single species, particularly zebra mussel (e.g., Johnson et al. 2001) and spiny water flea *Bythotrephes longimanus* (e.g., Muirhead and Macisaac 2005).

These limitations, along with the additional emphasis on early detection and rapid response (EDRR), highlight the need to better understand spatial movement and boater behavior. Early detection and rapid response is one component of the ANS management toolkit: prevention aims to intercept introductions before they arrive, EDRR aims to respond to and eradicate new introductions before they become established, and control aims to reduce the distribution and impacts of established ANS. Detecting nonindigenous species soon after their introduction may offer the best opportunity for effective control or eradication responses (Vander Zanden et al. 2010) and also provides a net economic benefit over the cost of control (Keller et al. 2008). Specifically, EDRR uses risk assessment outcomes to inform efforts related to active monitoring of ANS, with the goal of identifying ANS with the potential for high impacts and detecting these ANS before they establish and spread (Vander Zanden et al. 2010). This can occur formally or informally. Formally, gravity models have been used to predict which lakes may receive dreissenid

mussels, with Bossenbroek et al. (2007) correctly predicting Lake Mead, Nevada (though see above for limitations of gravity models). Informally, management agencies use factors such as lake size and popularity to choose sites for inclusion in monitoring programs.

One of the primary challenges when developing EDRR programs is how to prioritize monitoring sites and develop sampling strategies while maximizing limited budgets and personnel. Muirhead and MacIsaac (2005) demonstrated the importance of identifying highly connected water bodies. Rothlisberger et al. (2010) suggest using geographic locations of ANS to inform management efforts and reduce the risk of spread. Knowing which highly connected lakes to target is an important component of effective EDRR. Yet managers often lack empirical data to make these predictions, and knowing where to initiate and expand monitoring efforts remains a challenge.

The goal of this study was to develop an empirical mapping tool that incorporates surveys of boater movement and behavior to prioritize water bodies at higher likelihood of species transfer, thus facilitating further development of EDRR programs. We aim to demonstrate the utility of this mapping tool by identifying which, if any, water bodies have inbound and outbound boater movements with characteristics that increase the likelihood of species transfer.

In capturing demographic information in addition to boater behavior, the survey mentioned above can also provide a better understanding of differences in boater behavior, by boater demographic group (in this study, boater origin, boat type, and boater age). A better understanding of boater behavior relative to ANS transfer will allow agencies to tailor (and thus be more effective) in outreach efforts regarding ANS prevention when behavioral surveys or field sampling is not possible. As such, we test for differences in high-risk behaviors reported in the survey (e.g., not cleaning boats or trailers) based on boater demographic group (hereafter, "boater group").

The empirical mapping tool provides a visual representation of how the incorporation of boater movement and behavior changes the potential for species transfer. This tool, along with the analysis of demographic predictors of risk, enables improved site prioritization and management response.

Materials and Methods

Study Site

Michigan contains the most Great Lakes shoreline of any U.S. state and numerous inland water bodies. The state, therefore, has a large boating community with 812,066 registered boats in 2010 (National Marine Manufacturers

Association 2010). Larger numbers of recreational boaters provided an opportunity for a large sample size to demonstrate the application of this survey-based tool.

Survey Development

We targeted survey collection to water bodies (any inland lake, river, or Great Lakes harbor) that were accessible by recreational boaters, across a comprehensive geographic range within the state. Selection of water bodies was designed to maximize management outcomes, i.e., to understand where and how known infestations may spread. As such, we identified high traffic sites (as measured by transient recreational boaters or ballast discharge) and those with ANS whose distribution in Michigan is limited, but often at high densities (see next paragraph for discussion on this latter criterion; sensu Buchan and Padilla 1999; Rothlisberger et al. 2010). Transient boaters are those that visit more than one water body per ice-free season (spring thaw to winter freeze). Identification of sites was based on advice from aquatic invasive species specialists and outcomes from Rup et al. (2010) that identified high ballast water discharge sites. Toledo Harbor was included due to its proximity to heavily used Michigan waters and its status as one of the largest ballast water recipient ports in the Great Lakes (Rup et al. 2010).

To identify water bodies with ANS whose distribution in Michigan is limited, we considered macrophytes from the Michigan Department of Natural Resources (DNR) EDRR list (European frog-bit *Hydrocharis morsus-ranae,* flowering rush *Butomus umbellatus,* water lettuce *Pistia stratiotes*, parrot feather *Myriophyllum aquaticum*, Brazilian elodea *Egeria densa*, water hyacinth *Eichhornia crassipes*), as well as a high-profile species not yet in Michigan (*Hydrilla verticillata*) and a macroalgae with limited distribution (starry stonewort *Nitellopsis obtusa*). Collaboration with the DNR program was appropriate given its focus on macrophytes, which are commonly spread by recreational boating (Johnstone et al. 1985; Rothlisberger et al. 2010), and its status as the only active monitoring programs for ANS in Michigan at the time.

We collected surveys spanning the ice-free periods in 2012 and 2013 via boat launch visits, boat show attendance, targeted mailings, and online distribution. The primary question themes in the survey were between-use boat storage, details of past and future boater trips over the ice-free period, cleaning practices after trips, and activities and equipment related to angling. For details of past and future boater trips, the survey provided a blank table for boaters to complete that had columns for water body name, nearest city, and dates visited (i.e., water body selection was not dictated by the survey). The survey was approved under

Wayne State University's Institutional Review Board, behavioral research project number 1209011300.

(1) Boat launch visits. We surveyed boaters during the ice-free period of 2013. For water bodies with multiple launch sites, we chose the site with the most boater activity. We collected surveys at or near the selected launch and approached boaters during arrival or departure, depending on their availability. We provided a short verbal introduction to the study, a letter of informed consent, the survey, and an educational fact sheet on ANS in Michigan to those receptive to participation. The survey generally took 10–15 min to complete.

(2) Boat shows. We surveyed boaters at three major boat shows on their activities during the 2012 ice-free period. These were the Detroit Boat Show, 16–19 February 2013, Detroit, MI; Outdoorama, 21–24 February 2013, Novi, MI; and the Novi Boating Expo, 14–17 March 2013, Novi, MI. We took attendees receptive to participating through the same protocol as for the boat launch visits.

(3) Targeted mailings. We mailed surveys to 600 registered boaters (1200 total over two seasons), chosen randomly from a list provided by the Michigan Secretary of State. Criteria for receiving a survey were recipients of a renewal license (i.e., had owned their boat for at least 1 year), individuals that designated boat purpose as "pleasure," and individuals registered in a zip code associated with a water body identified for our surveys. We sent surveys for the 2012 season in February 2013 and for the 2013 season in September 2013. To improve the response rate, we mailed reminder post cards 2 weeks following the 2013 mailing.

(4) Online distribution. We distributed an online version of the survey via Great Lakes and Michigan listservs, Sea Grant communications, Michigan state park and recreation newsletters, lake associations, and aquatic recreational organizations (e.g., hunting, angling, and paddling). Participating boaters further distributed the online survey, including via social media sites.

Mapping Tool

We used ArcView GIS 10.2 (ESRI, Redlands, CA, USA) to identify water bodies that were potential sources of ANS and water bodies that were potential sinks for ANS transfer. We based this identification on the surveys of transient boaters. Each trip consisted of a boater leaving from and arriving at a water body; we divided these into "out" and "in" trips, respectively. We scored each trip according to

high-risk behaviors performed by the boater; higher scores represented higher likelihood of transfer. These behaviors consisted of not removing visible mud, plants, or animals from boats and trailers; not removing visible mud, plants, or animals from personal equipment; not emptying all water (e.g., from motors, jet drives, live wells, waders, and bait buckets); not allowing boats and equipment to dry at least 5 days before next use; not cleaning with either hot water, vinegar or salt solution, bleach solution, or high-pressure washing; greater number of days spent on the water body; greater number of trips between the same two water bodies; and greater number of different water bodies visited (hereafter, "high risk behaviors"). For each water body, we summed all "out" and "in" trips across all boaters to determine an overall score for each direction. That is, each water body was given a total score for incoming and outgoing trips. The mean trip scores were also found by dividing the total score by the number of incoming and outgoing trips, respectively.

To determine how each risk behavior should contribute to the trip score, we used expert judgment to consider ten scoring options. The expert panel consisted of experts from federal and state agencies, academic institutions, and non-governmental organizations with expertise in aquatic invasive species ecology and management, mapping Great Lakes stressors, monitoring for aquatic invasive plants, and risk assessment. The scoring options included options that did not consider all of the cleaning behaviors (rejected by experts as not representative of full risk), considered angling behaviors (rejected as not representative of exclusively boater-based transfer of ANS), and considered using the raw trip data (rejected by experts for reasons described below). Based on expert input, we chose the scenario that considered all boater behaviors (with each high-risk behavior assigned a "1" if performed; "0" if not) and categorized the continuous trip data (i.e., days on the water, number of trips, and number of different water bodies visited). Categorizing the raw trip data prevented large trip scores (e.g., 30 days spent on the water) from overwhelming other factors, but still retained these known proxies for likelihood of transfer. On the map, we displayed the mean trip score and the total trip score for each water body (subset of water bodies shown in Figs. 1, 2). Based on feedback from the expert panel, the mean and total scores were divided into five equal interval categories— 'very low', 'low', 'moderate', 'high,' and 'very high' scores—represented by colored symbols of different sizes. While this study used five categories of equal interval, scores could also be divided up in other ways (such as using standard deviations or fewer categories) based on management feedback. Mean trip scores were represented by color, and total trip scores were represented by size. Green and small symbols indicate lower scores; red and large symbols indicate higher scores.

Demographic Predictors

We tested whether any readily available demographic factors may serve as proxies for the high-risk behaviors identified above. We used the following demographic factors: state region (by Great Lakes watershed), boat type (e.g., pontoon, sailboat, personal watercraft), and boater age. We divided behaviors into two categories that represent different management challenges: (1) cleaning activities (removing visible mud, plants, or animals from boats and trailers; removing visible mud, plants, or animals from personal equipment; emptying all water; allowing boats and equipment to dry at least 5 days before next use; and completing at least one of the recommended wash methods (hot water, vinegar or salt solution, bleach solution, or high-pressure washing); and (2) bait-related activities (fishing with nets, excluding hand nets; disposing of leftover bait; and moving self-caught bait between water bodies) (ANS Task Force 2013).

We conducted a Pearson's χ^2 test to determine if there was a difference in self-reported cleaning and bait-related behaviors for each demographic factor. Post hoc analysis used the standardized residuals to interpret which cell(s) contributed to any significant χ^2 values.

Results

We found 17 water bodies that were considered high priorities for understanding boater use and behavior (Online Resource 1). We collected 1062 surveys for 2012–2013. For 2012, we received 430 surveys total (328 boat shows, 30 targeted mailings, and 72 online). For 2013, we received 632 surveys total (348 boat launch visits, 79 targeted mailings. and 205 online). Boat shows had the most receptive participants (80 %), followed by boat launch (60 %), and 2012 and 2013 mailings (5 and 13 %, respectively), with the online component indeterminate. Respondents showed high rates of removing organic matter from boats/trailers (89 %) and equipment (85 %), as well as for draining all water (83 %). However, the reported rate of drying was quite low (55 %; Table 1). We use the term "boaters" to refer to boaters surveyed in this study.

Mapping Tool

For the mapping tool, we used 445 surveys from transient boaters who had completed a total of 1113 trips. Boat launch (150 surveys) and boat show (153 surveys) contributed about equally to this number; online (109 surveys) and mailings (33 surveys) contributed fewer. The tool highlighted one water body with a very high mean trip score and five water bodies with high mean trip scores for inbound trips (subset of water bodies shown in Fig. 1). The tool also highlighted one water
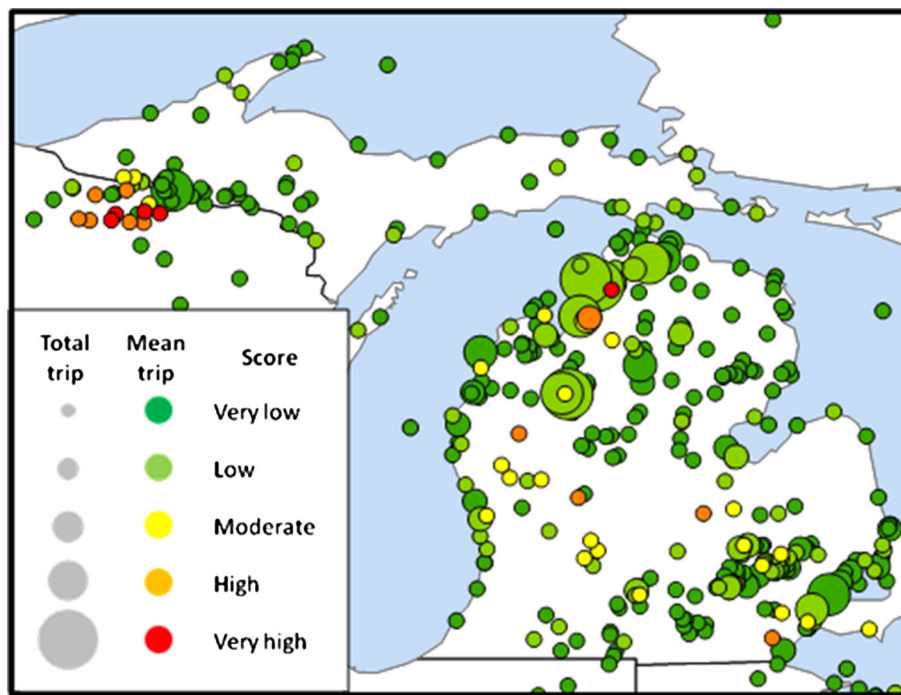
Fig. 1 Zoomed view of map of trips *into* water bodies, using ArcView GIS 10.2 (ESRI, Redlands, CA, USA), based on the surveys of transient boaters. Map shows the U.S. Great Lakes region, centered on Michigan. Each trip consisted of a boater arriving at a water body. We weighted each trip according to high-risk behaviors performed by the boater; higher scores represented higher likelihood of transfer. These behaviors consisted of not removing visible mud, plants, or animals from boats and trailers; not removing visible mud, plants, or animals from personal equipment; not emptying all water; not allowing boats and equipment to dry at least 5 days before next use; not cleaning with either hot water, vinegar or salt solution, bleach solution, or high-pressure washing; greater number of days spent on the water body; greater number of trips between the same two water

bodies; and greater number of different water bodies visited. For each water body, we summed all weighted trips across all boaters to determine an overall score. The mean trip scores were also found by dividing the total score by the number of incoming trips. The mean and total scores were divided into five equal interval categories— 'very low', 'low', 'moderate', 'high,' and 'very high' scores— represented by *colored symbols* of different sizes. Mean trip scores are represented by *color*, and total trip scores are represented by size. *Green* and *small symbols* indicate lower scores; *red* and *large symbols* indicate higher scores. While not discussed in the text, the survey also captured Michigan boaters traveling to water bodies outside the state; these are included in the map to show the potential implications for management (e.g., travel across management jurisdictions)

body with a very high mean trip score and seven water bodies with high mean trip scores for outbound trips (subset of water bodies shown in Fig. 2).

Using the mapping tool, we identified the top three Great Lakes and connecting waterways locations with the most boater-based inland connections (Lake Huron near Linwood, MI, Lake Michigan near Charlevoix, MI, and the Detroit River near Detroit, MI). We identified four Great Lakes and connecting waterways locations as having high scoring outbound trips (Lake Michigan near Muskegon and Charlevoix, MI, Lake Huron near Hessel, MI and also Lake St. Clair near Fair Haven, MI). One of these connections (Charlevoix) was particularly notable given the ballast discharge at this port (Rup et al. 2010). Finally, we identified the top three inland lakes that received the most boaters arriving from Great Lakes ports (Lake Charlevoix, Burt Lake, and Higgins Lake).

The survey results indicated that 42 % of boaters visited more than one water body, with the average boater having 2.5 connections. While most boaters made only a few trips,

there were several boaters who made up to ten unique trips in a season. We did not find any overlap of high or very high scoring water bodies when comparing weighted trips versus raw trip counts.

Demographic Factors

Each of the demographic factors was significant for at least one of the cleaning activities, and state region and age were significant for leftover bait disposal (Table 2). Fishing with nets and movement of self-caught bait between water bodies were very rarely reported and thus not appropriate for analysis.

State Region

Differences in behaviors were observed among boaters using different watersheds. A greater number of boaters from the Lake Michigan watershed than would be expected did not drain water from their boat and related equipment
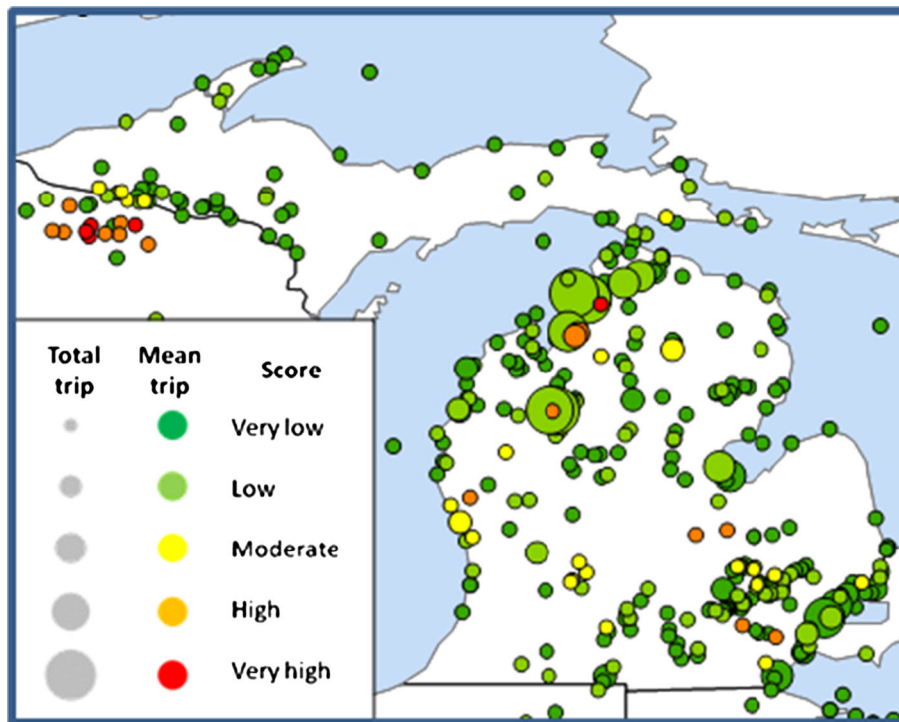
Fig. 2 Zoomed view of map of trips *out of* water bodies, using ArcView GIS 10.2 (ESRI, Redlands, CA, USA), based on the surveys of transient boaters. Map shows the U.S. Great Lakes region, centered on Michigan. Each trip consisted of a boater departing from a water body. We weighted each trip according to high-risk behaviors performed by the boater; higher scores represented higher likelihood of transfer. These behaviors consisted of not removing visible mud, plants, or animals from boats and trailers; not removing visible mud, plants, or animals from personal equipment; not emptying all water; not allowing boats and equipment to dry at least 5 days before next use; not cleaning with either hot water, vinegar or salt solution, bleach solution, or high-pressure washing; greater number of days spent on the water body; greater number of trips between the same two water bodies; and greater number of different water bodies visited. For each water body, we summed all weighted trips across all boaters to determine an overall score. The mean trip scores were also found by dividing the total score by the number of outgoing trips. The mean and total scores were divided into five equal interval categories—'very low', 'low', 'moderate', 'high,' and 'very high' scores—represented by *colored symbols* of different sizes. Mean trip scores are represented by *color*, and total trip scores are represented by size. *Green* and *small symbols* indicate lower scores; *red* and *large symbols* indicate higher scores. While not discussed in the text, the survey also captured Michigan boaters traveling to water bodies outside the state; these are included in the map to show the potential implications for management (e.g., travel across management jurisdictions)

($\chi^2 = 7.8$, $n = 403$, $df = 3$, $P \leq 0.05$). Lake Michigan watershed boaters generally did not complete one of the wash methods, while Lake Erie watershed boaters generally did ($\chi^2 = 28.9$, $n = 770$, $df = 3$, $P \leq 0.01$).

Boaters from the Lake Erie watershed tended to dump bait in the water and not save it for the next trip; boaters from the Lake Huron watershed tended to save bait for the next trip; and boaters from Lake Michigan tended to not dump bait in the water and saved it for the next trip ($\chi^2 = 68.3$, $n = 641$, $df = 15$, $P \leq 0.01$).

Boat Type

Pontoon users generally failed to complete three of the four cleaning activities (failure to remove organic matter from boats/trailers: $\chi^2 = 16.5$, $n = 434$, $df = 5$, $P \leq 0.01$; failure to remove organic matter from equipment: $\chi^2 = 20.3$, $n = 369$, $df = 5$, $P \leq 0.01$; failure to drain all water:

$\chi^2 = 22.4$, $n = 443$, $df = 5$, $P \leq 0.01$). Pontoon users also generally failed to complete at least one wash method ($\chi^2 = 30.7$, $n = 827$, $df = 5$, $P \leq 0.01$).

Boater Age

Older boaters (>50 years) tended not to remove organic matter, while younger boaters (40–49 years) tended to remove organic matter ($\chi^2 = 10.9$, $n = 419$, $df = 5$, $P \leq 0.05$). Younger boaters (40–49 years) tended to allow boat and equipment to dry at least 5 days ($\chi^2 = 11.3$, $n = 424$, $df = 5$, $P \leq 0.05$). Younger boaters also tended to complete at least one wash method ($\chi^2 = 24.9$, $n = 801$, $df = 5$, $P \leq 0.01$).

The youngest boaters (<30 years) tended to return bait to the shop, while the oldest boaters (>70 years) tended to dump bait in the water ($\chi^2 = 39.06$, $n = 661$, $df = 25$, $P \leq 0.05$).

Table 1 Summary of high-risk behaviors for transient boaters

Question	Responses ($n = 445$)	
	Yes (%)	No (%)
Move between Great Lakes and inland	48	52
Seen weeds attached to your boat or trailer while departing a water body	61	39
Removed visible mud, plants, or animals from boat and trailer	89	11
Removed visible mud, plants, or animals from personal equipment	85	15
Empty all water from boat	83	17
Allow boat to dry at least 5 days	55	45
Hot water, vinegar or salt solution, bleach solution, or high-pressure wash	73	27
Moved live well water between water bodies	3	97
Fish with nets	6	94
Participate in fishing tournaments	16	84
Pre-fish tournaments	74	26

Survey collection occurred at water bodies (any inland lake, river, or Great Lakes harbor) that were accessible by recreational boaters, across a comprehensive geographic range within Michigan (U.S) High traffic sites (as measured by transient recreational boaters or ballast discharge) and those with ANS whose distribution in Michigan is limited were the spatial focus of survey collection. Transient boaters are those that visit more than one water body per season. We collected 445 surveys from transient boaters spanning the ice-free periods in 2012 and 2013 via boat launch visits, boat show attendance, targeted mailings, and online distribution

Discussion

Many studies use the number of boaters at a particular water body as a proxy for likelihood of introduction (e.g., Padilla et al. 1996; Bossenbroek et al. 2001; Chivers and Leung 2012). The incorporation of boater behavior, however, led to a different set of high-risk water bodies than was found when only the number of boater trips was used. The effect of behavior is also demonstrated by Figs. 1 and 2, where the larger symbols (higher total scores, generally due to number of trips) do not correspond with the orange and red symbols (higher mean scores, generally due to boater behavior). This lack of overlap between weighted trips and simple trip counts suggests that the number of boater trips may not fully reflect the likelihood of invasion. This empirical mapping tool captures the boater behaviors that may improve predictions of likelihood. This tool also highlights several aspects of the vector considered in this application (recreational boating) relevant to management—specifically, connections to commercial ports, long-distance connections, and species transfer that may occur as a result.

Movement from Commercial Ports

Trips between Great Lakes and inland lakes have been implicated as a major source of spread inland (Muirhead and Macisaac 2005; Johnson et al. 2006). While Padilla et al. (1996) found 16.8 % of boaters surveyed moved between the Great Lakes and inland lakes in Wisconsin, we

found 48 % of boaters surveyed moved in this manner. Understanding connections between areas where new species may arrive and where they may travel (in this application, commercial ports and inland water bodies) is an important step in preventing the hub-and-spoke spread as seen in invasion biology, but also in other biosecurity concerns such as the spread of pandemics (McLafferty 2010).

Movement Between States

At the time of this study, the number of recreational anglers who travel between states was substantial; in 2011, over 20 % of anglers who fished in Michigan were from outside the state (U.S. Department of the Interior et al. 2011). In this study, 19.5 % of trips were made by out-of-state boaters.

One notable long-distance trip was to Eagle Mountain Lake, TX (about 2000 km from Michigan). This lake is less than a 3-h drive from four of the five reservoirs in which the mud crab *Rhithropanopeus harrisii* has established. While the mud crab is generally a saline or estuarine species, these populations reproduce in freshwater conditions (Richey 2004). As such, they are considered as potential invaders by the Great Lakes ANS Information System, a regional node of the U.S. federal database for nonindigenous species. Finally, we encountered several boaters who travel by boat between either the Great Lakes and Mississippi River System, or among all the Great Lakes from New York to Minnesota. Boaters who travel

Table 2 Results of χ^2 analysis of demographic factors that may serve as proxies for high-risk behaviors

Activity	Region (watershed)			
	χ^2	n	df	P
Remove mud, plants, animals from boat/trailer	3.65	393	3	0.302
Remove mud, plants, animals from equipment	3.21	342	3	0.361
Empty all water	7.85	403	3	**0.049**
Allow to dry for 5 days	2.14	399	3	0.550
At least one of the above	28.93	770	3	**0.000**
Leftover bait disposal	68.20	641	15	**0.000**
Activity	Boat type			
	χ^2	n	df	p
Remove mud, plants, animals from boat/trailer	16.50	434	5	**0.006**
Remove mud, plants, animals from equipment	20.27	369	5	**0.001**
Empty all water	22.44	443	5	**0.000**
Allow to dry for 5 days	9.51	440	5	0.090
At least one of the above	30.72	827	5	**0.000**
Leftover bait disposal	47.19	689	42	0.270
Activity	Age			
	χ^2	n	df	p
Remove mud, plants, animals from boat/trailer	10.90	419	5	**0.053***
Remove mud, plants, animals from equipment	6.12	355	5	0.300
Empty all water	9.13	426	5	0.100
Allow to dry for 5 days	11.30	424	5	**0.045**
At least one of the above	24.90	801	5	**0.000**
Leftover bait disposal	39.06	661	25	**0.036**

Demographic factors included state region (by Great Lakes watershed; Erie, Huron, Superior, and Michigan), boat type (closed cabin motorized, >20 ft open bow motorized, <20 ft motorized, pontoon, nonmotorized boat or canoe, sailboat, personal watercraft, and other), and boater age (<30, 30–39, 40–49, 50–59, 60–9, and >70 years). High-risk behaviors were divided into two categories that represent different management challenges: (1) cleaning activities (removing visible mud, plants, or animals from boats and trailers; removing visible mud, plants, or animals from personal equipment; emptying all water; allowing boats and equipment to dry at least 5 days before next use; and completing at least one of the recommended wash methods (hot water, vinegar or salt solution, bleach solution, or high-pressure washing), "at least one of the above"; and (2) bait-related activities (disposing of leftover bait in water, on land, in trash, by returning to bait shop, by giving to another angler, or by saving for next trip). The questions for "at least one of the above" and "leftover bait disposal allowed respondents to select more than one option, which is why sample size are greater than 445 (number of transient boater surveys). Pearson's χ^2 test was used to determine if there was a difference in these self-reported cleaning and bait-related behaviors for each demographic factor. Post hoc analysis used the standardized residuals to interpret which cell(s) contributed to any significant χ^2 values

* Denotes marginally insignificant

Bold represents activities significant at $p < 0.05$

long distances along waterways represent an important mode of transfer between these areas, as there is little opportunity for desiccation-related mortality of attached organisms.

While this survey was not distributed at fishing tournaments, these anglers may represent another source of long-distance travel. In the major fishing tournaments held this past year in Michigan, nearly half of the boats were from out of state (authors, unpublished data from FLW Everstart Series, Walmart Bass Fishing League, and Cabela's Masters Walleye Circuit). Compared to a Wisconsin study that estimated over 90 % of tournament anglers fish a location before the event, often spending three or more days (Phil Moy, pers. comm.), our study indicates that 74 % of transient tournament anglers pre-fish tournaments. While inspections are generally held at tournaments, they are of little value when most anglers have already visited the site prior to official inspection.

Species Transfer and EDRR

Knowledge of species distribution and impacts can add capacity to this mapping tool, as it allows managers to predict not just *that* species may be moving, but *what* species may be moving. Of the eight species considered, five have been found in Michigan (*H. morsus-ranae; B. umbellatus; P. stratiotes; M. aquaticum; E. crassipes*). These macrophyte species have resulted in negative impacts to freshwater taxa, primarily replacement of native plant communities through competition for light and substrate (e.g., Catling et al. 1988) and modification of abiotic factors (Cilliers et al. 1996), but also to aquatic invertebrates (Villamagna and Murphy 2010). Aquatic plants have also had quantifiable economic impacts, e.g., decreased property values (Zhang and Boyle 2010). Finally, macrophytes have been identified as vectors themselves for the transport of other ANS (Johnson et al. 2001).

As such, early prediction and prevention of new populations are important. Although we did not physically determine the proportion of boats with attached macrophytes, 33–45 % of boats traveling in Michigan have been found to carry at least one plant fragment (externally, not including interior surfaces or standing water) (Johnson et al. 2001; Rothlisberger et al. 2010). Asexual reproduction by these plant fragments results in limited Allee effects, heightening the potential for establishment. This mapping tool provides managers with a spatial representation of where boaters fail to remove plant fragments. While there has been insufficient time to determine the number of total species detections over all sites at higher risk, the DNR initiated investigation in 2014 at 13 sites identified by this study in June and July 2014 and found new populations of the macrophytes targeted by the DNR's EDRR efforts at six of them.

Management and Outreach Implications

Early communication with management and stakeholders is an important step to increasing the utility and uptake of research outcomes. As such, this study incorporated management considerations a priori. We targeted survey collection at water bodies that are of interest to management, given their status as potential transfer sites (Online Resource 1). The visual nature of the tool makes it easier for managers to identify priority sites. In this example, water bodies that appear as large and red represent high priority, and those that appear as small and green represent low priority for early detection work.

When a species' distribution is limited, intercepting outgoing propagules from source lakes is a more efficient method to preventing spread than intercepting incoming propagules to sink lakes (Drury and Rothlisberger 2008;

Rothlisberger and Lodge 2011). This approach corresponds to focusing efforts on outgoing boats from water bodies with high or very high scoring outbound trips. As boaters are most likely to have attached weeds leaving a water body if the launch is infested (Johnstone et al. 1985), actions to prevent outbound spread include clearing weeds in this area, as well as performing hand removal on boats and trailers (shown to be as effective as high-pressure washing; Rothlisberger et al. 2010).

Management plans should consider not only environmental, but also economic and social objectives, to be sustainable (Larson et al. 2011). Economic objectives are several—notably, sufficient long-term funding (Larson et al. 2011). Many ANS programs have short-term funding. A long-term funding source would allow improved planning and continuity for these programs. One option is adding a small fee to boater registration (several western U.S. states apply such a fee, e.g., Idaho Invasive Species Council) that could be used to fund components of an ANS management program, e.g., vessel inspections or boat washing stations. Social objectives include involving stakeholders and community members in monitoring and outreach efforts. Stakeholder involvement could engage lake associations for those water bodies identified here as potential source or sink sites. Lake associations at source sites, rather than over-extended state agencies, could be responsible for keeping launch areas clear or assisting with hand removal from boats and trailers. Associations at receiving sites could participate in plant monitoring programs to detect new populations.

An Adaptable Tool

While this application used macrophyte spread within the Great Lakes, the tool can be applied in other geographic contexts and with other taxa. The tool can be adjusted according to varying levels of information concerning the vector or species of interest and the methodology can be followed after a basic introduction to ArcGIS. As such, this tool is not limited by available expertise, as can be the case in more complex modeling exercises.

Development of adaptable and user-friendly tools to assist EDRR efforts is timely, as such programs are being developed from national to local scales (e.g., Westbrooks 2004; U.K. Department of the Environment 2013).

An understanding of connectedness within the recreational boater vector has been called for in coastal environments, as well. Areas where widespread boater movement may be responsible for intraregional spread from commercial hubs include Australia (Burgin and Hardiman 2011), Canada (Darbyson et al. 2009), and the North American Pacific Coast (Wasson et al. 2001; Clarke Murray et al. 2011).

While this tool does not use direct measures of propagule pressure, it does use well-accepted proxies for likelihood of transfer (ANS Task Force 2013). The user can adjust these proxies based on different goals or new knowledge. This mapping tool can also incorporate new information as additional survey work is completed. We recommend future survey efforts include online platforms, as this format provided the most complete and legible survey data. An online survey could also facilitate water body identification (one of the most time consuming components of data entry) via interactive maps (Chivers and Leung 2012). These online surveys could be collected during boater registration or similar activities.

This study has several limitations and assumptions common to survey work. First, these outcomes are likely conservative. Boaters surveyed at boat launches were eager to get on the water if surveyed prior to launching, or anxious to get home if surveyed coming off the water, and may have overlooked or inadvertently not checked the questions related to cleaning behaviors. Second, as in other studies (e.g., Chivers and Leung 2012), we assume that a boater's behaviors were the same for each of their trips. Finally, while the surveys captured many boaters and water bodies, it represents a relatively small subset of the total trips made. However, complete knowledge of boater movement is not possible and monitoring decisions will have to be made regardless. In identifying a set of potentially at-risk water bodies, this tool is part of a larger suite of tools that inform management decisions.

Survey Outcomes

There are many reports on rates of cleaning behavior. While this study collected this data primarily for the empirical mapping tool, reporting of these behaviors also allows agencies to gauge success of outreach and education efforts.

Encouragingly, there appears to be an increase in following best management practices. In a 2005–2007 survey, Rothlisberger et al. (2010) found that slightly less than one-third of Michigan boaters always cleaned their boats (compared to three-quarters of boaters in this survey) and around three-quarters of transient boaters always removed aquatic weeds (compared to 85 % of boaters in this survey). A 2011 Michigan Sea Grant survey found similar rates of cleaning behavior as our study (Lee et al. 2012).

Although survival rates for small, exposed macrophyte fragments are quite low (e.g., for Eurasian watermilfoil; Jerde et al. 2012), removing organic matter from boats, trailers, and equipment remains important. Macrophytes have high survival rates when insulated in large masses or by equipment (Jerde et al. 2012) and have been found to frequently harbor invertebrates (Johnson et al. 2001). Hand

removal remains an effective and simple prevention tool for macroalgae (Rothlisberger et al. 2010). Visual inspection is not effective against small-bodied organisms, however (Rothlisberger et al. 2010). Additionally, recreational boats can hold up to 1420 l of ballast water. Even when drained properly (which can be a difficult undertaking for wake boats that use water sacs), an un-dried boat can still harbor 4 l of water (Dalton and Cottrell 2013). The lower rates of not drying boats and, to a lesser extent, cleaning, found in our study therefore represent an important gap in the completion of best management practice.

We found that despite increased campaigns of "Don't Dump Your Bait" and the risks associated with species introduction and impact following land and water disposal (e.g., Ludwig and Leitch 1996; Greiner et al. 2012), 22 % of anglers in our survey disposed of bait in the water. While comprehensive surveys of bait disposal do not exist, two studies provide examples for comparison: in 2007, the rate of disposal in the water by anglers was 12 %, down from 41 % in 1993 (Litvak and Mandrak 1993; Keller et al. 2007). A 2013 survey of Great Lakes anglers found 82 % dispose of bait in the trash, indicating 18 % may do so in the water or on land (D. Jensen, pers. comm.) These continually high rates, combined with the fact that bought bait often contains ANS (Keller et al. 2007), support work that state agencies and researchers are conducting with the bait industry to eliminate ANS before bait reaches anglers.

Demographic Factors

The results from this study highlighted several demographic groups that appear to participate in high-risk behaviors. While on-site education and outreach efforts are important to preventing new introductions, so are non-field components such as online social media, presentations at lake meetings, and presence at boat shows or other boat-related venues. These efforts could target the demographic groups to address the high-risk behaviors in a variety of ways. For example, mailings related to boater registration that includes educational information on the importance of draining water and washing the boat after use (for Lake Michigan watershed residents) or the importance of not dumping bait in the water (for Lake Erie watershed residents) could exploit the difference by watershed in these behaviors. Billboards are another outreach effort used in ANS prevention campaigns. Rather than sharing a general message across the state, some billboards could focus on the specific high-risk behaviors particular to the specific watershed. Other differences in high-risk behaviors by demographic group could be leveraged by targeting boat inspections and washing. At busy boat launches, the personnel or equipment available for boat inspections or washes may be insufficient to keep up with demand. In

these situations, responsible personnel could prioritize in-specting or washing pontoons (whose owners generally failed to complete three of the four cleaning activities) and boaters >50 years in age (who tended not to remove organic matter). These efforts are only a few examples that could be used alone or in tandem with other outreach efforts. We note the large difference in number of registered boaters in Michigan (over 800,000 as of 2010) and the number of collected surveys (445 from transient boaters); as in many surveys, generalizations between survey respondents and the entire boating population should be made with care.

Conclusion

Early detection and rapid response efforts can be effective in early detection and removal of ANS (e.g., Wimbush et al. 2009), but they face many challenges, including the delay in publishing useful tools and disseminating knowledge once a study has been finished (Darbyson et al. 2009; Rothlisberger et al. 2010). In addition, the quality and availability of knowledge used to inform and prioritize EDRR efforts occur along a spectrum, from very low (educated guesses on potential ANS and their associated vectors) to very high (complete understanding of potential ANS and their associated vectors)—but generally present toward the low end of the spectrum.

This empirical mapping tool addresses this latter challenge by increasing the potential for better knowledge of the recreational boating vector. The tool demonstrates the ability to, and importance of, understanding and incorporating boater behaviors into predictions of water bodies that may receive new introductions. Where a survey of boater behaviors is not possible due to time or personnel constraints, the differences in high-risk behaviors by demographic groups provide insight into where outreach and monitoring efforts may still be focused effectively. Together, the results of this study will increase the ability to predict nonindigenous species transfer and make more informed EDRR decisions.

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