Fisheries

VOL 35 NO 3
MARCH 2010

American Fisheries Society • www.fisheries.org

AFS

Fish News
Legislative Update
Journal Highlights
Calendar
Job Center

Defining Overfished Stocks: Have We Lost The Plot?

Aquatic Invasive Species Transport via Trailered Boats: What Is Being Moved, Who Is Moving It, and What Can Be Done

Fisheries

VOL 35 NO 3
MARCH 2010

AMERICAN FISHERIES SOCIETY • WWW.FISHERIES.ORG
EDITORIAL / SUBSCRIPTION / CIRCULATION OFFICES
5410 Grosvenor Lane, Suite 110 • Bethesda, MD 20814-2199
301/897-8616 • fax 301/897-8096 • main@fisheries.org
The American Fisheries Society (AFS), founded in 1870, is the oldest and largest professional society representing fisheries scientists. The AFS promotes scientific research and enlightened management of aquatic resources for optimum use and enjoyment by the public. It also encourages comprehensive education of fisheries scientists and continuing on-the-job training.

Dues and fees for 2010 are:
$80 in North America ($95 elsewhere) for regular members, $20 in North America ($30 elsewhere) for student members, and $40 ($50) retired members.
Fees include $19 for *Fisheries* subscription.
Nonmember and library subscription rates are $132 ($127).
Price per copy: $3.50 member; $6 nonmember.

Fisheries (ISSN 0363-2415) is published monthly by the American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199 ©copyright 2010. Periodicals postage paid at Bethesda, Maryland, and at an additional mailing office. A copy of Fisheries Guide for Authors is available from the editor or the AFS website, www.fisheries.org. If requesting from the managing editor, please enclose a stamped, self-addressed envelope with your request. Republication or systematic or multiple reproduction of material in this publication is permitted only under consent or license from the American Fisheries Society.
Postmaster: Send address changes to Fisheries, American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199.

Fisheries is printed on 10% post-consumer recycled paper with soy-based printing inks.

Contents

COVER: Eurasian watermilfoil (*Myriophyllum spicatum*).
CREDIT: Eric Engbretson, www.underwaterfishphotos.com.

FEATURE:
INTRODUCED SPECIES

Aquatic Invasive Species Transport via Trailered Boats: What Is Being Moved, Who Is Moving It, and What Can Be Done

ABSTRACT: Trailered boats have been implicated in the spread of aquatic invasive species. There has been, however, little empirical research on the type and quantity of aquatic invasive species being transported, nor on the efficacy of management interventions (e.g., inspection crews, boat washing). In a study of small-craft boats and trailers, we collected numerous aquatic and terrestrial organisms, including some species that are morphologically similar to known aquatic invasive species. Additionally, a mail survey of registered boaters (n = 944, 11% response rate) and an in-person survey of boaters in the field (n = 459, 90% response rate) both indicated that more than two-thirds of boaters do not always take steps to clean their boats. Furthermore, we used a controlled experiment to learn that visual inspection and hand removal can reduce the amount of macrophytes on boats by 88% ± 5% (mean ± SE), with high-pressure washing equally as effective (83% ± 4%) and low-pressure washing less so (62% ± 3% removal rate). For removing small-bodied organisms, high-pressure washing was most effective with a 91% ± 2% removal rate; low-pressure washing and hand removal were less effective (74% ± 6% and 65% ± 4% removal rates, respectively). This research supports the widespread belief that trailered boats are an important vector in the spread of aquatic invasive species, and suggests that many boaters have not yet adopted consistent and effective boat cleaning habits. Therefore, additional management efforts may be appropriate.

John D. Rothlisberger, W. Lindsay Chadderton, Joanna McNulty, and David M. Lodge

Rothlisberger is a graduate student at the Center for Aquatic Conservation and Department of Biological Sciences, University of Notre Dame, Notre Dame, Indiana, and is now with the USDA Forest Service in Milwaukee, Wisconsin. He can be contacted at jrothlisberger@fs.fed.us. Chadderton is aquatic invasive species director for The Nature Conservancy's Great Lakes Project. McNulty is program coordinator and Lodge is director of the Center of Aquatic Conservation at the University of Notre Dame.

Especies acuáticas invasivas transportadas vía botes con remolque: qué se está moviendo, quién lo mueve y qué puede hacerse

RESUMEN: Los botes con remolque han sido implicados en la dispersión de especies acuáticas invasivas. Sin embargo, se ha llevado a cabo poca investigación empírica acerca del tipo y cantidad de especies acuáticas invasivas que están siendo transportadas así como de la eficacia del manejo a este respecto (p.e. tripulación para inspección y lavado de botes). En un estudio realizado acerca de pequeñas embarcaciones y remolques, se colectaron numerosos organismos acuáticos y terrestres, incluyendo algunas especies que son morfológicamente similares a especies acuáticas invasivas previamente conocidas. Adicionalmente se hizo un sondeo por correo a los dueños registrados de las embarcaciones (n = 944, 11% de tasa de respuesta) y un sondeo en persona en campo (n = 459, 90% tasa de respuesta). Ambos sondeos indicaron que más de dos tercios de dichos dueños no siempre limpian sus botes. Más aún, se hizo un experimento en condiciones controladas para determinar que la inspección visual y la remoción manual pueden reducir la cantidad de macrofitas en los botes hasta en un 88% ± 5% (media ± EE), siendo igualmente efectivo el lavado a alta presión (83% ± 4%) mientras que el lavado a baja presión no lo fue tanto (62% ± 3% tasa de remoción). En cuanto a la remoción de animales pequeños, el lavado a alta presión fue el más efectivo con un 91% ± 2% de tasa de remoción; el lavado con baja presión y la remoción manual fueron menos efectivos (74% ± 6% y 65% ± 4% de tasa de remoción, respectivamente). Este estudio apoya la creencia común que los botes con remolque son un vector importante en la dispersión de especies acuáticas invasivas; se sugiere, además, que muchos dueños de botes aun no han adoptado hábitos de limpieza consistentes y efectivos. Por lo resultan adecuados esfuerzos de manejo adicionales.

Invasive aquatic plants, such as Eurasian watermilfoil, can be transported among waterways when they become entangled on recreational boats, motors, and trailers.

INTRODUCTION

Much of the ongoing spread of aquatic invasive species (AIS) to inland waters throughout North America can be attributed to the overland movement of small-craft boats (Bossenbroek et al. 2001; Johnson et al. 2001; Leung et al. 2006). Small-craft boats are vessels less than 40 feet (12.2 m) in length, including powerboats, small commercial and recreational fishing boats, sailboats, personal watercraft, canoes and kayaks, and pontoon boats, that can be towed overland on trailers. Translocation of organisms by boaters can be intentional (e.g., as bait; Keller et al. 2007), but is often unintentional (Johnson et al. 2001; Puth and Post 2005), with organisms inadvertently carried in bilge water, live wells, and bait buckets. Organisms can also be entrained on boat exteriors, e.g., entangled on propellers and trailers, attached to other entangled organisms (Johnson et al. 2001). Thus, every time a boat is transported overland after use in an invaded waterway, there is the possibility that it will transfer AIS to uninvaded waterways.

Overland transport of small-craft boats is thought to be responsible for the spread of spiny waterflea (*Bythotrephes longimanus*; MacIsaac et al. 2004; Muirhead and MacIsaac 2005), Eurasian watermilfoil (*Myriophyllum spicatum*; Buchan and Padilla 2000), and zebra and quagga mussels (*Dreissena* spp.; Schneider et al. 1998; Leung et al. 2004; Stokstad 2007). These organisms are known to have considerable negative effects on the aquatic ecosystems they invade, with impacts including damages to fisheries (Vanderploeg et al. 2002; Mills et al. 2003; Marsden and Robillard 2004), interference with raw water usage (O'Neill 1996; Leung et al. 2002), decreased property values (Halstead et al. 2003), extirpation of native species (Nalepa et al. 1996; Strayer 1999), and threats to human health (Vanderploeg et al. 2001; Yule et al. 2006; Hogan et al. 2007). The recent invasion of the Great Lakes and inland lakes by Viral Hemorrhagic Septicemia (VHS, a fish virus; Lovell and Drake 2009) further emphasizes the potentially serious consequences of moving biological materials among waterways (Elsayed et al. 2006).

The Great Lakes region provides an opportunity to study how to better manage the risks of AIS spread by small-craft boaters. There are numerous aquatic resources in the region, including the Great Lakes themselves as well as abundant inland waterways. Moreover, recreational boating is an important driver of the regional economy (RMRC 2006). In the eight U.S. states bordering the Great Lakes, there are 4.2 million small-craft boats, nearly a third of all those currently in use in the United States (Thorp and Stone 2000). Likewise, in the Canadian provinces of Ontario and Quebec, there are over 2 million recreational boats (Thorp and Stone 2000).

The quality of the region's aquatic resources is threatened by AIS. For example, over 300 lakes in the region and multiple rivers have been invaded by zebra mussels, fouling water intakes of industrial facilities and reducing native biodiversity (Johnson et al. 2006). Eurasian watermilfoil, an invasive macrophyte that impairs navigation and recreation and displaces native macrophytes, is present in nearly 1,000 lakes in Michigan, Wisconsin, Illinois, and Indiana. The impacts of these and other species, combined with the importance of the resources they harm, have resulted in the region becoming a test bed for science and policy pertaining to the ecology and impacts of AIS. Thus, the stakeholders in the region tend to be generally aware of AIS issues and are concerned about reducing AIS impacts. In some cases, however, stakeholders lack empirical data about the spread of AIS by small-craft boaters and about the effectiveness of various techniques proposed to restrict spread. This lack of knowledge can limit the confidence of managers and the public that management interventions to limit spread of AIS are worthwhile.

Efforts to stem the spread of AIS via trailered boats in the Great Lakes region, as in most other regions, have focused on pre-launch boat inspections at uninvaded waterways and on campaigns to educate the public on actions that individuals can take to reduce the likelihood of transporting AIS. In contrast to pre-launch inspections sponsored by lake associations and government agencies, education campaigns emphasize boat inspection and cleaning when leaving a waterway. For example, regional campaigns such as the Clean Boats/Clean Waters programs of Wisconsin and Michigan (www.uwsp.edu/cnr/uwexlakes/cbcw/) and national programs such as Protect Your Waters (http://protectyourwaters.net) recommend the following actions for boaters to reduce their likelihood of transporting AIS: "(1) inspect and remove aquatic plants, animals, and mud from boat, trailer, and equipment before leaving the landing, (2) drain all water from boat, motor, live wells, bilge, bait buckets and other containers before leaving the landing, (3) ice your catch; don't leave landing with any live fish, bait, or fish eggs, (4) dispose of unused bait in trash, not in the water or on land, and (5) rinse boat and equipment with hot or high pressure water or dry boat for at least five days" (www.uwsp.edu/cnr/uwexlakes/cbcw/Pubs/AISprevention_steps.pdf). Regarding this fifth recommendation, some natural resource managers and private citizens advocate boat-washing stations on the public landings of waterways, contending that high-pressure washing is necessary to remove biological materials effectively.

Surprisingly, no rigorous scientific research is available on the efficacy of the main techniques advocated for removing organisms from trailered boats. Furthermore, few empirical efforts have quantified the types and numbers of organisms in transport. Moreover, data on boater compliance with the above-listed recommendations for preventing the spread of AIS are also lacking, and it is unknown if different sub-groups of boaters (e.g., recreational boaters, professional fishing guides) differ in their boat hygiene behaviors and, therefore, in their likelihood to transport organisms. A better understanding of these aspects of the trailered boat pathway is critical to improve policy and management intended to reduce the threat of additional invasions.

This report draws on data from an observational study, two surveys, and an experiment to reduce uncertainty in our understanding of the risks of AIS transport posed by the trailered boat pathway, and to examine efficacy of various cleaning techniques to remove organisms from the pathway. We estimate the number of organisms being transported by presenting data on the type and quantities of organisms collected from the external surfaces of boats and trailers. We document the steps boaters take to prevent AIS transport and how these behaviors may differ across sub-groups of boaters by surveying registered boaters by mail and in person. Finally, we experimentally test the efficacy of the three most common boat-cleaning methods (i.e., visual inspection and hand removal, low-pressure washing, and high-pressure washing) in removing organisms (i.e., macrophytes, zooplankton, and plant seeds) from the exterior surfaces of boats and trailers.

METHODS

Observational Study

We washed 85 boats arriving at (n = 36) and departing from (n = 49) two popular boat landings in the Northern Highlands Lake District of northern Wisconsin and the Upper Peninsula of Michigan (Big St. Germain Lake, Vilas County, Wisconsin [Latitude: 45.9344, Longitude: -89.5163] and Lake Gogebic, Gogebic County, Michigan [Latitude: 46.4999, Longitude: -89.5835]), between 26 August and 5 September 2006 to gather data on the types and quantities of aquatic organisms inadvertently transported by recreational boaters. We selected these landings because of their popularity and because the design of the boat launch allowed for convenient set up of our boat washing equipment. Invasive spiny waterfleas are present in Lake Gogebic, but no AIS likely to be inadvertently transported by recreational boaters are known to exist in Big St. Germain Lake. The size (e.g., number of parking spaces) and development (e.g., ramp construction material) of these landings are representative of typical inland lake public boat access sites in the Great Lakes region.

All arriving and departing boats were washed using a portable high-pressure wash and reclaim system, which was a modified version of a portable noxious weed removal system (WB500, Spika Manufacturing, Mocassin, Montana). This system, originally developed by the U.S. Forest Service to clean weed seeds and plant pathogens off vehicles and equipment used to fight wildfires (Trent et al. 2002), supplied the high-pressure wash (1800 psi) and the water filtration capabilities we desired. The wash water was captured on a waterproof mat and then pumped through a filtration and reclamation system, using a food-grade polyethylene filter (nominal pore size: 100 µm) that trapped materials removed from washed boats.

Although we washed a total of 85 boats, for logistical reasons, each filter collected the materials washed from 4 to 7 boats. The main reason for this pooling of samples was that boats tended to arrive at our washing station clustered together in time. Changing the filter in our washing unit took approximately 10 minutes. We estimate that at least one-half of the boats we washed would have bypassed our washing station because of their unwillingness to wait for filter changing. Because one of the main objectives of this aspect of our study was to obtain organisms from as many boats as possible, we chose to pool samples from multiple boats onto each filter. Thus, for the statistical analysis of this component of our research, the filter is the replicated unit of study. As filters were the replicated unit for this study, this gave us a sample size of 6 (filters) for arriving boats and 11 (filters) for departing boats. We used separate filters for departing versus arriving boats so that organisms originating from a lake could be distinguished from those arriving from elsewhere.

In the laboratory, we removed and weighed all material collected in the filters. We then subsampled the material from each sample (i.e., filter) by spreading it evenly over a flat-bottomed sorting tray divided into 12 equally-sized sectors. We used a random numbers table to select four sectors from which to collect material for detailed sorting and identification and enumeration of organisms and other biological materials. When drawing off material from a subsampled sector, we used an enclosed sectioning device with a foam bottom to form a watertight seal with the bottom of the tray to separate the sector from those adjacent to it and to prevent the inclusion in the subsample of any materials not in the chosen sector. We used information on the total wet mass of material collected in a filter (i.e., all collected material was weighed—not only that subsampled), the number of boats washed onto that filter, and the mean number of aquatic organisms in the four subsamples from each sample to calculate estimates of the quantity of biological materials moved over land on the exterior of recreational boats. Before the washing described above, each boat and trailer were inspected visually for vegetation fragments, all of which were removed, identified, and weighed. The visual inspection protocol followed the checkpoint guidelines given by the Wisconsin Clean Boats/Clean Waters program (www.uwsp.edu/cnr/uwexlakes/cbcw/handbook_forms/Check%20pts.pdf).

Mail Survey

We administered a mail survey in August 2005 to obtain data from a broad sample of small-craft boaters about their boat cleaning habits, particularly when moving their boat from one waterway to another. We mailed a total of 10,000 surveys to a random sample of registered boaters in Wisconsin and Michigan (i.e., 5,000 to each state), with the number of surveys sent to each county proportional to the number of registered boaters in each. We used the boater registration databases for the two states to select survey recipients.

For analysis, we combined the responses from both states. In the survey, we posed a number of questions about boaters' movement habits and other boating-related activities. Our main interests were how frequently boaters noticed and removed aquatic weeds attached to their boat and trailer, how regularly they cleaned their boat, what methods they used for boat cleaning, and how frequently they launched their boat in different lakes (Table 1).

In-person Northwoods Survey

We interviewed small-craft boaters in person to gather additional data on travel patterns and boat cleaning practices of boaters in the same region where we conducted our observational boat washing study. These interviews, conducted between 28 May and 15 August 2007, occurred at sites (e.g., lake association meetings, bait shops, campgrounds, and boat ramps) in several counties in and near the Northern Highlands Lake District of northern Wisconsin and the Upper Peninsula of Michigan, including Vilas and Oneida counties in Wisconsin and Iron, Gogebic, and Marquette counties in Michigan. We asked the same questions as those asked in the mail survey for these interviews (Table 1).

For the in-person survey, we interviewed two categories of boaters: general recreationalists (n = 424) and professional fishing guides (n = 35) to learn if these two categories of boaters had different movement patterns and boat hygiene practices that might affect their risk of spreading AIS.

Experiment

We performed two experiments to test the effects of cleaning method and duration on the removal of aquatic macrophytes (first experiment) and small-bodied animals and plant seeds (second experiment) from the exterior of recreational boats and trailers. In the macrophyte removal experiment, we used the invasive aquatic plant Eurasian watermilfoil as the test organism. In the

Table 1. Questions and responses from mail and in-person surveys are shown. Sample sizes are for the number of transient boaters (i.e., boaters that launch in more than one waterway during the season) that responded to the surveys.

Questions	Responses			
Before going from one lake or river to another, how often do you:	**Always**	**Sometimes**	**Never**	**Not applicable**
Clean your boat by rinsing, pressure washing, or drying?				
Mail (n = 396)	27%	34%	34%	5%
In-person: Guides (n = 35)	11%	75%	10%	4%
In-person: Recreational boaters (n = 135)	24%	42%	33%	13%
Notice weeds attached to your boat or trailer?				
Mail	9%	43%	40%	8%
In-person: Guides	11%	86%	0%	3%
In-person: Recreational boaters	42%	45%	9%	4%
Remove any aquatic weeds attached to your boat or trailer?				
Mail	57%	14%	13%	16%
In-person: Guides	96%	0%	0%	4%
In-person: Recreational boaters	87%	10%	1%	2%
If you trailer your boat among waterways, in how many different waterways have you launched your boat in the past two weeks? (mean ± SE)				
Mail	2.66 ± 0.14			
In-person: Guides	5.41 ± 0.80			
In-person: Recreational boaters	2.72 ± 0.42			

small-bodied organism experiment, our test organisms were the spiny waterflea, an invasive cladoceran, and the seeds of three species of wetland plants (*Alisma subcordatum*, *Verbena hastata*, and *Carex frankii*). The six cleaning treatments were identical in both experiments, and resulted from the factorial crossing of three levels of cleaning method with two levels of cleaning duration (90 seconds and 180 seconds). The three levels of cleaning method were: 40 pounds per square inch (psi) wash water pressure ("low pressure" hereafter), 1,800 psi wash water pressure ("high pressure" hereafter), and visual inspection of the boat and trailer accompanied by hand removal of organisms. We repeated both cleaning experiments seven times for each of the six treatments.

During each experiment, one person—the same individual for all replicates—placed a known quantity of biological materials (52–153 g of milfoil for the macrophyte experiment; 100 each of seeds of 3 wetland plant species and *Bythotrephes*) on a boat and its trailer, recording the placement locations of all materials. Milfoil was placed on and around the propeller, on the trailer bunks, and on other protruding parts of the boat and trailer where it could plausibly become attached. Small-bodied organisms were embedded in a water-based gel (L. A. Looks Mega-Hold hair styling gel, Henkel Consumer Goods, Inc., Irvine, CA), mimicking mud or foam that might stick to a boat or trailer, and the gel was adhered to the boat or trailer. The locations where biological materials were placed were selected randomly for each replicate. The same boat, a general-purpose 16-foot aluminum V-hull motorboat (1993 Fisher 1675 Plus, Springfield, Missouri), and single-axle steel trailer were used in all replicates.

A different person then cleaned the boat using the specified cleaning method (i.e., low-pressure wash, high-pressure wash, or visual inspection) and time treatment (i.e., 90 s or 180 s). We captured and filtered all water used in each washing replicate using the same portable wash and reclaim system used in the observational study described above. Finally, the person who had initially placed the materials on the boat and trailer recovered any items still attached.

To calculate percent removal for the macrophyte experiment, we divided the initial minus the final mass of *M. spicatum* on the boat by its initial mass. To measure removal rates for seeds and *Bythotrephes*, we enumerated the seeds and zooplankton captured in the filtration system for each replicate and divided this by the number of small-bodied organisms originally on the boat (i.e., 300). To determine statistical significance of differences in percent removal among treatments, we used a two-way ANOVA on the data from each experiment (i.e., macrophyte and small-bodied organisms), followed by a post-hoc Tukey HSD test for multiple comparisons.

RESULTS

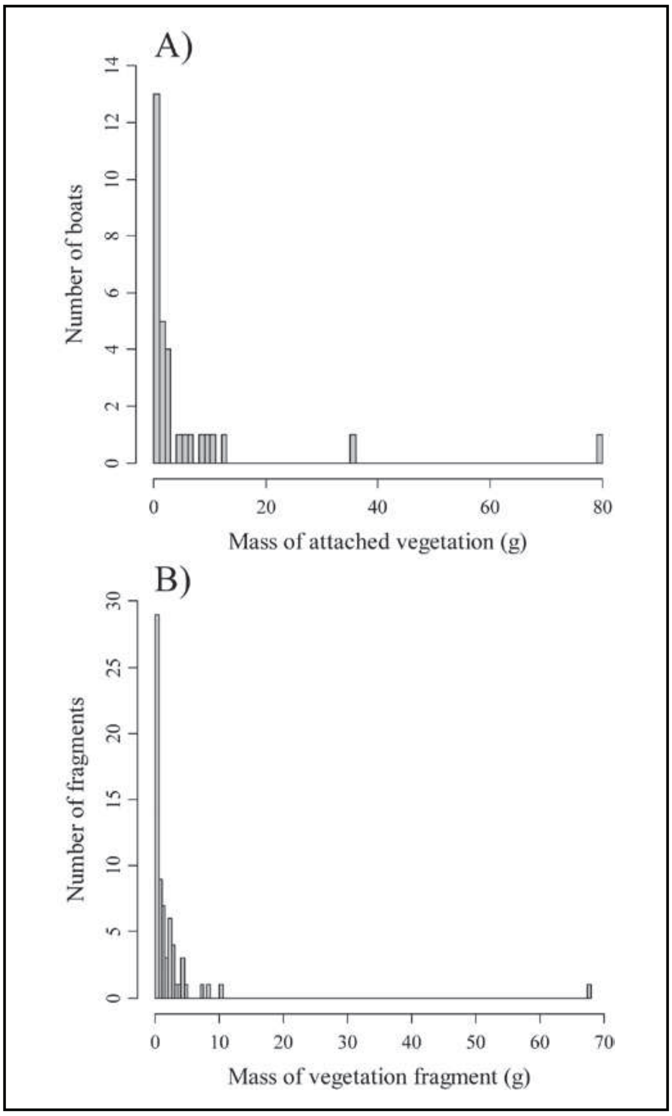
Observational Study

Of the 85 boats we inspected and washed during the observational study, 38 (45%) carried one or more plant fragments, but 30 of these had little material attached (i.e., < 5 g, Figure 1A). Boats and trailers leaving the lakes were three times more likely to be carrying vegetation than those arriving: 7 of 36 boats (19%) arriving at a lake had vegetation attached, whereas, 31 out of 49 boats (63%) leaving a lake had vegetation attached (Figure 2). The average biomass of macrophytes attached to a single boat and trailer was 6.4 ± 2.9 g (mean ± SE), with no statistically significant difference between boats leaving a lake and those arriving (Welch two-sample t-test: $t = -0.17$, $df = 20.96$, $P = 0.87$).

Of the 13 species of macrophytes collected from boats, none were invasive species (Table 2). We collected seven fragments of *Myriophyllum heterophyllum*, a native milfoil species that is morphologically similar to the invasive *M. spicatum*, a widespread nuisance species in North America. Most of the individual vegetation fragments we collected were very small, but some were quite large (Figure 1B).

We also collected 51 taxa of small-bodied organisms from the filter samples (Table 3), including 28 aquatic animals, among them amphipods, gastropods, and cladocerans. In our samples we found no AIS and no species known to be nonindigenous to the lakes where we worked. Among the aquatic organisms, 8 of the 18 orders we collected were crustaceans, including

Figure 1. Aquatic vegetation found attached to boats and trailers during field survey. Panel A is a histogram of the total mass of fragments on individual boats (bin width = 1 g). Panel B shows a histogram of the mass of individual vegetation fragments (bin width = 0.5 g).



zooplankton species (Table 3). Numerically, however, crustaceans, particularly zooplankton, were rarely encountered, with the exception of amphipods, which were abundant (Table 3). Aquatic insect larvae had lower taxonomic richness than crustaceans in our samples (4 of 18 orders encountered), but were numerically more common than the crustaceans. Midge larvae (Family: Chironomidae) were by far the most common aquatic organisms in our samples (Table 3). All three of the orders of mollusks we found in our samples were also relatively common numerically (Table 3). Most of the terrestrial organisms collected were either flying insects or tree seeds, primarily birch and elm (Table 3, Figure 2).

The average number of aquatic organisms transported on the boats and trailers we washed was 37.2. We cannot calculate the variability around this mean (e.g., standard error of the mean) because of the lost replicate identity that resulted from our pooling of multiple boats on to each filter and because of the uneven pooling of these samples (i.e., not every filter had the same number of boats washed on to it).

Mail Survey

A total of 515 boaters from Michigan and 429 from Wisconsin returned usable surveys. Some mailing addresses in the boater registration databases were outdated, resulting in 1,382 surveys returned as undeliverable. Thus, the response rate for the mail survey was 11% (i.e., 944/8,618). We did not conduct a non-response evaluation to determine the cause of this low response rate. More than half (58%) of the registered boaters responding to our survey reported that they kept their boat in the same waterway and therefore did not pose any risk of transporting AIS overland. The other 42% of respondents were transient boaters who launched their boat in multiple waterways during the boating season. For these boaters, the average number of different waterways in which they launched their boat in a two-week period was 2.66 ± 0.14 (mean ± SE). Of transient boaters, 27% said they always washed and/or dried their boat before launching it in a different waterway, 34% did this sometimes, and 34% never cleaned their boat (Table 1). For reasons unknown to us, the remaining 5% said that boat cleaning was not applicable to them.

The majority (57%) of transient boaters reported always removing aquatic weeds when noticed from their boats and trailers, but 14% said they did so only sometimes and 13% said they never removed aquatic weeds when they saw them (Table 1). The remaining 16% indicated that weed removal was not applicable to them, presumably because they never saw aquatic weeds attached to their boat or trailer. Thus, 68% of transient boaters did not always wash or dry their boat when moving it overland among waterways and 27% did not always remove aquatic weeds they saw attached to their boat and trailer.

In-person Northwoods Survey

Of the 508 individuals we approached for interviews, only 49 (46 recreationalists and 3 guides) declined to participate, giving a 90.4% response rate. Of the recreational boaters interviewed in person, most (68%) reported keeping their boat on a single lake for the entire season (e.g., spend summer camping by the only lake on which they launch their boats), and thus posed a low risk of spreading AIS. In our survey, a total of 135 recreational boaters (32%) reported using their boats at multiple lakes during the summer of 2007. When asked about AIS hygiene practices, 87% percent of recreational boaters reported always removing aquatic plants that they noticed attached to their boat or trailer, but 33% never pressure washed their boat or trailer (Table 1). In contrast to recreational boaters, professional fishing guides (n = 35 surveys) reported visiting nearly two times as many unique lakes in a two-week period (5.41 ± 0.80 vs. 2.72 ± 0.42 lakes, mean ± SE; Table 1). Furthermore, fishing guides were less likely than others to always clean their boats with washing and/or drying when moving between waterways (11% vs. 24%; Table 1). Fishing guides were also less likely to always notice aquatic weeds attached to their boats or trailers than recreational boaters (11% vs. 42%), but guides were more likely than others to always remove the weeds that they saw (96% vs. 87%; Table 1).

Experiment

High-pressure washing, and visual inspection combined with hand removal, removed a significantly greater percentage of

Figure 2. Average number and type of small-bodied organisms washed from recreational boats and trailers arriving at or departing from lakes in northern Wisconsin and the Upper Peninsula of Michigan. See Table 3 for further detail on taxa included in each taxonomic category.

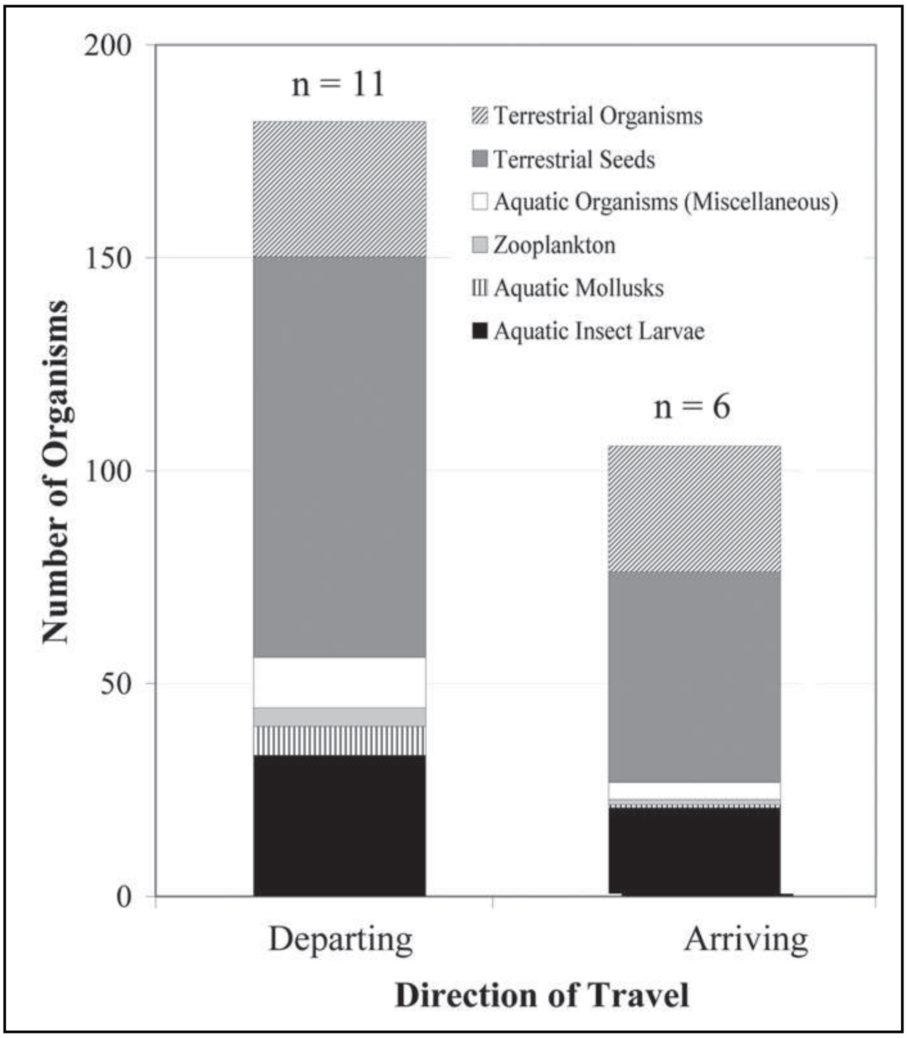


Table 2. Aquatic plant species and the respective number of fragments of each found on boats and trailers during observational field survey (sorted by frequency of occurrence).

Plant Species	# Fragments
Vallisneria americana	18
Potamogeton gramineus	9
Ceratophyllum demersum	8
Myriophyllum heterophyllum	7
Potamogeton pusillus	5
Potamogeton zosteriformis	5
Elodea canadensis	4
Najas sp.	4
Potamogeton richardsonii	2
Potamogeton robinsii	2
Zosterella dubia	2
Chara sp.	1
Potamogeton amplifolius	1

macrophyte vegetation than low-pressure washing ($F_{2, 36}$ = 21.1, P < 0.001; > 80% vs. ~63%; Figure 3A). High-pressure washing removed a significantly higher percentage of small-bodied organisms (i.e., wetland plant seeds and *Bythotrephes longimanus*) than did low-pressure washing or visual inspection plus hand removal ($F_{2, 36}$ = 15.4, P < 0.001; 90% vs. ~75%; Figure 3B). The duration of cleaning effort (90 vs. 180 s) did not significantly affect the percent removal of biological materials in either experiment (macrophytes: $F_{1, 36}$ = 0.81, P = 0.37; small-bodied organisms: $F_{1, 36}$ = 1.68, P = 0.20; Figure 3). There was also no significant interaction between cleaning method and duration of effort in either experiment (macrophytes: $F_{2, 36}$ = 0.30, P = 0.74; small-bodied organisms: $F_{2, 36}$ = 0.26, P = 0.77; Figure 3).

DISCUSSION

Widespread recognition that overland movements of boats are often responsible for spreading invasive plants (Buchan and Padilla 2000; Puth and Post 2005) and animals (Johnson et al. 2001; Muirhead and MacIsaac 2005; Keller and Lodge 2007) has prompted increased management concern. To date, however, management actions have largely focused on mitigating the impacts of these AIS through control and eradication efforts once they are already established in a body of water and inflicting harm (Simberloff et al. 2005; Lovell et al. 2006). Prevention efforts have been rarer, and most have concentrated on attempting to educate boaters about how individuals can reduce their likelihood of being a vector (www.uwsp.edu/cnr/uwexlakes/CBCW/). There are, however, no published studies that rigorously quantify the effectiveness of such education efforts in slowing the spread of AIS. Management actions specifically aimed at removing AIS from transportation pathways, such as recreational boats and trailers, may be a complementary and efficient way to reduce their spread (Lodge et al. 2006; Drury and Rothlisberger 2008).

Effectively managing the risk of AIS spread by small-craft boaters requires increased knowledge about what organisms are being transported, who is transporting organisms (i.e., how various sub-groups of boaters differ relative to their risk of transporting organisms), how often organisms are being transported, and how effectively various boat cleaning alternatives remove potentially harmful organisms from the pathway. Recent research efforts with implications for such decision-making have focused on predicting AIS spread based on network models of boater traffic among lakes (Leung et al. 2004, 2006; Drury and Rothlisberger 2008). For example, Drury and Rothlisberger (2008) demonstrated that for a wide range of hypothetical cleaning efficiencies (i.e., percentage of organisms removed through cleaning of boats and trailers) placing a given number of inspection and cleaning stations at invaded lakes slows landscape-level spread of AIS more effectively than placing the same number of stations at uninvaded lakes. Implicit in this and similar modeling efforts, however, are assumptions about the types and quantities of organisms being transported and about the ability of cleaning efforts to remove them from boats and trailers. This study provides some of the empirical data that was previously lacking, including the types of organisms boaters in the Upper Midwestern United States transport, the quantity of organ-

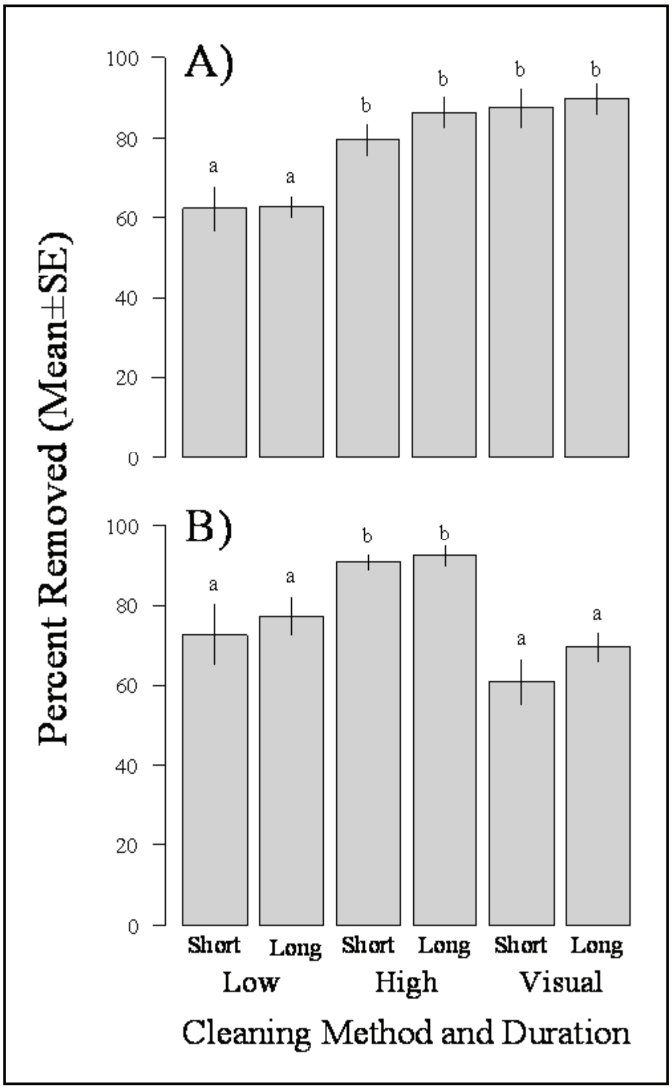
Table 3. Aquatic and terrestrial taxa collected in filters during the field survey. Taxa are identified variously to order, family, or genus.

Category	Order	Suborder	Family	Genus	Instar	Common Name	Total number collected from 85 boats washed (estimated from sub-samples)
Aquatic (Miscellaneous)	Amphipoda				Adult	Amphipod	209
	Isopoda				Adult	Isopod	3
	Oligochaete				Adult	Freshwater segmented worm	3
	Ostracoda				Adult	Ostracod	3
	Prostigmata				Adult	Water mite	206
Aquatic insect larvae	Diptera		Tipulidae		Larval	Cranefly	56
	Diptera		Chironomidae		Larval	Midge	740
	Diptera		Cuculidae		Larval	Mosquito	1
	Ephemeroptera		Baetidae		Larval	Baetid mayfly	18
	Ephemeroptera				Larval	Other mayfly	65
	Odonata	Zygoptera			Larval	Damselfly	18
	Odonata	Anisoptera			Larval	Dragonfly	89
	Trichoptera		Hydropsychidae		Larval	Caseless caddisfly	24
	Trichoptera		Leptoceridae		Larval	Leptocerid caddisfly	18
	Trichoptera				Larval	Other caddisfly	50
Aquatic mollusks	Mesogastropoda		Viviparidae	*Campeloma*	Adult	Campelomid snail	191
	Pulmonata		Planorbidae		Adult	Planorbid snail	18
	Pulmonata		Physidae	*Physa*	Adult	Physid snail	228
	Sorbeoconcha		Hydrobiidae	*Amnicola*	Adult	*Amnicola* snail	314
Zooplankton	Calanoida				Adult	Calanoid copepod	6
	Cladocera		Bosminidae	*Bosmina*	Adult	Waterflea	27
	Cladocera		Daphniidae	*Daphnia*	Adult	Waterflea	12
	Cladocera		Sididae	*Diaphanasoma*	Adult	Waterflea	27
	Cladocera				Adult	Waterflea	1
	Cyclopoida				Adult	Cyclopoid copepod	6
	Phylum: Rotifera				Adult	Rotifer	6
	Subclass: Copepoda				Larval	Copepod nauplius	3
	Subclass: Copepoda				Adult	Copepod	6
Terrestrial (Miscellaneous)	Araneae				Adult	Spider	205
	Coleoptera				Adult	Beetle	53
	Coleoptera				Larval	Beetle	62
	Collembola				Adult	Springtail	51
	Diptera				Adult	Other dipteran	153
	Diptera		Drosophilidae	*Drosophila*	Adult	Fruit fly	6
	Diptera		Ceratopogonidae		Adult	Gnat	285
	Diptera		Muscidae		Adult	Housefly	123
	Diptera		Chironomidae		Adult	Midge	695
	Diptera		Cuculidae		Adult	Mosquito	458
	Diptera		Ichneumondiae		Adult	Ichneumonid wasp	200
	Ephemeroptera				Adult	Mayfly	3
	Homoptera		Aphididae		Adult	Aphid	6
	Homoptera		Cicadelliae		Adult	Leafhopper	17
	Homoptera				Adult	True Bug	14
	Hymenoptera		Formicidae		Adult	Flying ant	117
	Hymenoptera		Formicidae		Adult	Ant	342
	Hymenoptera		Halictidae		Adult	Sweat bee	6
	Ixodida				Adult	Tick	294
	Lepidoptera				Larval	Catepillar	3
	Trichoptera				Adult	Caddisfly	9
Terrestrial seeds	Fagales		Betulaceae	*Betula*	Seed	Birch tree seed	2,931
	Rosales		Ulmaceae	*Ulmus*	Seed	Elm tree seed	3,596

isms boaters transport, and the effectiveness of various boat cleaning techniques. Our hope is that these data will inform improved risk management of AIS spread.

We found that organisms that are evolutionarily and morphologically similar to AIS in the Great Lakes region (e.g., Eurasian watermilfoil, spiny waterflea, and *Echinogammarus ischnus*) are being transported on small-craft boats and trailers (Table 4). Because we did not specifically target lakes known to have multiple invaders (only one of the two study lakes was known to harbor one invasive species—spiny waterflea), it was not surprising that we did not sample any animal or plant AIS. We did however sample several taxa similar to invaders known to be spreading in the region, e.g., spiny water flea and New Zealand mud snail, including the cladoceran *Diaphanosoma* spp. and several types of aquatic gastropods (e.g., hydrobids and physids). We also collected amphipods in our filter samples, suggesting that the non-native amphiphod *Echinogammarus ischnus* that is currently in the Great Lakes could be spread to inland lakes by boaters.

Figure 3. Results of experimental removal of biological materials from boat and trailer via boat washing or visual inspection. Panel A shows removal of *Myriophyllum spicatum* with different wash pressures and durations, and with visual inspection and hand-removal. Panel B shows data from the same treatments for the removal of small-bodied organisms.



Similarly, no invasive macrophyte species were collected from boats during our field survey, but the species we collected were representative of common aquatic vegetation communities in Northwoods lakes (e.g., *Vallisneria americana, Potamogeton gramineus*, and *Ceratophyllum demersum;* Wagner et al. 2007). As with small-bodied AIS, we would have been surprised to collect any invasive macrophytes, such as *M. spicatum*, in our samples, because the lakes where we washed boats were not known to contain invasive macrophytes. This expectation applied also to arriving boaters, because none of the nearby lakes (i.e., within 15 mile radius) had invasive macrophyte populations that were not under chemical control. If we had been working on a lake with a population of *M. spicatum*, it is highly likely that we would have found milfoil on boats, perhaps in even greater quantities than the native vegetation we found, given the tendency of *M. spicatum* to form dense mats of vegetation on the water's surface, enabling entanglement on boats (Smith and Barko 1990). Nevertheless, the native vegetation we found on boats is a useful surrogate for demonstrating the propensity of small craft to transport aquatic vegetation over land.

Despite many years of campaigns to educate boaters on how to avoid transporting organisms, our results demonstrate that overland transport of aquatic organisms by boaters still occurs frequently. If relatively diffuse educational campaigns stimulated boaters to take responsibility for their own boat hygiene, it would be a relatively inexpensive way to save the public the expense of equipment and employees required to clean boats. However, our data on self-reported cleaning rates and our observations of organisms attached to boats and trailers suggest that existing and previous education campaigns have not resulted in consistently high cleaning rates by boaters or in the use of highly effective cleaning practices in the Great Lakes region.

In Michigan and Wisconsin, states where educational efforts have been among the most vigorous in the United States, more than two-thirds of the boaters who responded to our surveys via mail and in-person do not always clean their boat when moving to another waterway, and more than a quarter of mail survey respondents reported not always removing aquatic weeds when they see them attached to their boat or trailer. This is not highly surprising in that social marketing research indicates that rates of behavioral change are relatively low in cases where compliance benefits society, but the individual who is being asked to take action receives little or no immediate benefit or gratification, particularly when the desired action is inconvenient to the individual (McKenzie-Mohr 2000). As this is the situation with boat cleaning, it is likely that to achieve high compliance rates educational efforts will need to be augmented with staffed cleaning stations placed at strategic locations and, possibly, enforcement and disincentives for non-compliance (i.e., fines). Two U.S. states in the Great Lakes region have already enacted laws making it illegal to launch a boat if there are potentially invasive aquatic species attached to the boat, trailer, or other equipment (Wisconsin Act 16, Section 30.715; Minnesota Statute 84D). Enforcement of these laws, however, remains a challenge and the strategic deployment of boat cleaning and inspection stations could be an efficient way to help increase compliance substantially. Our findings suggest that educational campaigns should continue to emphasize inspecting and cleaning boats and trailers when departing from a waterway and that cleaning stations and inspection crews should be deployed at sites where AIS are known to be present.

Our experimental results can help guide decisions about the kind of inspections and boat cleaning that may be most appropriate to a given situation. Understanding species' characteristics that affect their removal rates from boats and trailers is an important factor in selecting effective cleaning techniques. We found that transport of high-risk macrophytes can be prevented with a high probability through visual inspection and hand removal. However, visual inspection failed to detect small-bodied organisms, seeds, and resting stages of other species. Examples of small-bodied organisms in the Great Lakes region include the spiny and fish-hook waterfleas, *Bythotrephes longimanus* and *Cercopagis pengoi*, respectively, or even smaller, the deadly fish pathogen VHSv. If the spread of such small biological materials and organisms is a concern, visual inspection will not provide detection and removal with high probability. Alternatively, high-pressure washing can remove over 90% of small-bodied organisms, making it the most effective option we examined for preventing the transport of small organisms. The failure of visual inspection to detect a high percentage of small-bodied organisms is not surprising, but it is troubling because visual inspection of incoming boats and trailers is the most common type of government-sponsored or volunteer-organized intervention employed at boat ramps in the Great Lakes region (i.e., boat washing facilities are currently rare). During our field inspections of boats, we observed that, aside from the discovery of macrophytes, it was rare to find clear visual clues that small-bodied organisms might be attached to a boat or trailer (e.g., mud or foam deposits). Thus, it is unlikely that visual inspections under field conditions will discover and prompt removal of small-bodied organisms at a rate any higher than the ~63% rate in our experimental trials.

A limitation of our study that may have contributed to an overestimate of the effectiveness of all boat hygiene methods was our focus on techniques to clean only boat hulls and trailers. We did not sample the interior surfaces or standing water in boats. These surfaces and water reservoirs include carpets, live wells, bait buckets, and bilge water, all of which probably harbor AIS, especially small-bodied organisms. In fact, spiny waterflea have been found in bilge water samples (J. Muirhead, University of Alberta, pers. comm.). The release of bilge and live well water from lakes infected with VHSv into uninfected lakes may be a key vector in the spread of this deadly fish pathogen (Wisconsin Natural Resources Rule FH-40-07(E)). The prevalence of transport of VHSv and other pathogens in water held in boats merits further investigation, as does the effectiveness of washing in removing pathogens from the exterior and interior of boats. Additionally, in our experiment, we used only one model of boat and trailer. Boats and trailers vary in how difficult they are to clean, so our percent removal rates for given levels of effort do not necessarily represent what the removal rates would be for all boats and trailers. That said, our boat and trailer set up was relatively simple and would be in the lower range of cleaning difficulty. Thus, the percent removal rates we report are likely in the upper range of what can be achieved for the levels of cleaning effort we applied.

Efficient risk management of the spread of AIS by small-craft boaters requires determining if any sub-groups of boaters pose a disproportionately greater risk of transporting organisms among waterways. Our surveys indicated the existence of three different categories of boaters, for which management attention might appropriately differ. First, the majority of boaters (mail survey: 58%, in-person survey: 68%) keep their boat on the same body of water during the entire boating season and, therefore, pose a minimal threat for the overland spread of AIS. Second, in both the mail and in-person surveys, transient boaters reported visiting approximately three different waterways during a two-week period of the boating season, indicating a higher probability of AIS spread. Third, the professional fishing guides we surveyed reported visiting an average of more than five different waterways every two weeks. These data suggest that fishing guides pose the greatest risk of AIS spread, especially because they did not employ effective boater hygiene practices at a higher rate than other boaters. Focused efforts to ensure the inspection and cleaning of these most frequently moving boats—which may be analogous to superspreader individuals, i.e., individuals with many topological connections on the transmission network, in the human disease context (Riley 2007)—would likely pay high dividends in slowing AIS spread.

Our findings lead to two major management recommendations to slow the spread of AIS from the Great Lakes to inland waterways and among inland waterways in the region. First, we suggest increased management attention to identify and communicate with high-risk boaters. Such outreach would require more targeted efforts than the broad educational campaigns that have been employed previ-

Table 4. Nonindigenous species established in the Great Lakes that are morphologically similar to species collected in boat washing samples are listed. Species in bold are recognized as potentially important invaders.

Morphological category/ description	Selected nonindigenous taxa in Great Lakes	Representative taxa collected in boat washing samples
Plankton	***Bythotrephes longimanus* (spiny waterflea), *Cercopagis pengoi* (fish-hook waterflea),** *Daphnia galeata galeata*, *Daphnia lumholtzi, Eubosmina coregoni, Eubosmina maritime*, Copepods (5 spp.), Diatoms (17 spp.), Green alga (4 spp.)	*Bosmina* spp., *Daphnia* spp., *Diaphanasoma* spp., Rotifers, Copepods
Small benthic crustaceans and macroinvertebrates	***Echinogammarus ischnus, Hemimysis anomala* (bloody-red shrimp),** *Gammarus tigrinus*	Amphipoda, Isopoda,
Small benthic mollusks	***Potamopyrgus antipodarum* (New Zealand mud snail), *Dreissena polymorpha* (zebra mussel), Dreissena *rostriformis bugensis* (quagga mussel), *Corbicula fluminea* (Asiatic clam),** *Viviparus georgianus, Valvata piscinalis, Bithynia tentaculata, Sphaerium corneum, Pisidium henslowanum, Pisidium supinum, Cipangopaludina chinensis malleata, Pisidium amnicum, Pisidium moitessierianum, Elimia virginica, Gillia altilis*	*Campeloma* spp., *Physa* spp., *Amnicola* spp.
Other benthic organisms	Oligochaetes (6 spp.: *Branchiura sowerbyi, Gianius aquaedulcis, Potamothrix bedoti, Potamothrix moldaviensis, Potamothrix vejdovskyi, Ripistes parasita*)	Oligochaetes
Macrophytes	***Potamogeton crispus* (curlyleaf pondweed), *Myriophyllum spicatum* (Eurasian waterfoil),** *Hydrocharis morsus-ranae* (European frogbit), *Cabomba caroliniana* (fanwort)	*Vallisneria americana*, *Potamogeton* spp., *Ceratophyllum demersum*, *Myriophyllum heterophyllum*

Visual inspections of boats, motors, and trailers as they leave infested sites are important for slowing the spread of aquatic invasive plants.

ously. Our survey data suggest that professional fishing guides are one sub-group of small-craft boaters that move among waterways with extraordinary frequency and who currently employ less-than-ideal boat cleaning practices.

Second, we suggest that managers develop and use knowledge of the geographic location of invasive species within a region to inform efforts to manage the risk of future spread. Indeed, landscape-level approaches are increasingly recognized as highly important for effective management of natural resources, particularly aquatic ones (Post et al. 2008; Drury and Rothlisberger 2008; Vander Zanden and Olden 2008). For example, our experimental results suggest that knowing which lakes contain small-bodied AIS versus which contain only invasive macrophytes could guide the type of boat cleaning strategy employed to keep organisms from being transported away from already invaded lakes. In the Great Lakes region there are particular locations where high-pressure washing would be most useful. Such sites include (1) high-traffic boat landings on the Great Lakes (e.g., landings near major cities such as Green Bay, Cleveland, Chicago, and Toronto) which contain numerous small-bodied AIS (e.g., *Bythotrephes*, *Hemimysis*), (2) inland waterways currently invaded with spiny waterflea (e.g., Lake Gogebic, Michigan; Gile Flowage, Wisconsin), and (3) waterways where VHSv is known to occur (e.g., Lake Winnebago, Wisconsin). Inland waterways that harbor only invasive macrophytes could be effectively managed with visual inspection and hand removal of plants at boat landings.

ACKNOWLEDGEMENTS

We thank Mark Fedora, Nick Schmal, and Mike Ielmini of the U.S. Forest Service for their help in organizing this project. Sheilah Kennedy and Jeff and Richard Delfeld of SK-Environmental (Okanogan, Washington) furnished the portable wash-reclaim system and gave essential technical support and field assistance. Ted Ritter, AIS coordinator for Vilas County, Wisconsin, provided invaluable logistical and field support. Special thanks are due to Jody Peters for help identifying macrophytes and to Kevin Pangle for supplying *Bythotrephes* for our experiments. Elizabeth D. Tucker helped to design the mail survey. Reuben Keller's help was crucial to the successful implementation of the in-person surveys. We are grateful to Brandon Feasel and Neil Wallace for personally interviewing scores of boaters and to Matt Barnes, Mike McCann, Sarah Sutton, and Tim Campbell for their tireless laboratory work. Funding from the National Science Foundation for the ISIS project (DEB 02-13698 to DML), the Great Lakes Protection Fund (Grant #797 to DML), and a University of Notre Dame Schmitt Fellowship (to JDR) made this work possible.

High-pressure washing of boats and trailers is a highly effective way to remove small-bodied organisms, but is no more effective than visual inspection and hand removal of aquatic plants.

REFERENCES

Bossenbroek, J. M., C. E. Kraft, and **J. C. Nekola.** 2001. Prediction of long-distance dispersal using gravity models: zebra mussel invasion of inland lakes. Ecological Applications 11:1778-1788.

Buchan, L. A. J., and **D. K. Padilla.** 2000. Predicting the likelihood of Eurasian watermilfoil presence in lakes, a macrophyte monitoring tool. Ecological Applications 10:1442-1455.

Drury, K. L. S., and **J. D. Rothlisberger.** 2008. Offense and defense in landscape-level invasion control. Oikos 117:182-190.

Elsayed, E., M. Faisal, M. Thomas, G. Whelan, W. Batts, and **J. Winton.** 2006. Isolation of viral haemorrhagic septicaemia virus from muskellunge, *Esox masquinongy* (Mitchill), in Lake St. Clair, Michigan, USA reveals a new sublineage of the North American genotype. Journal of Fish Diseases 29:611-619.

Halstead, J. M., J. Michaud, S. Hallas-Burt, and **J. P. Gibbs.** 2003. Hedonic analysis of effects of a nonnative invader (*Myriophyllum heterophyllum*) on New Hampshire (USA) lakefront properties. Environmental Management 32:391-398.

Hogan, L. S., E. Marschall, C. Folt, and **R. A. Stein.** 2007. How non-native species in Lake Erie influence trophic transfer of mercury and lead to top predators. Journal of Great Lakes Research 33:46-61.

Johnson, L. E., A. Ricciardi, and **J. T. Carlton.** 2001. Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. Ecological Applications 11:1789-1799.

Johnson, L. E., J. M. Bossenbroek, and **C. E. Kraft.** 2006. Patterns and pathways in the post-establishment spread of non-indigenous aquatic species: the slowing invasion of North American inland lakes by the zebra mussel. Biological Invasions 8:475-489.

Keller, R. P., A. N. Cox, C. Van Loon, D. M. Lodge, L.-M. Herborg, and **J. Rothlisberger.** 2007. From bait shops to the forest floor: earthworm use and disposal by anglers. American Midland Naturalist 158:321-328.

Keller, R. P., and **D. M. Lodge.** 2007. Species invasions from commerce in live aquatic organisms: problems and possible solutions. Bioscience 57:428-436.

Leung, B., J. M. Bossenbroek, and **D. M. Lodge.** 2006. Boats, pathways, and aquatic biological invasions: estimating dispersal potential with gravity models. Biological Invasions 8:241-254.

Leung, B., J. M. Drake, and **D. M. Lodge.** 2004. Predicting invasions: propagule pressure and the gravity of allee effects. Ecology 85:1651-1660.

Leung, B., D. M. Lodge, D. Finnoff, J. F. Shogren, M. A. Lewis, and **G. Lamberti.** 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London Series B-Biological Sciences 269:2407-2413.

Lodge, D. M., S. Williams, H. J. MacIsaac, K. R. Hayes, B. Leung, S. H. Reichard, R. N. Mack, P. B. Moyle, M. Smith, D. A. Andow, J. T. Carlton, and **A. McMichael.** 2006. Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16:2035-2054.

Lovell, S. J., and **L. A. Drake.** 2009. Tiny stowaways: analyzing the economic benefits of a U.S. Environmental Protection Agency permit regulating ballast water discharges. Environmental Management 43:546-555.

Lovell, S. J., S. F. Stone, and **L. Fernandez.** 2006. The economic impacts of aquatic invasive species: a review of the literature. Agricultural and Resource Economics Review 35:195-208.

MacIsaac, H. J., J. V. M. Borbely, J. R. Muirhead, and **P. A. Graniero.** 2004. Backcasting and forecasting biological invasions of inland lakes. Ecological Applications 14:773-783.

Marsden, J. E., and **S. R. Robillard.** 2004. Decline of yellow perch in southwestern Lake Michigan, 1987-1997. North American Journal of Fisheries Management 24:952-966.

McKenzie-Mohr, D. 2000. Promoting sustainable behavior: an introduction to community-based social marketing. Journal of Social Issues 56:543-554.

Mills, E. L., J. M. Casselman, R. Dermott, J. D. Fitzsimons, G. Gal, K. T. Holeck, J. A. Hoyle, O. E. Johannsson, B. F. Lantry, J. C. Makarewicz, E. S. Millard, I. F. Munawar, M. Munawar, R. O'Gorman, R. W. Owens, L. G. Rudstam, T. Schaner, and **T. J. Stewart.** 2003. Lake Ontario: food web dynamics in a changing ecosystem (1970-2000). Canadian Journal of Fisheries and Aquatic Sciences 60:471-490.

Muirhead, J. R., and **H. J. MacIsaac.** 2005. Development of inland lakes as hubs in an invasion network. Journal of Applied Ecology 42:80-90.

Nalepa, T. F., D. J. Hartson, G. W. Gostenik, D. L. Fanslow, and **G. A. Lang.** 1996. Changes in the freshwater mussel community of Lake St Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great Lakes Research 22:354-369.

O'Neill, C. R., Jr. 1996. National zebra mussel information clearinghouse infrastructure economic impact survey: 1995. Dreissena! 7:1-5, 1-12.

Post, J. R., L. Persson, E. A. Parkinson, and **T. van Kooten.** 2008. Angler numerical response across landscapes and the collapse of freshwater fisheries. Ecological Applications 18:1038-1049.

Puth, L. M., and **D. M. Post.** 2005. Studying invasion: have we missed the boat? Ecology Letters 8:715-721.

RMRC (Recreational Marine Research Center). 2006. Recreational boating statistical abstract 2005. National Marine Manufacturers Association, Chicago, Illinois.

Riley, S. 2007. Large-scale spatial-transmission models of infectious disease. Science 316:1298-1301.

Schneider, D. W., C. D. Ellis, and **K. S. Cummings.** 1998. A transportation model assessment of the risk to native mussel communities from zebra mussel spread. Conservation Biology 12:788-800.

Simberloff, D., I. M. Parker, and **P. N. Windle.** 2005. Introduced species policy, management, and future research needs. Frontiers in Ecology and the Environment 3:12-20.

Smith, C. S., and **J. W. Barko.** 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management 28:55-64.

Stokstad, E. 2007. Feared quagga mussel turns up in western United States. Science 315:453-453.

Strayer, D. L. 1999. Effects of alien species on freshwater mollusks in North America. Journal of the North American Benthological Society 18:74-98.

Thorp, S., and J. Stone. 2000. Recreational boating and the Great Lakes–St. Lawrence Region. Great Lakes Commission, Ann Arbor, Michigan.

Trent, A., D. Karsky, and **S. Gilmour.** 2002. MTDC portable vehicle washer: interim report. 0234-2836-MTDC, USDA Forest Service Technology and Development Program, Missoula, Montana.

Vander Zanden, M. J., and **J. D. Olden.** 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences 65:1512-1522.

Vanderploeg, H. A., J. R. Liebig, W. W. Carmichael, M. A. Agy, T. H. Johengen, G. F. Fahnenstiel, and **T. F. Nalepa.** 2001. Zebra mussel (*Dreissena polymorpha*) selective filtration promoted toxic *Microcystis* blooms in Saginaw Bay (Lake Huron) and Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 58:1208-1221.

Vanderploeg, H. A., T. F. Nalepa, D. J. Jude, E. L. Mills, K. T. Holeck, J. R. Liebig, I. A. Grigorovich, and **H. Ojaveer.** 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Wagner, K. I., J. Hauxwell, P. W. Rasmussen, F. Koshere, P. Toshner, K. Aron, D. R. Helsel, S. Toshner, S. Provost, M. Gansberg, J. Masterson, and **S. Warwick.** 2007. Whole-lake herbicide treatments for Eurasian watermilfoil in four Wisconsin lakes: effects on vegetation and water clarity. Lake and Reservoir Management 23:83-94.

Yule, A. M., J. W. Austin, I. K. Barker, B. Cadieux, and **R. D. Moccia.** 2006. Persistence of *Clostridium botulinum* neurotoxin type E in tissues from selected freshwater fish species: implications to public health. Journal of Food Protection 69:1164-1167.