Pressure washer use in the control of aquatic invasive non-native species

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Introduction

Invasive non-native species (INNS) are considered to be the second greatest threat to global biodiversity second only to habitat loss and destruction (Mack et al. 2000). Freshwater systems are particularly vulnerable to the introduction of INNS due to their exposure to multiple potential pathways of introduction of new species, which can make control difficult to implement. Freshwater ecosystems are already impacted by pollution, agricultural run-off and altered hydrology (Strayer 2010), potentially making them more vulnerable to invasion.

It is considered that fishing, boating and leisure activities are collectively responsible for almost 40% of aquatic species introductions into Europe (Gallardo & Aldridge 2013). These include the release of boat ballast water and the stocking and subsequent escape of non-native fish or crustaceans introduced for aquaculture or sport. However, they also include the accidental transfer of INNS "hitchhiking" on equipment used during recreational activities, such as boats, cars, trailer, waders, wet suits and fishing equipment (Ludwig & Leitch 1996; Buchan & Padilla 1999; Johnson, Ricciardi & Carlton 2001; Gates *et al.* 2008; Stebbing, Sebire & Lyons 2011; Stasko et al. 2012; Bacela-Spychalska et al. 2013). Such accidental transfer is thought to have been responsible for new introduction and spread of species, such as the introduction of the killer shrimp, *Dikerogammarus villosus* into the UK (Johnson et al. 2001; Bothwell et al. 2009; Kilian et al. 2012).

To try and improve bio-security amongst stakeholders in the freshwater environment Defra launched the Check, Clean, Dry campaign in 2010. However, specific advice on how participants should undertake cleaning of equipment is needed. It is important that any cleaning treatment recommended to UK water users is easy and economical for people to source, requires no specific training or protective equipment to use and has no impact on the environment when disposed (potentially in large volumes) (Kilroy et al. 2006). Moreover, the recommended cleaning treatment needs to be effective at killing a wide range of aquatic INNS. Targeted species prevention, for example by focusing on species transmission choke points, has been found to be more effective than non-targeted prevention. The point at which water users leave a water body known to contain INNS is an ideal location to implement controls to prevent further spread.

In recognising the threat posed by recreational activities in the spread of INNS the United States the Clean Boating Act (CBA) was passed by congress in 2008. Within the context of the CBA recreational vessels includes canoes, kayaks, motor boats, personal watercraft (such as jet skis), yachts and sailboats. Another important element of the CBA is that it not only applies to inland waters, but also coastal water (up to 12 miles from the shore). While the CBA regulates discharge from recreational vessels of known pollutants such as hull anti-fouling and sewage, it also covers the accidental transfer of INNS. This has provided the USA with a legal framework by which the cleaning of recreational vessels can be enforced.

Thermal control (i.e. the use of heat in the control of INNS) is considered to be one of the most efficient, environmentally sound and cost effective methods by which to prevent the accidental spread of aquatic INNS (O'Neill & MacNeill 1991; Beyer, Moy & Stasio 2010; Stebbing et al. 2011; Perepelizin & Boltovskoy 2011). Several studies have demonstrated the potential effectiveness of thermal control across a range of taxonomic groups. In addition to *D.villosus*, Beyer et al. (2010) found that hot water can also cause 100% mortality in zebra mussels (*Dreissena polymorpha*), quagga mussels (*Dreissena rostriformis*) and spiny water fleas (*Bythotrphes longimanus*). It has also been found as effective against the invasive algae *Didymo germinata* (Kilroy et al. 2006). A study conducted by Cefas (Stebbing et al. 2011) indicated that submersion in hot water at 45˚C was sufficient to cause 100% mortality in the killer shrimp (*Dikerogammarus villosus*) in a matter of seconds. This finding has since been adopted as the biosecurity advice given to water users by the Norfolk Broads Authority (Broads Authority 2013). Additional work under taken by Cefas in collaboration with Leeds and York Universities has demonstrated the effectiveness of thermal control on a range of INNS for the UK. This work provides further evidence on the generic effectiveness of thermal control.

Establishing upper temperature limits for target species is important to determine the potential efficacy of thermal control. Providing advice to stakeholders for methods by which thermal control can be applied is of equal importance to ensure application in an appropriate and effective manner. The application of thermal control to personal equipment is relatively straight forward (i.e. submersion or rinsing in hot water >45°C for 15 minutes) in comparison to the treatment of larger, more complex objects such as boats, boat motors, trailers and vehicles. This report aims to provide some further insight into how larger items of equipment that are difficult to submerge can be cleaned to prevent INNS translocation. Globally there has been an increasing amount of advice on bio-security recommending the use of pressure washing (see Ward et al. 2012 for review) for the

control of INNS. This report therefore focuses primarily on the use of pressure washers in combating INNS.

Washer types and design

The principle of a pressure washer is that water enters the machine and is put under pressure by an integral pump. The pressurised water is then expelled at force. The force of the water is determined by the pressure exerted and the size of the outlet. In a hot water pressure washer there is the addition of a heat exchanger to raise the temperature of the water to aid in the cleaning process. In a steam pressure washer the water pressure is reduced but the heat exchanger in kept working as normal. This results in a higher water temperature creating steam. The temperature of the steam would be around 140°C, this is called wet steam because of the high water content. Some pressure washers with particularly effective heat exchangers, heat water up to 170°C, and produce dry steam, with low (5%) water content.

There are a myriad of different washer types and designs available to fit different cleaning purposes and needs from infrequent domestic use to frequent industrial usage. These will range from; units designed for cleaning flat surfaces such as floors; small hand held units; static units found on petrol station forecourts; units that are mobile with built in power supplies for remote use; and those used for industrial cleaning of power stations. Given the broad range of units there will be one available for any scenario in which pressure washers a likely to be deployed in the control of INNS. However, pressure washers do require three main components for use: 1) water supply 2) power supply and 3) a suitable surface on which the item to be cleaned, and the pressure washer, can be placed.

The majority of pressure washers come in a common gun trigger format normally housed in a lance. The lance is a long rigid structure at the end of a hose which has a trigger for water delivery and houses the nozzle. Longer lances allow extended coverage and are safer as the operator is a distance from the steam/water delivery. Lances can also be angled (straight, 22°, 45°, 90°) to clean inaccessible areas, for boat washing 45° is considered preferable as this will enables the underside of boats to be reached without stooping. Some units are able to function with 2 users operating simultaneously, normally at the same pressure, but at a reduced water flow. On more expensive units, the lance may house controls for both water flow and pressure.

The nozzle is important in water/steam delivery as it controls the release pressure; a more fanned spray will cover more area but at reduced pressure. Nozzle apertures are measured in degrees, a 0° jet will be concentrated and fast, while a 40° nozzle (generally the widest found) will force

water/steam over a greater area. A rotary nozzle can provide both sustained pressure and additional agitation by rapidly spinning, increasing the coverage of the jet without any additional manipulation.

The majority of washers are either electric or fuel-powered (petrol/ diesel) or a combination of the two. For large mobile units or areas not connected to mains electricity, fuel based generators would be most viable. There are also some solar powered units which, if effective, would be both practical and environmentally friendly.

Pressure washers tend to use less water than normal garden hoses, for example a garden hose will use approximately 34L per minutes in comparison to a pressure washer that will use between 10 and 18L per minute. With steam pressure washers even less water is needed. The majority of pressure washers are able to either take water from mains supply or from other unpressurised sources such as water butts, rivers and lakes. However, care should be taken if drawing water other than mains supply to ensure that material isn't taken up that may cause damage to the pump. In most cases a filter is supplied to avoid this from occurring.

There are 3 main variables to consider when selecting a power washer: pressure normally measured in pounds per square inch (PSI), water flow normally measured in gallons per minutes (GPM) or litres per minutes (LPM) and working power measured in horse power (HP). While pressure will determine how good the machine is at breaking the bonds between the surface and the object that is to be removed from it, the water flow effects how quickly the item is washed away once the bonds between it and the surface have been broken. Working power will determine how much pressure and water flow the unit is capable of- the higher the working power the more pressure can be generated and the higher the flow rate.

Washer specification requirements will depend on the type of work load expected from the machine as summarised in table 1. Light duty is defined as washers producing between 1000-2000 PSI (suitable for cleaning car, boats and garden furniture), medium duty as 2100-2800 PSI (suitable for removing grease and heavily soiled equipment) and heavy duty as 2900-5000 PSI (stripping paint and heavy oil stains).

Table 1. A summary of the type of washer required depending on duty (http://www.ultimatewasher.com/learning-center/how-to/how-to-purchase.htm).

What do you want to pressure wash?			
	Light duty	Medium duty	Heavy duty
Agriculture Machinery	.	.	X
Airplanes	X	X	.
Barbecue Grills	X	.	.
Bicycles	X	.	.
Boats	X	X	.
Bricks	.	X	X
Buildings	.	X	X
Buses	X	X	.
Cars	X	X	.
Concrete Driveways	.	X	X
Decks	.	X	X
Farm Equipment	.	.	X
Food Processing Plants	.	X	X
Garages	.	.	X
Garbage Cans	X	.	.
Garden Tools	X	.	.
Gutters & Downspouts	X	X	.
Hot Tubs	X	X	.
House Sidings	.	X	X
Industrial Plants	.	X	X
Lawn & Patio Furniture	X	.	.
Lawn Tractors	X	X	.
Lawnmowers	X	X	.
Motorcycles	X	.	.
Patios	.	X	X
Pools	.	X	X
RV's	X	X	.
Screens	X	.	.
Service Areas	.	.	X
Sidewalks	X	X	.
Spas	X	X	.
Swing Sets	X	.	.
Trucks, Pick-ups	X	X	.
Walkways	.	X	X
Wood Fences	X	X	.

Cold water pressure washers

Cold water pressure washers are an effective means by which common dirt and contaminant can be removed. In Australia cold water blasting has been found to be effective at removing INNS, such as kelp (*Undaria* spp.) gametophytes from shells, at pressures >2000 PSI at a distance of 100mm for 2 seconds (Forrest & Blackmore 2007). Whilst effective at removal, it does not necessarily destroy all organisms, and is unlikely to affect organisms caught in crevices or small spaces on equipment where the pressure of water required to remove the organism will be increased. Rothlisberger (2009) found that for small-bodied organisms and plant seeds, boat washing was highly effective: 91% ± 2% removal rate for high-pressure wash, 74% ± 6% for low-pressure wash, and 65% ± 4% for manual removal. These methods were also effective for aquatic macrophytes. Hand removal following visual inspection can reduce aquatic plant material by 88% ± 5%; high-pressure wash was similarly effective (83% ± 4%), but low-pressure wash was considerably less effective (62% ± 3%).

Heated pressure washers

The addition of heat to pressure washing is beneficial in removing stubborn contaminants, such as grease and oil, helping to break the bonds between surface and contaminant. Boat cleaning with power washers at >40°C has been recommended to control the spread of zebra mussels (*Dreissena polymorpha*), spiny water flea (*Bythotrephes longimanus*), viral hemorrhagic septicaemia virus (Beall 2005; AveLallemant & Marcquenski 2007), and is one of the most commonly used methods to control fouling in industrial cooling water systems (Jenner et al. 1998). Exposure to water at >60°C was 100% lethal to Eurasian water milfoil (*Myriophyllum spicatum*) regardless of exposure time during experiments designed to simulate hot water cleaning of water craft (Blumer et al. 2008). Similarly, exposure to a water spray at >60°C for 10s or >80°C for 5s was 100% lethal to adult zebra mussels, although at <50°C, mortality was <100% (Morse 2009). Hot-water spray at 60°C for 5s or longer can lead to 100% quagga mussel (*Dreissena rostriformis bugensis*) mortality (Wong et al. 2010, Comeau et al. 2011). Wong et al. (2010) did not use (high) pressured water, but rather a heated unpressurised hose to successfully conduct field trials on fouled boats (see figure 1 below). It is therefore apparent that pressure is not required in the application of thermal control even for larger objects. However, the addition of pressure will dislodge organisms, so those that may not be exposed to sufficient water temperature are likely to be dislodged. With the addition of pressure there is less time for the water to cool from point of release to contact with the target surface/organisms ensuring water is delivered as close the minimum required temperature as possible. The addition of pressure also allows the user to cover more surface area more quickly and at a distance from the target surface.

Figure 1. Images taken from a report produced by Wong showing boat cleaning using hot unpressurised water to effectively remove zebra mussels from boat hulls.

Guidance developed by the Aquatic Nuisance Species Task Force (United States) for the cleaning of recreational vessels, provides specific advice for each major component of the vessels, these cleaning recommendations are:

- Spray/rinse hull and other external areas with high pressure (2,500 psi) hot water (60°C) for a minimum of 10 seconds.
- Rinse/flush motors with hot water (48°C) for 2 minutes.
- Rinse/flush interior compartments with hot water (48°C).

Work carried out by William Burchnall of the Norfolk Broads Authority (2012) clearly demonstrates that heated pressure washers can be effective at ensuring the delivery of hot water to a surface for the purpose of thermal control. With an off the shelf heated pressure washer (maximum water temperature output of 90°C), it was possible to achieve temperatures >50°C providing that the hose nozzle was held within 50cm of the surface being treated, with run off temperature also in access of 50°C. The units pressure output was approximately 2500 PSI and therefore would fall into the medium duty category provided above. This study does suggest that some guidance on the most effective way in which to use heated pressure washers as bio-security measures are required for users, e.g. distance that nozzle is held from surface. However, operators would normally hold the nozzle between 20 and 40 cm from the work surface to make best use of water pressure. The fact that run off from these trials maintained a temperature in excess of 50°C means that even if not caught in the direct blast from a washer there is still a high probability that if washing is conducted thoroughly with water reaching all areas of an item of equipment being washed then any attached organism will come into contact with sufficiently heated water. It should be noted however than water temperature, especially run off will be affected by ambient temperature, although the majority of INNS are less active and therefore less likely to be caught on equipment during colder months.

A key element in thermal control is maintaining a minimum water temperature throughout the wash period. Most washers have a thermostat controlled burner, therefore once water temperature reaches the set point, the boiler will turn off, resulting in a drop in water temperature until the thermostat detects this and the boiler is turned back on. Models are available that overcome these issues by keeping the boiler on for longer so that water temperature does not fluctuate as much.

Steam pressure washers

Steam cleaners are increasingly common as a detergent-free method of home cleaning and disinfection. Steam cleaners have the added advantage of sterilising as well as being effective against stubborn contaminants. However, as the temperature of the water expelled from a steam cleaner is around the boiling point of water, it will condense quickly after the steam is released. This is particularly the case in cold conditions where steam will cool and dissipate quickly especially with

the addition of air movement conditions. With the steam cooling rapidly on discharge, and being expelled at a lower pressure than hot water washers, the nozzle would have to be held closer to the target surface for effective (>45°C) temperatures to be met. This would reduce the surface areas covered by the spray, requiring more time to clean and the user having to stand closer to the surface being cleaned. A potential way around this issue would to use units that can expel steam at much higher pressure; however there would be potential health and safety issues with their use.

Testing of pressure washers on live animals

Limited testing of 3 pressure washer types, cold water, hot water and steam was under taken, examining their impact on live killer shrimp *Dikerogammarus villosus.* Each washer type was tested by spraying fine mesh bags (10x10cm) containing 10 live *D. villosus* at varying distances (25, 50, 75 and 100 cm) from the nozzle of the pressure washer. The net bag containing the *D. villosus* was pinned to a board with an electronic thermometer probe and the washer set up at the distance being tested. The washer was fired for 10 seconds at the bag. Immediately after the bag containing the *D. villosus* was placed into freshwater for 1 hour. After 1 hour the percentage mortality was calculated. A fresh batch of animals was used per distance tested for each pressure washer type; no animal was used more than once in the experiment. Although ideally the *D. villosus* should have been placed on a surface to be sprayed for more realistic simulation, as the tests had to be conducted in the open for health and safety purposes keeping the animals in bags was considered prudent to prevent escape. All testing was conducted in a sheltered area under cover to prevent wind variability between tests.

The pressure washer used was a Nilfisk Alto Neptune 2. This is an electric (230V) trolley design, with a maximum pressure of 2,000 PSI and capable of producing 80/150°C. The unit was used with temperature setting at cold, 80°C (hot water) and 150°C (steam). Using the same unit on different settings for the tests allowed for variables other than the water temperature to be maintained at a constant (although pressure does drop with increased temperature).

Results

Table 2 below presents the result as percentage mortalities observed at the distances tested for each washer type. Low level mortalities (30%) were observed with cold water when used at close (25cm) range. This is likely to have been a result of physical damage to the animals. With the introduction of heat mortalities increased considerably (100%), however this decreased with distance from the washer nozzle. Hot water treatments were effective over a greater range, with 100% mortalities observed at 25, 50 and 75 cm distance. Steam treatment produced 100% at 25 cm,

but the effective range decreased, 60% mortalities at 50 cm and 0% at 75 and 100 cm. It should be noted that while users had no issues with the use of either the cold water or the hot water settings, when the steam cleaner was used, and especially at close range, splash back from the surface would cause some burning on exposed skin.

Table 2. Results from the testing of pressure water types (cold water, hot water and steam).

Distance (cm)	Cold water (% mortality)	°C	Hot water (% mortality)	°C	Steam (% mortality)	°C
25	30	11	100	65	100	97
50	10	11	100	50	60	43
75	10	11	100	46	0	29
100	0	11	0	34	0	18

Discussion

Hot water is a valuable tool in the control of INNS, being relatively environmentally benign, cheap, readily available, easy to use and not requiring specific training or protective equipment to use or produce. While thermal treatment is easily applied to personal items of equipment and clothing through submersion, its use is more problematic on larger items of equipment such as canoes, kayaks, motor boats, personal watercraft (such as jet skis), yachts and sailboats.

Pressure washing with cold water has been found to be more effective than hand searching or washing with a conventional hose at the removal of some INNS, but relies solely on the physical removal of the organism as a result of the pressure of the water. The addition of heat increases the effectiveness of pressure washing further, killing exposed animals that have not been removed physically. Thermal control of INNS can be achieved at relatively low and safe water temperatures. In the majority of studies conducted water between 40°C and 60°C were found to be effective at causing mortality in target organisms. Pressure washers producing water at these temperatures can be used safely without protective clothing or training, as the lances are designed to give adequate separation between the user and the hot water produced. The risk of scalding depends upon the temperature of the water and the length of time the skin is exposed to it. For example, a person could be scalded when their skin is in contact for just ten seconds with water at a temperature of around 54°C; at 66°C this decreases to just one second (Angel 2012). Therefore 60°C is safe to use by members of the public applying due care and attention. Hot water pressure washers are able to easily achieve required temperatures for thermal control with the added benefit of physical removal. With adequate pressure a hot water pressure washer is able to deliver 60°C water at a reasonable

distance while still providing good surface coverage. Water runoff from hot water pressure washers is still of a high enough temperature to cause mortality in a wide range of INNS. This would mean that even those that have been knocked off are still likely to be killed in the runoff water.

Steam pressure washers while able to deliver higher temperature do not have the range to deliver required temperatures to a surface from a distance. Increasing the PSI of a steam cleaner would extent a steam pressure washers effective range, but this will be a significant increase in cost. Working with high pressure steam at output levels that match the effectiveness of hot water units, would have health and safety issues as the steam on release and the runoff would be at a temperature that would cause burns within a matter of seconds. Therefore protective clothing and training would be required for use in thermal control. While the use of excessive heat may be a 'belt and braces' approach ensuring that the minimum required temperature is delivered, the reduced range of a typical low output or the health and safety issues with high output units, makes the use of steam pressure washers a less viable option for thermal control of INNS. However, it should be noted that small hand held units commonly available for commercial use would be a viable option for disinfecting smaller items of equipment, especially those that are difficult to submerge or where prolonged submersion may not be an option. However, due to the low pressure of the steam being expelled from such unit the steam rapidly dissipates and therefore are not ideal for use outdoors, especially in windy conditions.

There are such a wide range of pressure washer units available of varying quality and price that it a suitable unit can be found for most scenarios. Rather than recommend specific units, which would be difficult (and inappropriate for a government agency) it would be easier to suggest minimum working requirements for effective use. This would not only depend on the units ability to deliver the required temperature, but also on the frequency of use, with more robust models being required if likely to receive heavy usage. Ensuring the units have a power and water supply in addition to a suitable surface to be used upon is essential. This may not be such an issue with situations where cleaning is conducted in areas with facilities (such as a sailing club), in more remote locations these may be issues, especially in relation to power supply. For use in remote locations units with built in power supplies are available, but these would require regular maintenance, potentially adding additional burdens and costs to a control programme.

Recommendations

Hot water pressure washers are the tool of choice in thermal control of INNS on larger items and recommended for use by a number of organisations. Given their ability to deliver suitable

temperatures over a reasonable distance and surface area coverage then it is recommended that these are used for thermal treatment of larger items in GB. All units that have been tested in reference to the distance over which water temperatures can be maintained fall into the medium duty category (see table 1), or 2100-2800 PSI. This is in line with advice provided to boat owners in the USA (2500PSI). While delivering suitable temperatures and pressure, medium use units are also more robust and therefore have a degree of longevity for more cost effective control programmes.

Ideally washing stations should be placed at pinch points such as slip ways. Given that these are fixed locations, it is recommended that static hot water pressure washer units are installed. Cabinet style units have several distinct advantages over more traditional mobile units:

1. The unit is permanently connect to water and power supply, and will therefore not require unpacking and set up before use.
2. The operator does not have access to the setting (pressure, temperature, detergent flow) and therefore these setting can be set to ensure best use.
3. The potential for theft is reduced.
4. There are fewer trailing hoses and cables, avoiding trip hazards and snags.
5. Static systems can be coin fed allowing for charges to be made where this is considered appropriate.

Slip ways provide a solid surface on which cleaning can be conducted and will be near a suitable water supply (i.e. river or lake) as long as the units' intake is suitably filtered. In remote locations it may be possible to have the units' fuel powered. In remote locations where canoes and kayaks may be launched it may not be feasible to consider installing (and maintaining) pressure washers. Increasing awareness of thermal control amongst water users will therefore be important, and potentially having hot water pressure washers set up at more convenient locations such as ranger posts. In the absence of a hot water pressure washer then recommending the use of cold water pressure washers available on most garage forecourts may be an alternative, although less effective than hot water pressure washers.

Fuel powered mobile hot water pressure washer units are recommended for use by field workers moving large items of equipment between sites where INNS are present. These can be easily loaded/unloaded and can be used to clean equipment using water present on site. If not available then cold water pressure washer use should be recommended as an alternative, although less effective.

References

Angel, C. (2012). Controlling Scalding Risks from Bathing and Showering. *UKHCA Guidance report*.

AveLallemant, S. and S. Marcquenski. (2007). Boat and equipment disinfection protocol-2007. Wisconsin Department of Natural Resources, Madison,WI. 5 pp. http://www.dnr.state.wi.us /fish/documents/disinfection_protocols.pdf. Accessed July 28, 2007.

Bacela-Spychalska, K., Grabowski, M., Rewicz, T., Konopacka, A. & Wattier, R. (2013) The "killer shrimp" *Dikerogammarus villosus* (Crustacea, Amphipoda) invading Alpine lakes: overland transport by recreational boats and scuba-diving gear as potential entry vectors?: Potential vectors of killer shrimp invasion in alpine lakes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 23, 606–618.

Beall, M. (2005). Aquatic invasive species: a handbook for education efforts. Wisconsin Department of Natural Resources, Publication WT-825 2005. Madison,WI. 119 pp.

Beyer, J., Moy, P. & Stasio, B. (2010) Acute Upper Thermal Limits of Three Aquatic Invasive Invertebrates: Hot Water Treatment to Prevent Upstream Transport of Invasive Species. *Environmental Management*, 47, 67–76.

Blumer D.L. Newman R.M. & Gleason F.K. (2008) Can hot water be used to kill Eurasian watermilfoil? Journal of Aquatic Plant Management 47: 122-127.

Bothwell, M.L., Lynch, D.R., Wright, H. & Deniseger, J. (2009) On the Boots of Fishermen: The History of Didymo Blooms on Vancouver Island, British Columbia. *Fisheries*, 34, 382–388.

Buchan, L.A.J. & Padilla, D.K. (1999) Estimating the Probability of Long-Distance Overland Dispersal of Invading Aquatic Species.pdf. *Ecological Applications*, 9.

Forrest, B.M. & Blakemore, K.A. (2006) Evaluation of treatments to reduce the spread of a marine plant pest with aquaculture transfers. *Aquaculture*, vol. 257, pp. 333–45.

Gallardo, B. & Aldridge, D.C. (2013) The "dirty dozen": socio-economic factors amplify the invasion potential of 12 high-risk aquatic invasive species in Great Britain and Ireland. *Journal of Applied Ecology*.

Gates, K.K., Guy, C.S., Zale, A.V. & Horton, T.B. (2008) Adherence of *Myxobolus cerebralis* Myxospores to Waders: Implications for Disease Dissemination. *North American Journal of Fisheries Management*, 28, 1453–1458.

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

Kilian, J.V., Klauda, R.J., Widman, S., Kashiwagi, M., Bourquin, R., Weglein, S. & Schuster, J. (2012) An assessment of a bait industry and angler behavior as a vector of invasive species. *Biological Invasions*.

Kilroy, C., Lagerstedt, A., Davey, A. & Robinson, K. (2006) Studies on the survivability of the invasive diatom *Didymoshenia geminata* under a range of environmental and chemical conditions.

Ludwig, H.R. & Leitch, J.A. (1996) Interbasin Transfer of Aquatic Biota via Anglers' Bait Buckets. *Fisheries*, 21, 14–18.

Mack, R., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. & Bazzaz, F.A. (2000) Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications*, 10, 689–710.

Morse, J.T. (2009) Assessing the effects of application time and temperature on the efficacy of hot-water sprays to mitigate fouling by *Dreissena polymorpha* (zebra mussels Pallas). Bio-fouling 25: 605-610.

O'Neill, C.R. & MacNeill, D.B. (1991) The zebra mussel (*Dreissena polymorpha*): an unwelcome North American invader.

Perepelizin, P.V. & Boltovskoy, D. (2011) Hot Water Treatment (Chronic Upper Lethal Temperature) Mitigates Biofouling by the Invasive Asian Mussel *Limnoperna fortunei* in Industrial Installations. *Environmental Science & Technology*, 45, 7868–7873.

Rothlisberger, J.D., Chadderton, W. L., McNulty J. & Lodge, D. M. (2010). Aquatic Invasive Species Transport via Trailered Boats: What is being moved, who is moving it and what can be done. *Fisheries* 23:121-132.

Stasko, A.D., Patenaude, A.L., Strecker, A.L. & Arnott, S.E. (2012) Portage connectivity does not predict establishment success of canoe-mediated dispersal for crustacean zooplankton. *Aquatic Ecology*, 49, 9–24.

Stebbing, P., Sebire, M. & Lyons, B. (2011) Evaluation of a number of treatments to be used as biosecurity measures in controlling the spread of the invasive killer shrimp (*Dikerogammarus villosus*).

Strayer, D.L. (2010) Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. *Freshwater Biology*, 55, 152–174.

Jenner, H. A., J. W. Whitehouse, C. J. L. Taylor and M. Khalanski. (1998). Cooling water management in European power stations: Biology and control. Hydroecol. Appl. 10:1-225.