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Research Article

Identifying target factors for interventions to increase boat cleaning in order to prevent spread of invasive species

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Abstract

Overland transport of recreational boats is among the most important distribution vectors for aquatic invasive zebra and quagga mussels between inland waters. Simple measures such as instructing boat owners how to prepare their boat for transport so that the boat does not carry invasive species are considered to be important prevention measures. Nevertheless, the net effects of such measures are poorly understood and the boat cleaning behavior of boat owners has never been studied in detail before the implementation of such preventive measures. Using a "self-report" questionnaire, we investigated the boat cleaning behavior of boat owners in Switzerland where almost no preventive measures have been taken yet. We found that the self-reported boat cleaning rates are high, with 92% of boaters cleaning their boat upon finding mussels attached to their boat and 84% of them cleaning their boat before a transport. Nevertheless, only half of the boat owners report using high pressure washing to clean their boat before overland transport and many use ineffective cleaning methods.
We show the importance of informing boat owners on the appropriate methods to remove invasive species from their boat and suggest that high pressure washing facilities should be made available at all potentially infested water bodies. Furthermore, our analysis shows that the boat cleaning behavior could be significantly improved by changing how boat owners value the perceived costs and benefits of cleaning, as well as by increasing their awareness of the potential negative impacts on aquatic ecosystems caused by non-native species. With regard to a possible spread of zebra mussels to uninfested alpine lakes and the imminent spread of quagga mussels in Switzerland, we conclude that the Swiss boating community would be open to accepting implementation of prevention measures.

Key words: recreational boating, distribution vectors, *Dreissena polymorpha*, behavioral change, preventive measures

Introduction

Invasive species are among the most important threats to biodiversity in aquatic ecosystems (Sala et al. 2000). Many aquatic invasive species lead to high economic effects, and once they are established and reach high population densities, it is nearly impossible to eliminate them from their invasive range (Pimentel et al. 2005). Thus, it is of high importance to prevent the spread of such species to not yet invaded habitats. The natural spread of exclusively aquatic species is generally limited by the dendritic structure of river-lake systems (Fagan 2002). Overland transport of recreational boats has been shown to be among the most important distribution vectors for the ongoing secondary spread of aquatic invasive species in such systems (Johnson et al. 2001; Leung et al. 2004; MacIsaac et al. 2004). Overland transport has been demonstrated for species such as the spiny water flea (*Bythotrephes longimanus*) (MacIsaac et al. 2004), the Eurasian watermilfoil (*Myriophyllum spicatum*) (Buchan and Padilla 2000), the killer shrimp (*Dikerogammarus villosus*) (Bacela-Spychalska et al. 2013), and zebra mussels (*Dreissena polymorpha*) (Johnson

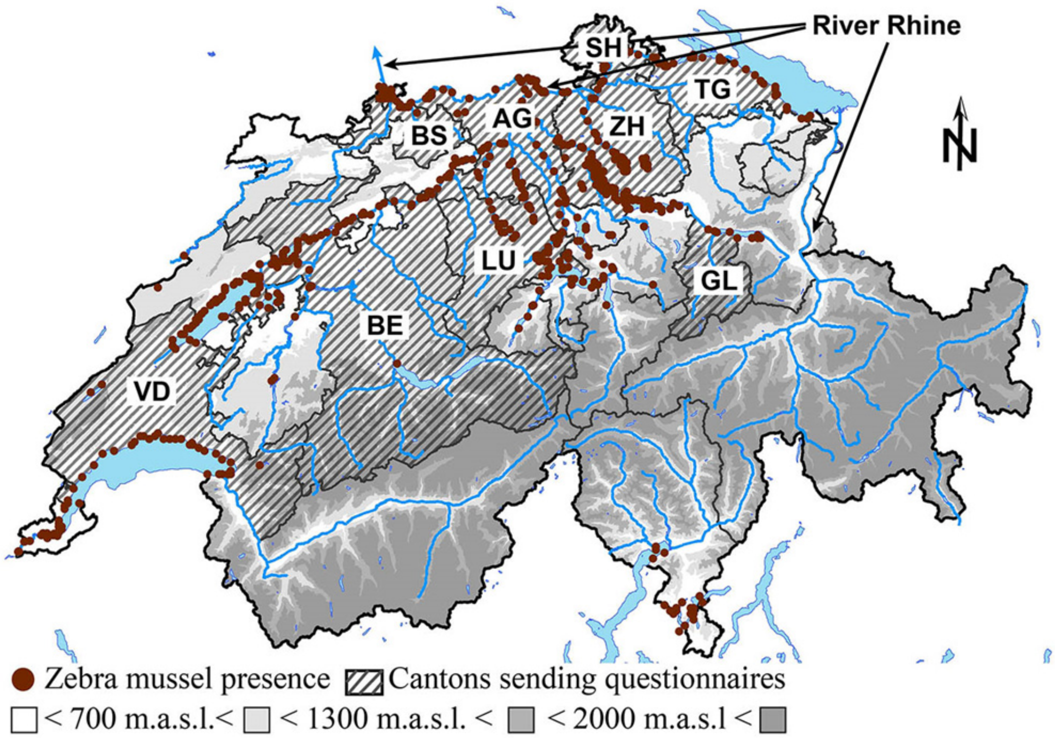

Figure 1. Zebra mussel distribution in Switzerland (brown dots) and the cantons involved in this study (striped area). German speaking cantons Aargau (AG), Basel (BS), Glarus (GL), Luzern (LU), Schaffhausen (SH), Thurgau (TG) and Zürich (ZH), the French speaking canton Vaud (VD) and the bilingual canton Bern (BE). The questionnaire was available in German and French. Data on the distribution of zebra mussels was collected in 2011 from cantonal offices, the CSCF (Swiss Centre of Faunistic Cartography) and environmental offices. Grey shades show different levels of altitude. To date, zebra mussels have not been found above 1300 m.a.s.l. (meters above sea level, area in darker grey and darkest grey shades).

et al. 2001; De Ventura et al. 2016). The transport of aquatic invasive species is known to be mostly unintentional (Johnson and Carlton 1996). Organisms were found to be transported in bilge wells, live wells, bait buckets, attached to the boat exterior or entangled in macrophytes, which were attached to the boat or the boat trailer (Johnson et al. 2001).

Research on recreational boats as vectors in aquatic environments has focused on two closely related invasive species, the quagga mussel (*Dreissena rostriformis bugensis* Andrusov, 1897) and the zebra mussel (*Dreissena polymorpha* Pallas, 1771). These species cause a range of negative impacts on the ecology of invaded rivers and lakes (Ricciardi et al. 1995; Strayer 2009) and impose high economic costs (Pimentel et al. 2005). Overland transport of small boats is known to be mainly responsible for the distribution of these two species between inland waters throughout the United States (Padilla et al. 1996; Bossenbroek et al. 2001). In North America, zebra mussels were found to be transported overland attached to macrophytes entangled on trailered boats (Johnson et al. 2001). In Switzerland, macrophytes are rarely entangled with boats or boat trailers, but zebra mussels are often fouling the boat hull, propeller, keel, engine area or other irregularities on the boat exterior (De Ventura et al. 2016). In our previous study, we found that roughly 40% of year-round or seasonally moored boats carried zebra mussels. Of those, 5% were transported between water bodies without being kept out of water for longer than two days, allowing the survival of mussels during the overland transport. We estimated that roughly 800 of such boats that impose a high risk of distributing zebra mussels were transported between water bodies every year. Such transports took place between all navigable water bodies in Switzerland.

To date, zebra mussels occur in nearly all larger lakes and rivers in Switzerland, except those at higher altitudes (Figure 1). The quagga mussel was

Table 1. Summary of measures asked of boat users and other people dealing with aquatic organisms on US lakes and rivers. This is an example of rules implemented by the "Stop Aquatic Hitchhikers" campaign of the U.S national Aquatic Nuisance Species task force (Aquatic Nuisance Species (ANS) Task force 2015).

	Action to take	When	Detailed action
A)	Remove all visible mud, plants and animals from boats trailers and boat equipment	Before leaving any water body	• Remove any visible plants, plant fragments, fish or animals. • Remove mud and dirt since it too may contain a hitchhiker. • Do not transport any potential hitchhiker, even back to your home. Leave them at the site you visited.
B)	Eliminate all water from the boat and boat equipment	Before transporting the boat to another water body	• Eliminate all water from every conceivable. • Remove water from motors, jet drives, live wells, boat hulls, scuba tanks and regulators, boots, waders, bait buckets, seaplane floats, swimming floats.
C)	Clean and dry anything that came into contact with the water	Before transporting the boat to another water body	• Use hot (< 40° C or 104° F) or salt water to clean your equipment. • Wash your dog with water as warm as possible and brush its coat. • If hot water is not available, use high pressure washing. • If possible, allow for 5 days of drying time before entering new waters
D)	Do not release any plants or animals into a water body which do not originate from the same water body	In general	• Do not release anything from your aquarium into or near a body of water. • Do not release unused bait into the waters you are fishing.

recently detected in the Swiss Rhine (De Ventura 2015, unpublished data) and is expected to spread widely in Switzerland via recreational boating (Martens and Schiel 2012; De Ventura et al. 2016). It has been shown to colonize water bodies with lower temperatures (Roe and MacIsaac 1997) and lower nutrient loads (Baldwin et al. 2002) than the zebra mussel. Therefore, the quagga mussel might well spread via recreational boating to most water bodies in Switzerland, including the mussel free alpine lakes. Thus, it is important to prevent the further spread of zebra and quagga mussels through the overland transport of small craft boats. A reduction in the strength of this vector would lead to reduced propagule pressure on uninfested lakes and rivers (Lockwood et al. 2005; Simberloff 2009) and may greatly reduce the establishment risk of zebra and quagga mussels in these water bodies (Bossenbroek et al. 2001; Leung and Mandrak 2007).

In Switzerland (and in most other European countries), very little action has been taken by local authorities to reduce the risk that invasive species spread through recreational boating activities. To our knowledge there are no regulations addressing this problem and only a few tentative outreach campaigns have informed boat users about invasive species and boat cleaning measures. However, in North America a series of measures have been implemented to prevent the spread of zebra and quagga mussels (Rothlisberger et al. 2010). In regional and national information campaigns (summarized in Table 1), boat owners were instructed to clean their boats and equipment, remove attached organisms and let the boat and equipment dry before an overland transport (Aquatic Nuisance Species (ANS) Task force 2015). Recommended methods for cleaning were mostly hot water spraying or high pressure washing. Boat cleaning stations have been installed at the main overland transport routes. In some states (e.g. Wisconsin and Minnesota) such regulations have been imposed by law with enforceable fines (http://dnr.wi.gov/topic/invasives/boat.html). In a study from U.K., Anderson et al. (2014) have shown that 64% of anglers and 79% of canoeists use their boat in different river catchments within a fortnight and are therefore likely to distribute invasive species if they fail to clean their equipment. In the same study it was shown that 12% of anglers and 50% of canoeists cleaned their equipment before transporting it to a new catchment, but if canoeists had heard of the "Check, Clean, Dry" campaign, they cleaned their boat and equipment 40% more often (http://www.nonnativespecies.org/checkcleandry/).

Unfortunately, there has not been enough research evaluating the efficacy of regulations, information campaigns and promotion of boat cleaning methods.

It is known that the most effective methods to completely remove fouling mussels from a boat are hot water spraying (Morse 2009; Comeau et al. 2011) or high pressure washing (Rothlisberger et al. 2010). Rothlisberger et al. (2010) showed that in the area of Wisconsin roughly 60% of boat owners did not always clean their boat before a transport and they confirmed that small-craft boats are still an important distribution vector, even after prevention measures had been implemented (beginning in the 1990s). To our knowledge the cleaning behavior of boat owners has never been studied before major prevention measures have been taken. Furthermore, no research has been done to investigate the factors that determine the boat cleaning behavior of the boat owners and how they value different costs and benefits of boat cleaning. Consequently, it is difficult to know the best arguments that could be used to convince boat owners to help prevent the spread of invasive species. The boat owner may be equally motivated to clean the boat because of perceived direct benefits in reducing the drag of the boat, but may also value the society-level benefits related to the prevention of invasive species. However, in order to assess the net effect of regulations and information campaigns it is necessary to assess the situation before the measures are taken. Specifically, studying cleaning behavior, cleaning motivation and overland transportation habits might help to better design measures, target the right audience, and help to find the right arguments to convince boat owners to clean their boats before an overland transport.

In this study, we investigated the boat cleaning behavior of recreational boat owners in Switzerland using a questionnaire. We evaluated the data of the questionnaire in the context of the results from our earlier study on mussel fouling and boat transportation frequencies (De Ventura et al. 2016). The results of the questionnaire were analyzed to investigate the following questions:

1. How often do boat owners clean their boats and how do they evaluate boat cleaning?
2. What characterizes boat owners who clean their boats after they have detected mussels on the boat?
3. What characterizes boat owners who use high pressure washing before transporting their boat to another water body?

Based on our results we built a model to test the alternative measures to reduce the strength of overland boat transport as a distribution vector. Finally, we discuss the importance of prevention measures with regard to a possible spread of zebra and quagga mussels to uninfested alpine lakes in Switzerland.

Methods

Questionnaire

We investigated the cleaning behavior of boat owners in Switzerland using a questionnaire. Data were gathered by self-administered questionnaires (available in German and French), which were distributed by mail and could be filled out on paper or online via the internet. The questionnaire consisted of 30 items asking about: a) socio-demographic data, b) characteristics of the boats, c) presence of fouling water animals on the boat exterior, d) overland transport events between water bodies, e) cleaning habits, f) cleaning motivation, and g) the awareness of aquatic non-native species. For example, we asked boat owners whether they cleaned their boats after they detected fouling mussels. In a set of general questions, which were not directly related to the distribution of non-native species, we asked boat owners how they evaluated different types of costs and benefits of removing fouling water animals and how much money they spend on boat cleaning per year. In another set of questions, we asked whether they thought that recreational boats are an important distribution vector for aquatic animals and whether they think that non-native species may have negative impacts on aquatic ecosystems (Supplementary material Table S1). We also asked boat owners which cleaning methods they used before they transported their boat overland. We indicated options of "brushing", "scraping", "flushing with water", "washing with high pressure" and "other method". We did not explicitly ask about the use of hot water spraying, salt water spraying or high pressure washing with hot water, as boat owners in Switzerland rarely have the equipment for these methods available. We further asked "what were the reasons for not cleaning the boat before a transport". The invitation letter informed boat owners that participation was voluntary, and how the investigators could be contacted in case of questions. Filling out the questionnaire took about 15 minutes.

Nine of the total 26 cantonal shipping agencies (state authorities where boats have to be registered in Switzerland) sent the questionnaires to a random sample of 20% of the registered boat owners (Figure 1). Roughly 10,500 boat owners received the survey and 3,561 of them filled in and returned the questionnaire (response rate = 34%). Respondent's boats were distributed over 30 navigable lakes and several rivers, which are almost exclusively and intensively used for recreational boating. Cases of overland transport by boat owners were reported for all navigable Swiss lakes and the areal coverage of the sampling is shown in Figure 1. With a total of 99,200 private boats registered at cantonal offices in 2013 (Swiss Federal Statistical Office 2014) the returned questionnaires covered roughly 3.7% of all registered boats in Switzerland. Among the 3,561 boat owners who returned the questionnaire 89% were men (average age 57.3 years ± 13.1 SE). The distribution of boat types (motor boats, sailing boats, boats without motor) reported in the survey was similar to the distribution provided by the cantonal shipping agencies (Swiss Federal Statistical Office 2014), indicating that the survey is representative of the registered boats in Switzerland (Supplementary material Figure S1).

Statistical analysis of the survey data

We used logistic regression models to evaluate which of the independent variables assessed in the survey best explained: a) whether boat owners cleaned their boat or not after they had found mussels (variable: boat cleaning), and b) whether boat owners used high pressure washing to clean their boat before an overland transport (variable: high pressure washing). Generally, we included only explicit answers in the analysis and answer categories, such that “don’t know” or “other option” responses were excluded. The variable “reaction to fouling” asked boat owners how they reacted after they had detected mussels on their boat (Supplementary material Table S1). Possible answers were “no reaction”, “all removed”, “unsuccessful attempt to remove all mussels”, or “boat cleaned by dockyard”. From the “reaction to fouling” responses, we created the binary variable “boat cleaning” containing the two categories “yes” or “no” by recoding the answers of “no reaction” into the category “no” and the answers for “all removed”, “unsuccessful attempt to remove all mussels” and “boat cleaned by dockyard” into the category “yes”. To allow for a robust statistical test on the use of high pressure washing, we created a new binary variable “high pressure washing” by recoding the answers from the question about high pressure washing frequencies. The ordinal categories “never”, “rarely” and “sometimes” were recoded into the new category “rare” and the answers “mostly” and “always” into the category “often”.

We used the following procedure to evaluate alternative models for the two dependent variables “boat cleaning” and “high pressure washing”. To start with, we included only seasonally or year-round moored boats in the analysis. We excluded boats that were stored on land as they were almost never fouled with mussels (De Ventura et al. 2016). Then, we explored the Spearman correlations between all continuous and ordinal explanatory variables that we used in the models using the function “rcorr” of the “Hmisc” package (Harrell 2013) in R (R-Core-Team 2014). We followed this by testing the Spearman correlations of all explanatory variables, including categorical variables for each of the two models a) and b) in separate categorical principal component analyses (CatPCA) in SPSS (IBM-Corporation 2012). Some of the Spearman correlations between pairs of explanatory variables exceeded 0.5, indicating high multi-collinearity and precaution for multivariate regression analyses (Supplementary material Table S3).

Among the variables for which boat owners estimated the different types of costs and benefits of removing mussels from their boats, those that described different types of costs such as difficulty, time expenditure, perceived monetary costs, and strenuousness were highly correlated, as well as those describing the benefit and importance of cleaning (Supplementary material Table S2, Table S3). We thus further explored the Spearman correlations among cost and benefit variables in a categorical principal component analysis (CatPCA) in SPSS (Linting et al. 2007). The resulting two-dimensional model explained 79% of the total variance in the data. Dimension 1 explained 75% of the variance of the four cost variables while dimension 2 explained 87% of the variance of the two benefit variables (Figure 2). We used the object scores of these two principal components (two variables: “cost” and “benefit”) in the consecutive logistic regression analyses for boat cleaning and the use of high pressure washing as explanatory variables. For plotting and analyzing the data we normalized the object scores by dividing the scores with the standard deviation of the mean. Subsequently, we shifted the object scores by subtracting the minimum negative value in order to get rid of negative values and then scaled them with a factor such that all values lay between 0 and 4. We did this because this was the scale we used in the questionnaire and it would be an intuitive scale to interpret the results. The results for the logistic regression model were the same with transformed and untransformed data.

We used stepwise model selection to evaluate the logistic regression models for boat cleaning and high pressure washing. We conducted the forward stepwise model selection based on statistical significance of each variable and compared fit of the alternative models using Akaike Information Criterion (Table 2B and 3B). We repeated the model selection after inserting the independent variables in different order and finally tested the models with backward model selection to evaluate if the same model appeared as the best model. Forward and backward procedure

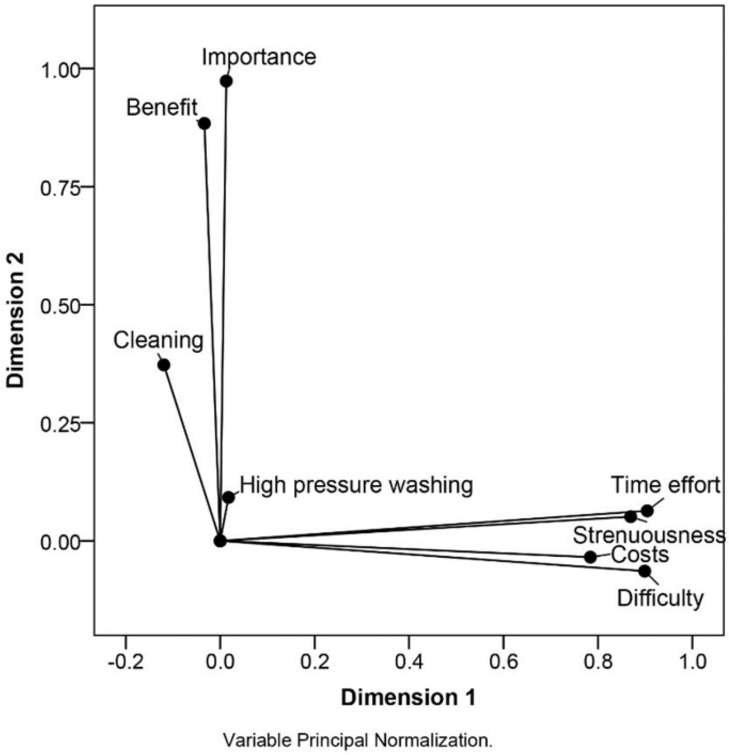

Figure 2. Two dimensional plot of the CatPCA (categorical principal component analysis) for cost-benefit variables such as difficulty, time expenditure, monetary costs and strenuousness, benefit and importance. Cleaning (as binary variable with the options "yes" and "no") and high pressure washing (as binary variable with the options "rare" and "often") were added to the CatPCA as supplementary variables and thus did not influence the calculated correlation structure but are shown as component loadings in relation to the dimension for cost (dimension 1) and the dimension for benefit (dimension 2).

always resulted in the same final model including the same statistically significant effects. Logistic regression models were fitted using the statistical package R, version 3.0.2 (R-Core-Team 2014).

The resulting models predicted the probability of boat cleaning and high pressure washing as a function of explanatory variables (Table 2A and 3A). We subsequently calculated the predicted probability of events in each category of the three explanatory variables "perceived costs", "perceived benefits" or "awareness of the damage to ecosystems", while holding the other two independent variables at their mean values (Figure 5A, 5B and 5C). We calculated the predicted probability for high pressure washing from the final model including only "awareness of the damage to ecosystems" as the explanatory variable (Figure 5D). We further assumed that it would be difficult to change the perception of boat owners who already perceived costs to be low, and benefits and damage to ecosystems to be high. On the other hand, the values of perceived costs above the population mean (above 1.3) and the values of perceived benefits or the awareness of the damage to ecosystems below the population means (below 3.35 and 3.8, respectively) might be changed more easily. Thus we present in three scenarios how the cleaning rate will change if the perceived costs, benefits and the estimated damage on ecosystems are shifted for all boat owners below or above certain values, which lay close to the population means (perceived costs below 2 (medium), perceived benefit above 3 (high) and awareness of the damage to ecosystems above 4 (high); Figure 5A, B and C). Similarly, we present a scenario of how the rate of high pressure washing will change if the estimated damage on ecosystems is shifted above a value of 4 (high) for all boat owners (Figure 5D).

Results

How often do boat owners clean their boats and how do they evaluate boat cleaning?

When owners of seasonally or year-round moored boats were asked how they reacted after they had detected mussels growing on their boats, roughly 25% answered that they did not clean or unsuccessfully attempted to clean their boats. While 8.4% of boat owners did not clean their boats at all, 16.8% of boat owners reported that they had unsuccessfully tried to remove mussels from their boat (Supplementary material Table S1). On average, the estimated monetary cleaning costs per year were moderate, with CHF 346 (~EUR 320) and CHF 363 (~EUR 336)

Table 2. A) Results of the final logistic regression model with boat cleaning (whether owners of seasonally or year-round moored boats reported NOT to clean their boat after detecting mussels on the boat exterior) as dependent variable. We included all the explanatory variables for which we found significant effects. (AIC = 565, residual deviance = 557 on 1147 degrees of freedom, Loglikelihood = −271.8). The columns show the included independent effects, the Likelihood Ratio chi-square statistics for each effect (LR Chisq), the degrees of freedom (Df), corresponding p-values, variable categories and the odds ratios (OR), with confidence intervals (OR CI 2.5% and OR CI 97.5%). **B)** We show one example of the stepwise forward model selection procedure based on p-values and AIC. The columns show the variables at each of the model selection steps, the p-value of the corresponding variable in this step, the resulting AIC value and whether the variable was kept in the model or discarded for the next step.

A) Dependent variable: boat cleaning = no, N = 1299

Independent variable	LR Chisq	Df	p-value	Sig.	Factor category	OR	OR CI 2.5%	OR CI 97.5%
Cost dimension	11.6	1	< 0.001	***	continouus	1.73	1.27	2.36
Benefit dimension	52.1	1	< 0.001	***	continouus	0.16	0.09	0.26
Damage ecosystem	10.3	1	< 0.005	**	ordinal	0.73	0.60	0.88

B) Forward Stepwise selection based on p-values and AIC

Variable added	p-value of added variable in the model	AIC of the resulting model	Keep or remove variable from the model
Null Model: boat cleaning (yes or no) ~ 1		715	
Estimated benefits for cleaning	< 2.2e-16	640	keep
Estimated costs for cleaning	< 0.001	629	keep
Awareness of the damage to ecosystems	< 0.005	565	keep
Awareness of the distribution of aquatic species through recreational boating	0.42	557	remove
Monetary cleaning costs	0.68	510	remove
Antifouling usage	0.25	525	remove
Boat material	0.99	570	remove
Overland transport (yes or no)	0.57	565	remove

Table 3. A) Results of the final logistic regression models with "high pressure washing" (whether boat owners reported to clean their boat rarely or often before a transport event) as dependent variable. We analyzed the data for owners of year-round and seasonally moored boats, who had reported at least one over land transport event from one lake to another within the past five years. We included all the explanatory variables with significant effects (AIC = 209.46, residual deviance = 203.46 on 158 degrees of freedom (Df), Loglikelihood = −101.7 with Df =3). The columns show the included independent effects, the corresponding Likelihood Ratio chi-square statistics (LR Chisq), degrees of freedom (Df), p-values, variable categories, odds ratios (OR), with confidence intervals (OR CI 2.5% and OR CI 97.5%), number of boats often high pressure washed (N), and percent of boats which were often high pressure washed before a transport. **B)** We show one example of the stepwise forward model selection procedure based on p-values and AIC. The columns show the variables at each of the model selection steps, the p-value of the corresponding variable in this step, the resulting AIC value and whether the variable was kept in the model or discarded for the next step.

A) Dependent variable: high pressure washing, N = 176

Independent variable	LR Chisq	Df	p-value	Sig.	Factor category	OR	OR CI 2.5%	OR CI 97.5%
Damage ecosystem	6.37	1	< 0.05	*	Ordinal	1.45	1.09	1.96

B) Forward Stepwise selection based on p values and AIC

Variable added	p-value of added variable in the model	AIC of the resulting model	Keep or remove variable from the model
Null Model: high pressure washing ~ 1		242.7	
Mussel fouling	0.37	241	remove
Awareness of the damage to ecosystems	< 0.05	216	keep
Awareness of the distribution of aquatic species through recreational boating	0.91	211	remove
Boat material	0.61	220	remove
Antifouling usage	0.18	206	remove
Estimated benefits for cleaning	0.18	216	remove
Estimated costs for cleaning	0.95	218	remove
Monetary cleaning costs	0.74	203	remove

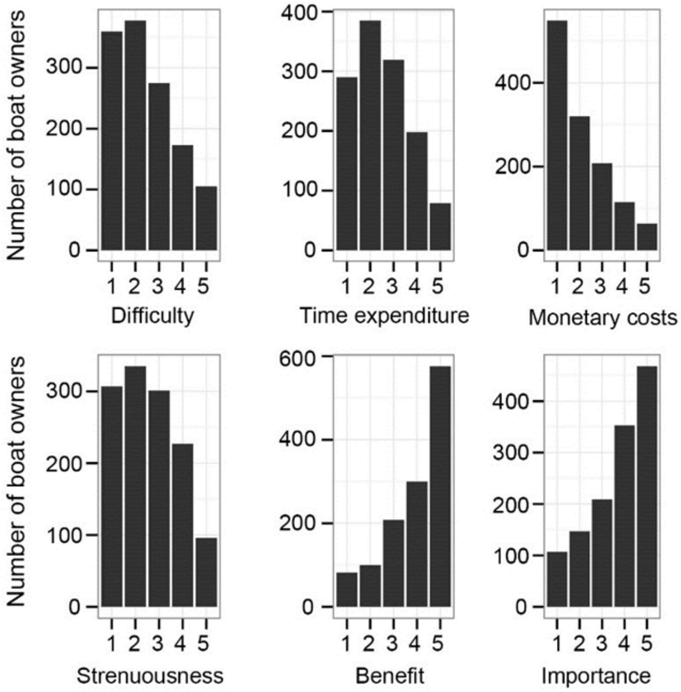

Figure 3. How owners of seasonally or year-round moored boats estimated difficulty, time expenditure, (monetary) costs, strenuousness, benefit and importance of boat cleaning, on a scale between 1–5: very low (1), low (2), medium (3), high (4) or very high (5).

for seasonally or year-round moored boats, respectively, but these costs varied considerably between individuals (between 0 CHF and 10,000 CHF (~EUR 9,267)). When asked how they evaluated the costs and benefits of cleaning on a scale between 1 (low) and 5 (high), most boat owners estimated the different types of costs as moderate (mean scores for difficulty, time expenditure, monetary costs and strenuousness were 2.4, 2.5, 2.1 and 2.6, respectively) while they estimated the benefit and the importance of cleaning as higher (mean scores for benefit and importance were 4 and 3.7, respectively; Figure 3). The CatPCA-scores for the benefit of cleaning were relatively high (mean = 3.35 on a scale between 0 and 4, SE = 0.005) while the CatPCA-scores for the costs were rather moderate (M = 1.31 on a scale between 0 and 4, SE = 0.009).

Among all boat owners who kept their boats year-round or seasonally in water, 83% reported cleaning their boats always or mostly before they transport it overland, with one of the following methods: scraping, brushing, low pressure spraying or high pressure washing (Supplementary material Table S1). However, only 55% of these boat owners used high pressure washing always or most of the time before a transport (Supplementary material Table S1). The most often named reason why boat owners did not clean their boat before a transport was that they thought their boat was already clean (55% of respondents). Another often named reason was the lack of time (29%), while other reasons such as lack of motivation, indifference, high costs or simply forgetting to clean were named rarely (Supplementary material Table S1).

On average, boat owners consider it likely that recreational boats transport aquatic animals between water bodies (M = 3.9 on a range between 1 and 5; Figure 4) and that there are negative effects on ecosystems if boats spread non-native aquatic animals between water bodies (M = 3.8 on a range between 1 and 5). The respondents were rather undecided whether the distribution of native aquatic species through recreational boating might also have beneficial effects for the aquatic ecosystems (M = 2.3 on a range between 1 and 5).

What characterizes boat owners who clean their boats after they have detected mussels on their boat?

When we examined why boat owners do not clean their boat after detecting mussels we found that those who were concerned about the costs of cleaning (as perceived difficulty, time expenditure, estimated monetary costs and strenuousness of cleaning) cleaned their boat significantly less often ($p < 0.001$, odds ratio = 1.73; Table 2A, Figure 5A). Also the boat owners who rated the benefits of cleaning lower were significantly more reluctant to clean ($p < 0.001$, odds ratio = 0.16; Table 2A, Figure 5B). How the boat owners rated the negative effects of the spread of non-native species on ecosystems was strongly and positively correlated with the declared frequency of cleaning ($p < 0.005$; Table 2A, Figure 5C). Against our expectations, the cleaning rate did not depend on whether boat owners were aware of the fact that recreational boats might spread aquatic species between water bodies (Table 2B). Also, the estimated monetary cleaning costs did not significantly (and negatively) influence whether boat owners cleaned their boat or not.

Our model predicts that reducing the perceived costs for all boat owners below a value of 2 (medium perceived costs) would reduce the number of boat owners who do not clean their boats after detecting mussels by one third (from 8.1% to 5.4%; Figure 5A and 6). To accomplish such a shift, perceived costs would only need to be reduced for 16% of boat owners ($N_{>2}$ = 182). If the perceived benefit of cleaning could be increased above a value of 3 (high) for boat owners with lower values (14% of boat owners, $N_{<3}$ = 158) the proportion of boat owners who do not clean could be reduced to 5.4% (Figure 5B). Increasing the awareness of the damage to ecosystems above a level of 4 (high) for boat owners with lower values (31% of boat owners, $N_{<4}$ = 368) would have a similar effect and on average the proportion of boat owners who do not clean could be decreased to 5.1% (Figure 5C). If, for all boat owners, perceived costs were reduced to a medium level and, at the same time, perceived benefits and the awareness of the damage to ecosystems were increased to a high level, the proportion of boat owners who do not clean could be reduced to 1.5% (Figure 6).

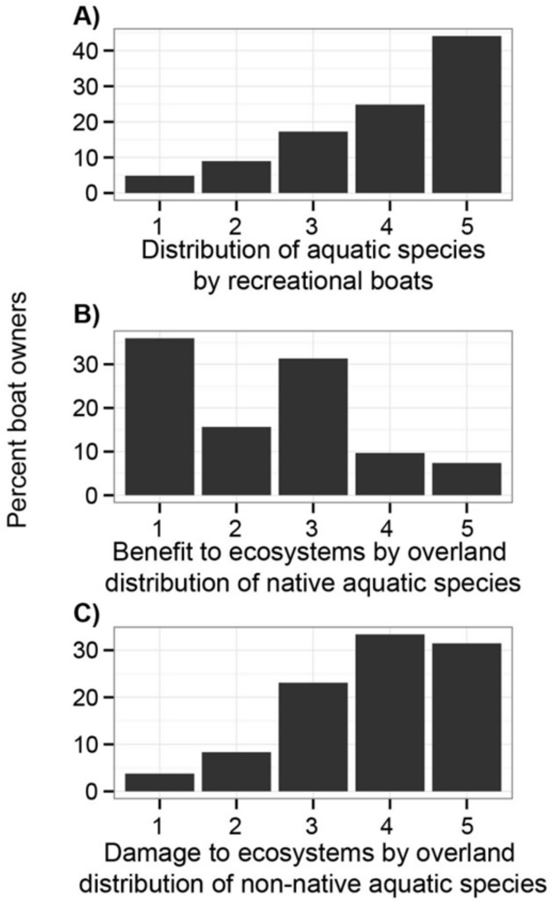

Figure 4. Percentage of boat owners who rated A) the probability that aquatic species are distributed by overland transport of recreational boats, B) the probability that aquatic ecosystems benefit from the distribution of native species by recreational boating and C) the probability of damage evoked through the spread of non-native species on aquatic ecosystems either very low (1), low (2), medium (3), high (4) or very high (5).

What characterizes boat owners who use high pressure washing before transporting their boat to another water body?

The higher the boat owners ranked the ecological damage evoked by non-native species on aquatic ecosystems, the more often they cleaned their boat using high pressure washing ($p < 0.01$, odds ratio = 1.45; Figure 5D). Our model predicts that increasing this type of awareness above a level of 4 (high) for all boat owners, would increase the average proportion of boat owners using high pressure washing from 55% to 66%. Neither the two composite variables "cleaning costs" or "cleaning benefits" nor the variables "awareness of the distribution of aquatic species by recreational boating" showed significant effects on the rate of using high pressure washing. Thus, these variables influence whether boat owners clean their boats at all, but not whether they clean it with effective or less effective methods. From this finding, we can conclude, that providing infrastructure for high pressure washing would already increase the use of the most effective boat-cleaning methods. Against our expectations, "boat usage types", "boat material" or "mussel fouling" did not show any significant effect on the rate of using high pressure washing.

Discussion

Our results show that only 8.5% of boat owners, who kept their boat year-round or seasonally in water did not clean their boat when they detected fouling water animals such as zebra mussels on their boats. Moreover, 83% of boat owners reported to clean their boats always or most times before overland transport.

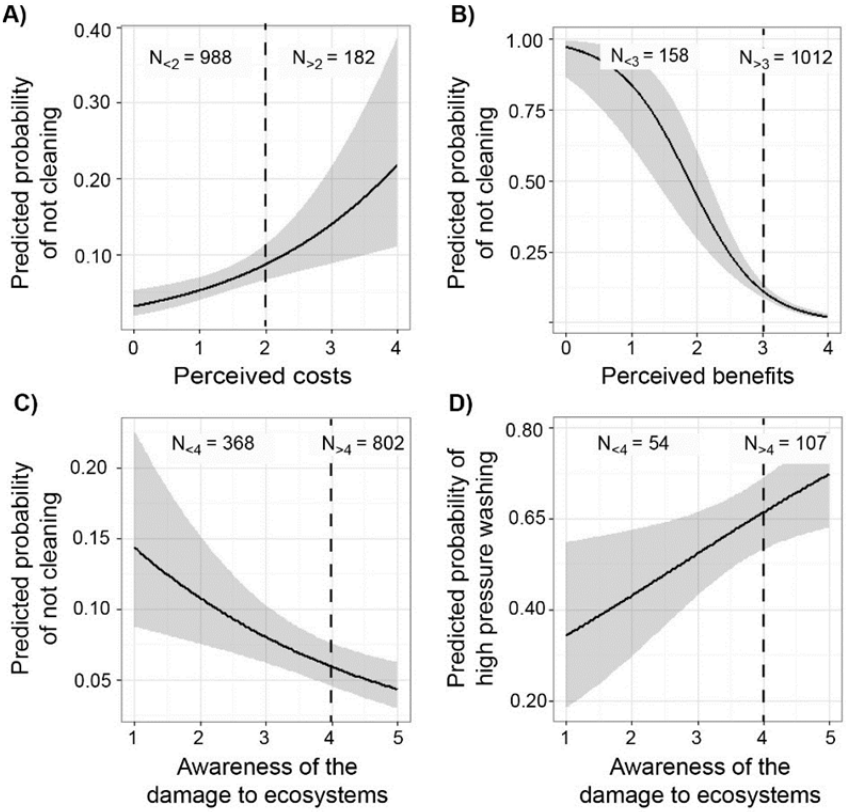

Figure 5. The predicted probabilities for boat owners not to clean their boat after finding mussels on the boat exterior, for the different levels of A) perceived costs (values between 0 = very low and 4 = very high), B) perceived benefits (values between 0 = very low and 4 = very high) and C) the awareness of the damage to ecosystems evoked by aquatic non-native species (values between 1 = very low and 5 = very high). The grey area depicts the standard errors of the predicted probabilities. D) The predicted probabilities for boat owners to clean their boat with high pressure washing before transporting a boat, for the different levels of how boat owners valued the damage on aquatic ecosystems evoked through the spread of non-native species. In the four predictive scenarios, we assume that measures may shift the values of perceived costs below 2, of perceived benefits above 3, and of the awareness of the negative impacts above 4, indicated by the dashed lines. We also show how many boat owners belonged to the group below or above the dashed lines (N).

These can be considered high rates, as there are currently no regulations in Switzerland and very few public awareness campaigns have been undertaken to encourage boat owners to clean their boats and prevent transport of non-native species overland. These self-reported boat cleaning rates are higher than the results of the North American study by Rothlisberger (2010), who found that two thirds of boat owners did not clean their boat before a transport. Thus, the underlying willingness to clean the boat seems to be high in Switzerland and the behavior of boat owners might be different in Switzerland from those in the United States. Unfortunately, we have not found information about boat cleaning rates in the Great Lakes region before authorities started to take measures. Thus, it is difficult to quantify the impact of those measures and information campaigns.

The predictions retrieved from our model on boat cleaning show that measures changing the perceived costs and benefits and the awareness of the damage to ecosystems evoked by non-native species, could have a strong effect on boat cleaning rates. A reduction in the perceived costs such as time expenditure, strenuousness, or difficulty may be achieved by providing improved cleaning facilities and cleaning instructions to boat owners at harbors and boat ramps. Moreover, providing information on the problems caused by species invasions may increase the awareness of the damage caused by non-native species. We assumed that the above mentioned measures may have the strongest effect on boat owners who declared perceived costs above the population mean (= 1.3) and perceived benefits or the awareness of the damage to ecosystems below the population

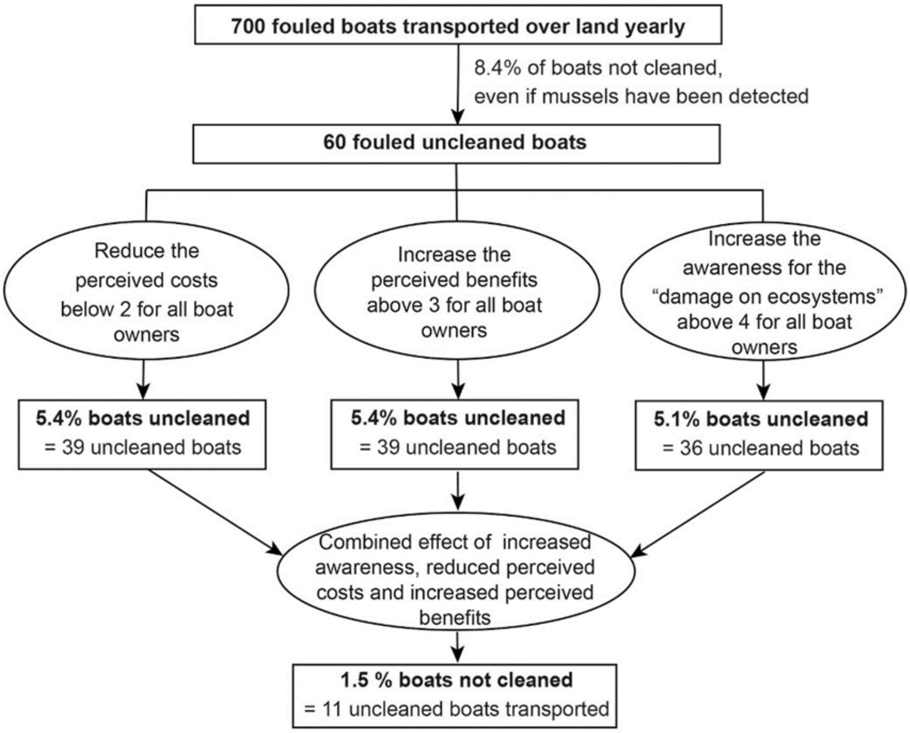

Figure 6. Flow chart showing the effects of reducing the perceived cleaning costs, of increasing the perceived benefits of cleaning, of increasing the awareness of the damage to ecosystems or a combination of all three measures on boat cleaning behavior (whether a boat is cleaned or not after mussels have been detected). Numbers show how many boats are NOT cleaned and thus may act as an overland transport vector of zebra mussels.

means (3.35 and 3.8, respectively). Thus, we present three scenarios where the three independent variables are shifted below or above certain values for all boat owners, which lay close to the population means (Figure 5). All three scenarios would reduce the proportion of uncleaned boats to 5.4%, 5.4% and 5.1% respectively, compared to 8.1% if no measures are taken (Figure 6). It is still possible that such reduction is not enough to reduce the spread of non-native species sufficiently. Nevertheless, our model further predicts that if effective measures were taken on all three aspects the reduction in uncleaned boats would be significantly higher leaving roughly 1.5% boats uncleaned (Figure 6).

Even if cleaning rates are high and might be considerably increased by the measures described above, only half of the investigated boat owners always or most of the time use high pressure washing to clean their boat before a transport. High pressure washing and hot water sprays (Morse 2009; Rothlisberger et al. 2010; Comeau et al. 2011) are known to be the most effective methods to completely remove fouling mussels. Since boat owners in our study area rarely have the equipment for washing with hot water (neither at harbors, boat ramps, or at home), we did not distinguish between high pressure washing with hot or cold water in the questionnaire. Nevertheless, our results suggest that the number of transport events of infested boats is reduced by roughly 50% through boat cleaning, in a best case scenario (assuming that boat owners who declared to high pressure wash their boat also have used this method effectively). As the other cleaning methods such as scraping, brushing or low pressure rinsing are considered to be less effective (not tested in this study), increasing the rate of high pressure washing may be crucial to considerably reduce the proportion of boats transporting zebra mussels and potentially other invasive species (e.g. quagga mussels or resting stages of invasive bryozoans).

Informing boat owners about the fact that recreational boats might spread non-native species and that those species may have negative impacts on ecosystems and socioeconomics, could increase the rate of high pressure washing (from 55% to 66%) but will likely not be sufficient to prevent spread (Table 3A,

Figure 5D). Unfortunately, the data set to test which variables would affect the rate of high pressure washing was relatively small (N = 176) because we asked boat owners about their use of different cleaning methods only in the cases of an overland transport and only a few owners of water moored boats had also transported their boat overland. We also did not explicitly ask boat owners about their reasons for their choice of cleaning method. One such reason might be that boat owners often do not have high pressure washing facilities available, as we have learnt from discussions with boat owners and authorities. In an ideal situation, authorities and boating clubs would provide washing stations with high pressure and hot water at each harbor, boat ramp or other places where boats are frequently taken out of the water along with information panels on how to clean a boat appropriately and effectively. The effects of providing high pressure washing stations on the rate of appropriate boat cleaning were not tested in this study. However, such measures would certainly help to convince more boat owners to use this method when washing their boat. Providing effective cleaning facilities, may also translate into reduced values of perceived costs such as "difficulty" or "time expenditure" and thus result into higher cleaning rates as shown in our predictive model (Figure 5).

A relatively high proportion of boat owners (16.5%) acknowledged that it is difficult to clean the boat completely of mussels and reported that they had not succeeded in doing so. From our discussions with workers at shipyards, we learned that even with knowledge and the appropriate equipment it can be difficult to remove all mussels from the engine area and other irregularities on the boat exterior. Furthermore, considering that a large proportion of moored boats were infested with very small mussels (< 5mm), which are difficult to detect with the untrained eye (De Ventura et al. 2016), a significant proportion of boat owners may not be aware that their boat was infested. For those reasons, the proportion of boat owners not removing (all) mussels from their boats might be underestimated in our data. As the results on whether boat owners clean their boat "upon finding mussels" or "before a transport" showed similar cleaning rates, the cleaning rate itself might not be so much overestimated as the cleaning success. This finding again shows the importance of clear instructions on boat cleaning skills and providing appropriate boat cleaning facilities to boat owners, or having boats cleaned in shipyards were appropriate cleaning tools and know-how are present.

Additionally, a quarantine time (of at least two weeks) where boats are dried and kept out of water before they can be transported to a new water body might reduce the overland transport of invasive mussels. Zebra mussels larger than 10 mm can survive up to 10 days out of water (Ricciardi et al. 1995) while smaller zebra mussels were found to survive for up to two days at 25 °C air temperature (De Ventura et al. 2016). For seasonally or year-round moored boats, half of the boats were kept only two days or less on land, likely allowing the survival of zebra mussels during the transport. The problem with a quarantine time is that mussels might survive in places in or on the boat that stay moist during the quarantine time and which are also difficult to clean. Nevertheless, we think that an increase in appropriate boat cleaning potentially coupled with a quarantine time may greatly reduce the overland transportation rate of zebra mussels and other aquatic invasive species.

Conclusions

In Switzerland, the majority of boat owners that responded to our survey cleaned their boat when they detected mussels and also before transporting their boat overland. Almost 90% of respondents were aware (medium to very high awareness) that recreational boats can distribute aquatic species and that those may have negative impacts on ecosystems. This might indicate that Swiss boat owners are generally amenable to information campaigns providing information on invasive species and advice on how to prevent the spread of invasive species through appropriate boat cleaning. Based upon our results, we note the following outcomes and suggested measures.

First, it is most important that information campaigns are carried out at all potentially infested water bodies to inform boat owners about appropriate cleaning methods to eliminate invasive species from their boat effectively. Second, we suggest that high pressure washing facilities (preferably with hot water) are provided by authorities in these places. Third, the cleaning rate might be further increased by changing how people perceive the costs and benefits of cleaning and how they value the damage on aquatic ecosystems caused by the distribution of non-native species (Figure 6). Additionally, we recommend that a quarantine time should be implemented for seasonally and year-round moored boats. Cleaning is hard to control even if it is regulated and also a quarantine time might not always be followed. It is questionable whether incentives, such as rebates for cleaning, or penalties for failing to clean would be effective measures as they are difficult to be passed by a democratic process and then, controlled and enforced. Nevertheless, if underlying willingness for boat cleaning is as high as in our study, the above mentioned measures may be effective to significantly reduce the overland transport of mussels and thus, effectively slow down or prevent the further spread of zebra and quagga mussels.

We want to highlight that for Switzerland, measures should be taken as soon as possible, since the quagga mussel has already arrived in a harbor in Basel (De Ventura 2015, unpublished data) and has the potential to spread further from there. Quagga mussels were often found to spread slower than zebra mussels but in many cases eventually invaded the same habitat as the zebra mussel and displaced its congener (Karatayev et al. 2011). We thus urgently recommend to apply the suggested measures to prevent the further distribution of zebra mussels by recreational boats.

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Supplementary material

The following supplementary material is available for this article:

Figure S1. Percent of boats per boat type are shown for each of the cantons.

Table S1. A summary of the survey results showing all variables discussed in this paper.

Table S2. Overview on the spearman correlation structure of continuous and ordinal explanatory variables tested in the models for the dependent variables ‘boat cleaning’ and ‘high pressure washing’.

Table S3. Spearman correlations of explanatory variables, including categorical variables, tested in the models for A) boat cleaning and B) high pressure washing.

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