Sensitivity of native and introduced fish species to changes in flow velocity of European rivers

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Introduction

In order to evaluate the current and future impact of river modifications on native and non-native fish species assemblages there is a need to collate data on sensitivity of various species groups to individual and multiple environmental stressors (i.e, physical, chemical and biological factors). These data can be used to model and to assess the individual and combined effects of these stressors on native and non-native fish species.

This study focusses on tolerance of riverine fish species to flow velocity because changes in flow velocity conditions are recognized as an important stress factor for fish species. During the last century, most European rivers have been heavily modified to facilitate water use, navigation and other ecosystem services. These modifications alter the physical and hydrological river conditions resulting in changes in river flow velocity (e.g., increase in variability and extreme flow conditions). For instance, rheophilous species will face too low flow velocity in impounded river sections, whereas in free flowing streams an increase in flow velocity variability may cause a limiting factor for limnophilous biodiversity. Navigation induced water displacement adds extreme variation in water flow velocity to already altered flow conditions (Del Signore et al., 2015). In addition to the direct human mediated modifications, climate change affects river flow velocity conditions (Middelkoop et al., 2001; Verzano et al., 2012; Arnell and Gosling, 2013; Van Vliet et al., 2013). Precipitation will become more seasonal and intense, also influencing flow velocity conditions of rivers (Arnell and Gosling, 2013; Van Vliet et al., 2013).

Riverine ecosystems are also colonized by unintentional and deliberately introduced fish species. Differential sensitivity of native and non-native species to changes in flow velocity may affect species composition of riverine ecosystems and competitive interactions between species. We hypothesize that 1) the maximum flow velocity tolerance differ between both species groups since differential sensitivity was also found for several other environmental stressors, such as temperature (Leuven et al., 2011), and 2) that species sensitivity distributions for maximum flow conditions differ for various river catchment in Europe.

Method

The flow velocity sensitivity database constructed by Del Signore et al. (2015) was updated and extended by a literature search using Google Scholar, with the search term consisting of 'Latin species name' and 'flow velocity'. All native and non-native fish species occurring in European rivers were included in this literature search. The first 50 search results were included in the literature review. If a search resulted in less than 50 hits, a second search was performed using only the term 'flow' in combination with the Latin species name.

The flow velocity sensitivities of adult fish species were then analysed using species sensitivity distributions (SSDs), a model that describes the mean sensitivity and the range of sensitivity of a set of species to an environmental limitation (Aldenberg et al., 2002; Posthuma et al., 2002), expressed as the potentially not occurring fraction (PNOF) of species. SSDs were constructed using the statistical software R (R Version 3.2.0; R Core Team, 2015) through fitting a log normal distribution to the data. Subsequently, the mean (μ), standard deviation (StDev, σ) and certainty of each parameter were calculated for each SSDs. Three subsets were made based on the origin of a species: 1) European native species; 2) European species that are present in European rivers outside their native range; 3) Non-European species that were introduced in European rivers.

Differences in PNOF between the three fish species groups were analysed using equation. 1:

$$Z = \frac{x_1 - x_2}{\sqrt{SEx_1 + SEx_2}}$$

where X_1 and X_2 represent either the μ or σ of the compared SSDs and SE_{x1} and SE_{x2} are the standard error of the used

Table 1. The mean tolerance and standard deviation (StDev) of the species sensitivity distributions for the three different subsets using data on maximum flow velocity tolerance of fish species.

	Mean tolerance*	StDev*	Data points (n)
EU native	1.919 (0.045)	0.357 (0.032)	62
EU non-native	1.774 (0.068)	0.347 (0.048)	26
non-EU non-native	1.723 (0.095)	0.454 (0.067)	23

*Standard error between brackets

parameter (Paternoster et al., 1998). With a critical level of 0.05; differences between SSDs were not significant when the *z*-score was between -1.9599 and 1.9599.

In order to test if the PNOF curves varied at different spatial scales, additional comparisons between native and non-native species at a catchment scale were made. The non-native species subset per river consisted of all non-native species irrespective of their origin (European or non-European). Additional data was collected on the fish diversity of five major rivers of Europe. This enabled comparing the PNOF of native and non-native species groups per river. The river Rhine was included in the analyses since it serves as an invasion corridor within Europe. Furthermore, four additional rivers were selected based on their geographical distribution across Europe and data availability (Ebro, Meuse, Vistula and Danube). Subsequently, differences between the derived SSDs were analysed using equation 1.

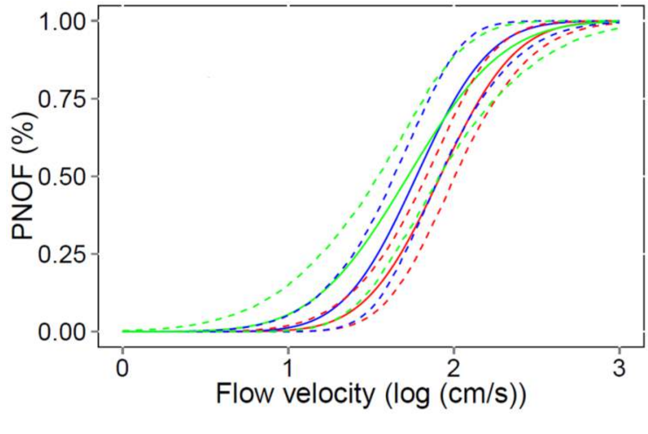

Figure 1. Species sensitivity distributions (SSDs) for log10 transformed maximum flow velocity tolerance of three groups of fish species; Red: European native species; Blue: European species that are present in European rivers outside their native range; Green: Non-European species that were introduced in European rivers. (dotted lines depict the 95% confidence interval; the parameters of each SSD are listed in table 1).

Results

The PNOF curves of native and non-native fish species based on maximum flow velocity sensitivity consistently differ at continental as well as river catchment scale (Fig. 1 and 2). However, the mean and standard deviation of the mean PNOF of native and non-native species groups do not significantly differ (Table 1).

The catchment scale analyses yield similar results as the SSDs at European scale. For all five rivers non-native species assemblages show a slightly higher mean PNOF than native species, but these differences are not statistically significant (Fig. 2; Table 2). Moreover, non-native and native species sensitivity distributions do not significantly differ between the five rivers.

Discussion

No significant difference in mean PNOFs was found between native and non-native adult freshwater fish species on a continental and catchment scale. Thus both hypotheses on differential species sensitivity for maximum flow velocity are not supported by our data. This implies that the SSDs derived at the continental level can be used to predict the PNOF of adult fish species when the maximal flow velocity of a river habitat changes. This is especially useful when data on species composition or species specific tolerance is scarce for a specific river site.

The effect of maximum flow velocity on native and non-native species diversity is equal. However, an increasing number of non-native species are currently dominating fish species assemblages in various riverine habitats. It is possible that other life stages (juveniles, larvae or eggs) of native and non-native species differ in flow velocity sensitivity, thereby explaining recent dominance shifts of species. However, there is not yet enough data available for these life stages to perform a sound SSD-PNOF analysis. In addition, other environmental factors may affect the dominance of non-native species. Therefore, several other environmental factors should be included in effect predictions of future flow velocity conditions on the establishment of non-native fish species.

An effort should be made to perform research on the flow velocity tolerance of different life stages of both native and non-native fish species. Furthermore, data on other stress factors should be collated in order to identify other limitations of native fish species that might explain a dominance shift to non-native species (e.g. temperature).

Conclusions

- SSDs for maximum flow velocity tolerance of native and non-native adult fish species did not differ significantly at continental as well as river catchment scale.
- The derived SSDs can be used to predict the potential effects of changes in maximum flow velocity on PNOF of adult fish species at various spatial scales (i.e., location, river and continent).
- In order to support appropriate ecological impact assessments and biodiversity modelling we recommend to derive SSDs for 1) minimum and optimum flow velocity, 2) variability in flow conditions, 3) different life stages, guilds and migratory groups, 4) subsets of non-native species (deliberately introduced versus unintentional), 5) other environmental factors, and 6) their combined effects.

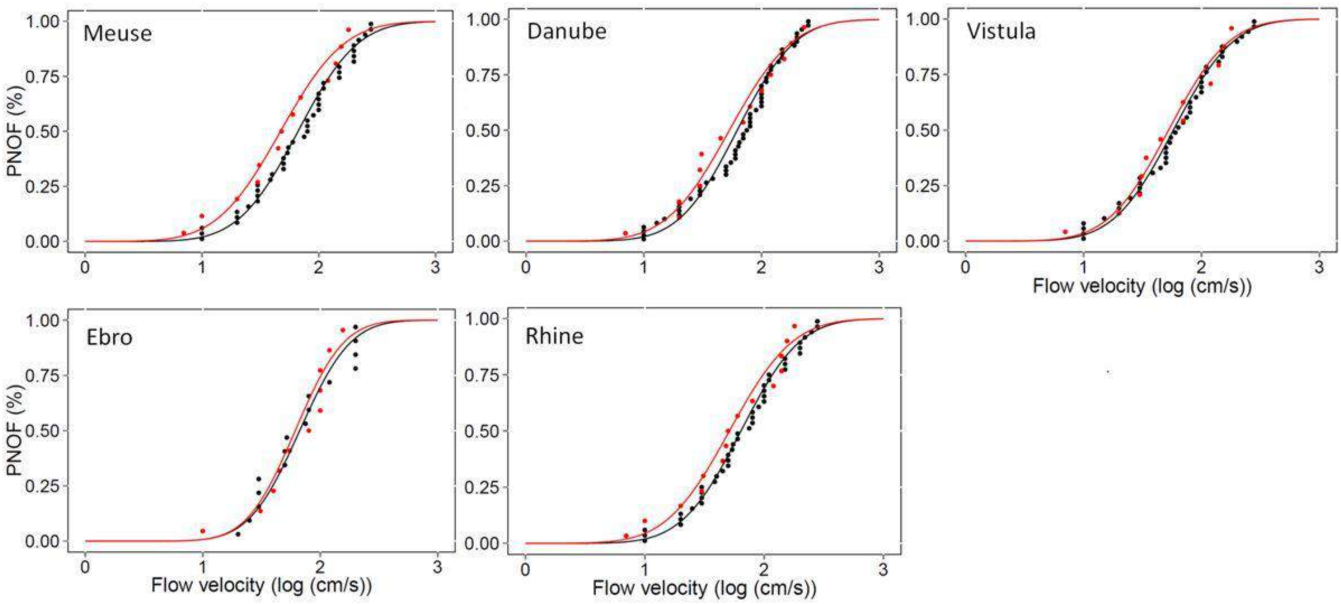

Figure 2. Species sensitivity distributions (SSDs) for log10 transformed maximum flow velocity tolerance of native (black) and non-native (red) species in the five European rivers.

Table 2. The mean tolerance and standard deviation (StDev) of the species sensitivity distributions for the five European rivers using data on maximum flow velocity tolerance of fish species.

River	Status	Mean tolerance*	StDev*	Data points (n)
Ebro	non-native	1.788 (0.098)	0.325 (0.069)	11
	native	1.826 (0.085)	0.340 (0.060)	13
Meuse	non-native	1.673 (0.119)	0.429 (0.084)	12
	native	1.823 (0.063)	0.401 (0.044)	10
Vistula	non-native	1.722 (0.116)	0.403 (0.082)	15
	native	1.763 (0.060)	0.398 (0.042)	14
Rhine	non-native	1.710 (0.108)	0.418 (0.076)	44
	native	1.796 (0.060)	0.390 (0.043)	43
Danube	non-native	1.727 (0.112)	0.420 (0.079)	42
	native	1.794 (0.052)	0.387 (0.037)	55

*Standard error between brackets

References

Aldenberg, T., Jaworska, J.S., Traas, T.P. (2002) Normal species sensitivity distributions and probabilistic ecological risk assessment. In Posthuma, L., Suter, G.W., Traas, T.P. Eds, Species sensitivity distributions in ecotoxicology. Lewis, Boca Raton, FL, USA: 49-102.

Arnell, N.W., Gosling, S.N. (2013) The impacts of climate change on river flow regimes at the global scale. Journal of Hydrology 486: 351-364.

Del Signore, A., Lenders, A.J.R., Hendriks, A.J., Vonk, J.A, Mulder, C., Leuven, R.S.E.W. (2015) Size-mediated effects of water-flow velocity on riverine fish species. River Research and Applications doi: 10.1002/rra.2847

Leuven, R.S.E.W., Hendriks, A.J., Huijbregts, M.A.J., Lenders, H.J.R., Matthews, J., van der Velde, G. (2011) Differences in sensitivity of native and exotic fish species to changes in river temperature. Current Zoology 57: 852-862.

Middelkoop, H., Daamen, K., Gellens, D., Grabs, W., Kwadijk, J.C.J., Lang, H., Parmet, B.W.A.H., Schädler, B., Schulla, J., Wilke, K. (2001) Impact of climate change on hydrological regimes and water resources management in the Rhine basin. Climate Change 49: 105-128.

Paternoster, R., Brame, R., Mazerolle, P., Piquero, A. (1998) Using the correct statistical test for the equality of regression coefficients. Criminology 36: 859-866.

Posthuma, L., Suter, G.W., Traas, T.P. (2002) Species sensitivity distributions in ecotoxicology. Lewis Publishers, Boca Raton, FL, USA.

R Core Team (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Van Vliet, M.T.H., Franssen, W.H.P., Yearsley, J.R., Ludwig, F., Haddeland, I., Lettenmaier, D.P., Kabat, P. (2013) Global river discharge and water temperature under climate change. Global Environmental Change 23: 450–464.

Verzano, K., Bärlund, I., Flörke, M., Lehner, B., Kynast, E., Voß, F., Alcamo, J. (2012) Modeling variable river flow velocity on continental scale: current situation and climate change impacts in Europe. Journal of Hydrology 424–425: 238–251.