

## **The combined effects of desiccation, temperature and salinity on mollusc species during extremely low discharges of rivers**

Effets combinés de l'assèchement, la température et la salinité sur les espèces de mollusques de rivière en période d'étiage

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### **RÉSUMÉ**

Les changements climatiques risquent d'accroître la fréquence et la durée des périodes d'étiage et de crue des cours d'eau européens. En outre, on sait que la salinité augmente en période de faible débit ainsi qu'avec l'augmentation des influences des marées dans les estuaires. Ces changements de conditions environnementales affecteront la biodiversité des cours d'eau, en particulier celles des espèces sessiles et benthiques telles que les mollusques aquatiques. Comprendre les phénomènes d'extinctions locales des espèces autochtones, ainsi que le potentiel invasif des espèces allochtones, requiert des connaissances sur les réponses de ces espèces aux changements environnementaux. Dans cette optique, nous avons évalué les effets spatio-temporels de l'assèchement, la température de l'eau et la salinité sur la fraction potentiellement affectée des espèces autochtones et allochtones de mollusques dans le Rhin. L'effet combiné de ces facteurs environnementaux est plus élevé pour les espèces autochtones que pour les espèces allochtones. L'assèchement s'avère être la principale cause de stress environnemental limitant la présence des espèces, quelle que soit leur origine. La température affecte principalement les espèces autochtones en raison de leur plus faible tolérance thermique.

### **ABSTRACT**

Climate change is expected to increase the frequency and duration of low discharge and high water temperature events in European rivers. In addition, salinity will increase during low discharges or by increase of tidal influences in river estuaries. These changing environmental conditions will affect riverine biodiversity, especially sessile and bottom dwelling species such as aquatic molluscs. Understanding local native mollusk extinction and invasiveness of exotic species requires knowledge on species responses to changing environmental conditions. Therefore, spatiotemporal effects of desiccation, water temperature and salinity on the potentially affected fraction of native and non-native mollusc species in the river Rhine were assessed. The combined effect of these environmental factors is higher for native than for non-native molluscs. Desiccation proved to be the primary environmental stressor limiting both native and non-native species presence. Temperature mainly affected native species due to their lower temperature tolerance compared to non-native, alien species.

### **KEYWORDS**

Bivalves; gastropods; native; non-native; species sensitivity distribution

## INTRODUCTION

The frequency and duration of extremely low discharges and high water temperature events in Northwestern European rivers is expected to increase due to climate change (Van Vliet et al. 2013). In addition, the salinity of river water may increase due to lower discharges and stronger tidal influences in estuarine areas caused by sea level rising (Verbrugge et al. 2012). Changes in river conditions will also affect riverine biodiversity. An increase in water temperature may lead to a shift from cold-water to thermophilic species. Decreasing discharges will result in desiccation of littoral zones in rivers and water bodies in the floodplain. Dependent on the weather conditions and duration desiccation eventually causes mortality of aquatic species due to air exposure (Collas et al. 2014). With increasing frequencies and duration of extremely low discharges, the likelihood of desiccation events in the littoral zones will also increase thereby affecting local species assemblages. Especially molluscs are sensitive to these changes in environmental conditions due to their sessile or bottom dwelling nature. Moreover, several non-native molluscs species invaded rivers in Europe and had a profound impact on biodiversity and ecosystem functioning. Understanding the responses of native and non-native species to changing river conditions will enable model predictions of climate change impact on riverine biodiversity and ecosystems. As a case study, we assessed the spatiotemporal effects of desiccation, temperature and salinity on native and non-native mollusc assemblages in the littoral zone of the river Rhine.

## 1 MATERIALS AND METHODS

Mollusc species sensitivity distributions (SSDs) were derived for desiccation, temperature and salinity (Collas et al. 2014; Verbrugge et al. 2012). These SSDs describe the variation among species in their sensitivity to an environmental factor. The mean and standard deviation of the derived SSDs were used to analyse the spatiotemporal trends of desiccation, water temperature, salinity and combined effects on mollusc species in the littoral zone of the river Rhine (i.e., a groyne field near Lobith). These effects were expressed as the potentially not occurring fraction (PNOF) of species. The combined effects of desiccation, temperature and salinity were calculated according to the following equation:

$$\text{PNOF}_{\text{DTS}} = 1 - (1 - \text{PNOF}_D) * (1 - \text{PNOF}_T) * (1 - \text{PNOF}_S)$$

Where *D*, *T* and *S* indicate desiccation, temperature and salinity, respectively. Not occurring fractions (NOFs) were derived using field survey data for this location for the period 1988-2003. The relative contributions of PNOFs for individual and multiple stressors to the NOF were calculated for the native and non-native mollusc species pool. Subsequently, a model was constructed that depicts the spatiotemporal variation of combined effects of these stressors on potential species occurrence in the littoral zone (i.e., a groyne field near Lobith). The water level, temperature and salinity data used in the model were obtained from a web-based portal ([www.waterbase.nl](http://www.waterbase.nl); Fig. 1).

## 2 RESULTS AND DISCUSSION

Comparisons of the model predictions with field data on species occurrence during the period 1988-2003 revealed that the combined PNOF explained 62 and 80% of the actual not occurring fraction for native and non-native species, respectively (data not shown). Native species were strongly affected by both desiccation and temperature (Fig. 2A). Non-native species were predominately affected by desiccation (Fig. 2B). Due to the high effect of desiccation on both native and non-native species, the combined PNOF effect is mainly determined by desiccation.

Predictions for a year with extremely low river discharges show that the combined effect of desiccation, temperature and salinity frequently limits the mollusc species occurrence in the littoral zone of the river Rhine at Lobith. The combined effect is higher for native species than for non-native species.

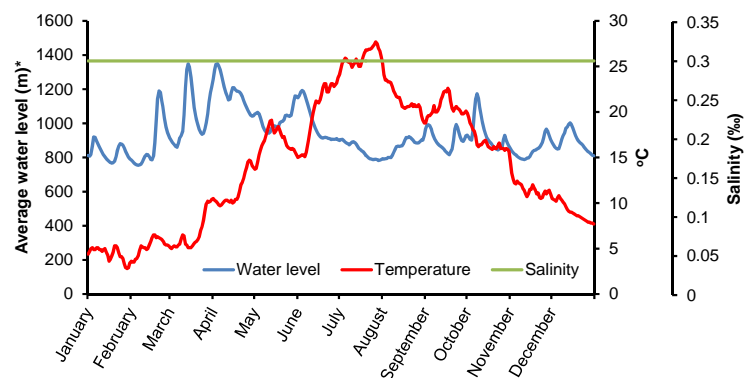


Figure 1. The water level, temperature and salinity of the river Rhine at Lobith during the year 2006 (\* Above average sea level).

Native molluscs were additionally limited during June, July and August (Fig. 3A) opposed to non-native species (Fig. 3B). Based on the previously described difference in temperature effect between native and non-native species, we can conclude that the difference in limitation during the summer is caused by high water temperatures. Our results support that desiccation is the primary environmental factor that determines diversity and composition of native and non-native mollusc assemblages.

The described approach can be used to predict the effect of climate change for the entire river continuum (from head waters to estuaries). Additionally, the concept can also be applied to other river systems when river specific SSDs are available. Further improvement is possible through including effects of other environmental factors, such as flow velocity, oxygen availability and water pollution.

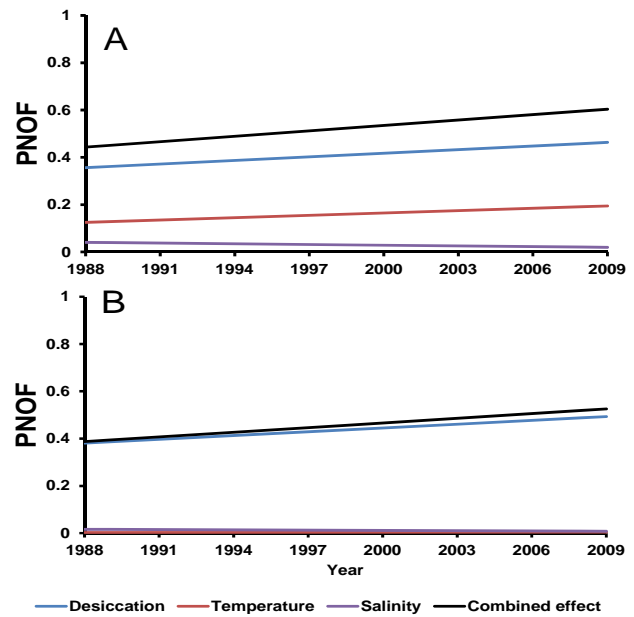


Figure 2. Linear regressions of the potentially not occurring fraction (PNOF) of (A) native and (B) non-native mollusc species calculated for desiccation, temperature, salinity and the combined effect of these stressors in the river Rhine at Lobith.

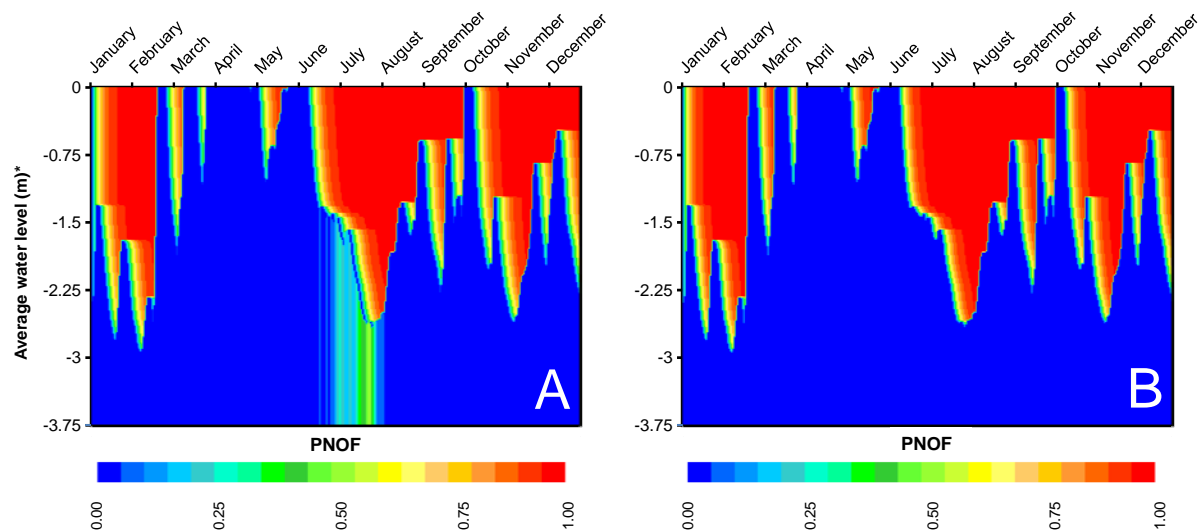


Figure 3. Potentially not occurring fraction (PNOF) due to the combined effect of desiccation, temperature and salinity on (A) native and (B) non-native molluscs in the littoral zone of the river Rhine at Lobith in the year 2006 (\* Above average sea level).

### 3 ACKNOWLEDGEMENTS

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