The role of habitat heterogeneity as driver for diversity and abundances of young-of-the-year riverine fishes

Le rôle de l'hétérogénéité de l'habitat en tant que moteur de la diversité et de l'abondance des juvéniles de poissons riverains

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RÉSUMÉ

L'hétérogénéité spatiale de l'habitat est de plus en plus reconnue comme faisant partie d'une zone d'alevinage qui fonctionne bien pour les communautés de poissons riverains. Les modèles conceptuels sur les relations entre la configuration spatiale des parcelles d'habitat et la biodiversité et l'abondance des poissons locaux dans les systèmes fluviaux ont rarement été testés avec des données empiriques. Dans cette étude, nous avons lié la qualité et la configuration spatiale des parcelles d'habitat (littoral) à la diversité et à l'abondance des poissons fluviaux YOY (jeunes de l'année), en utilisant des données à haute résolution spatiale et temporelle. Entre 2017 et 2020, nous avons collecté les données de 46 projets de restauration de plaines inondables et de 26 sites de contrôle dans le canal principal du Rhin inférieur (Pays-Bas), résultant en 2194 événements d'échantillonnage. Nous avons caractérisé l'environnement à différentes échelles spatiales (échantillon (~0,1 km), projet de restauration (~1,0 km) et niveau de la rivière (~10 km)), et avons associé 43 variables d'habitat aux abondances de poissons YOY et à la diversité gamma des poissons riverains locaux. communauté via une approche multivariée par étapes. Nous présentons ici les résultats préliminaires de notre approche et discutons des aspects de l'environnement local et de son hétérogénéité qui sont les plus critiques pour différents indicateurs de l'état des communautés de poissons riverains dans le bas Rhin.

ABSTRACT

Spatial habitat heterogeneity is increasingly recognized as part of a well-functioning nursery area for riverine fish communities. Conceptual models on the relationships between spatial configuration of habitat patches and local fish biodiversity and abundances in riverine systems have been rarely tested with empirical data. In this study we related the quality and spatial configuration of (shoreline) habitat patches to the diversity and abundance of YOY (young-of-the-year) riverine fishes, using spatially and temporally high-resolution data. Between 2017-2020 we collected data from 46 floodplain restoration projects and 26 control sites in the main channel of the lower river Rhine (the Netherlands), resulting in 2194 sampling events. We characterised the environment on different spatial scales (sample (~0.1 km), restoration project (~1.0 km) and river level (~10 km)), and related 43 habitat variables to YOY fish abundances and species richness of the local riverine fish community via a stepwise multivariate approach. Here we present preliminary results of our approach and discuss which aspects of the local environment and its heterogeneity are most critical for different indicators of riverine fish community status in the lower river Rhine.

KEYWORDS

Biodiversity, ecological responses, nursery habitat, riverine fish community, river restoration

1 INTRODUCTION

To improve recruitment success and biodiversity of riverine fish in the lower river Rhine, authorities in the Netherlands have reconstructed numerous floodplains since the 1990s.This resulted in local habitat of increased quality, but not in the expected increase in diversity and abundance of riverine fishes. The lack of substantial improvement of the riverine fish community may be caused by a mismatch in the spatial configuration of nursery habitats in the reconstructed floodplains, as compared to the historical, natural floodplains. Throughout their life, riverine fishes require different functional habitats of suitable environmental conditions for each specific stage (Stoffers et al., 2021). Nursery habitat conditions are directly influenced by hydromorphological (e.g.: water flow, substratum type) and biotic variables (e.g.: food availability, chlorophyll), as well as by water quality parameters (e.g.: conductivity, turbidity). The proper scale and spatial organisation (habitat heterogeneity) of essential habitats at these early life stages contributes greatly to the their survival (Van Looy et al., 2019; Ward et al., 1999). The objectives of this study were to (1) evaluate the functioning of different types of floodplain restoration projects as nursery area for the riverine fish community, and (2) identify the most important nursery habitat components, including the role of habitat heterogeneity.

2 METHODS

We collected a detailed data set on YOY riverine fish communities and their physical habitat preferences in 46 floodplain restoration projects in 3 branches of the lower river Rhine (the Netherlands), as well as in 26 control sites in the main channel. We evaluated the nursery function of isolated waters, tidal channels, one-sided connected channels (1SC) and two-sided connected channels (2SC). Fish communities were assessed as a whole (including all species), and as rheophilic, eurytopic and limnophilic fish community. Communities were assessed by abundances (fish per 100m^2), and species richness (diversity at restoration project level).

We characterised habitat variables on three relevant spatial scales for YOY fish: sample level (~0.1 km), project level (~1.0 km) and river level (~10 km). Many of the 42 habitat variables were measured during field sampling, while floodplain channel metrics and data on habitat heterogeneity was retrieved from satellite images and aerial photographs taken annually. We used multivariate analysis (RDA: Redundancy Analysis) with a stepwise modelling approach to identify the most important nursery habitat components for rheophilic, eurytopic and limnophilic fish abundances (Figure 1).

3 RESULTS AND DISCUSSION

From 2017-2020, we collected fish community data for 46 restoration projects and 26 control sites (main channel), resulting in 1253 sampling sites. Fish were recorded at each restoration project type, but abundances varied greatly. Highest abundances of YOY fish were found in 1SC (293.3±99.9 fish per 100m^2), followed by 2SC (133.6±37.4). For respectively the main channel and tidal channels we recorded mean abundances that were 11 to 18 times lower than for 1SC. Species richness was highest for 2SC (15.9±0.8 species per project) and 1SC (14.5±0.7), whereas diversity was significantly lower for tidal channels, isolated waters, and the main channel.

Table 1. Overview of fish community responses for control and floodplain restoration project types. Fish responses are shown as mean ± se fish per 100m^2. Means were tested for significance with a Kruskal–Wallis H-test. Dunn's test with Bonferroni correction was used to test for pairwise comparison between project types.

		Control	Restoration project type			
Ecological guild	Fish response	Main channel (N=39)	Isolated water (N=11)	Tidal channel (N=18)	1SC (N=53)	2SC (N=61)
Fish community	Abundances	24.5±7.9^b	114.6±42.3^b	16.4±6.2^b	293.3±99.9^a	133.6±37.4^a
	Species richness	7.9±0.8^b	7.4±1.4^b	9.3±1.0^b	14.5±0.7^a	15.9±0.8^a
Eurytopics	Abundances	21.2±8.1^c	52.8±15.9^{bc}	15.4±6.1^c	277.6±97.6^a	111.1±32.4^{ab}
	Species richness	4.8±0.6^b	5.4±1.3^b	6.5±0.4^b	9.1±0.4^a	8.9±0.4^a
Rheophilics	Abundances	3.2±1.0^b	0.0±0.0^c	1.0±0.1^{bc}	7.8±2.1^{ab}	12.8±2.4^a
	Species richness	2.4±0.2^{bc}	0.4±0.4^c	2.3±0.3^{bc}	2.4±0.3^b	4.6±0.4^a
Limnophilics	Abundances	0.0±0.0^b	61.8±44.7^a		8.0±7.6^a	9.7±9.5^{ab}
	Species richness	0.1±0.1^b	1.4±0.4^a		1.2±0.3^a	0.67±0.20^{ab}

For common eurytopic species such as roach (*Rutilus rutilus*), perch (*Perca fluviatilis*) and bream (*Abramis brama*) we observed similar patterns in community responses between the different restoration project types, as for the overall fish community. Both abundances and species richness of rheophilic species, such as ide (*Leuciscus idus*), nase (*Chondrostoma nasus*), and barbel (*Barbus barbus*), were significantly higher for 2SC than for other project types. In contrast to the other ecological guilds, rheophilic species richness for sites in the main channel was not significantly different from 1SC. Rheophilics were least observed (or even absent) in isolated waters, whereas both abundances and species richness of the YOY limnophilic fish community was highest for this restoration project type.

Overall, with highest levels of YOY fish abundances and species richness, 1SC and 2SC provide best nursery conditions for YOY fish from all studied restoration project types. 1SC and 2SC primarily differ in flow conditions and therefore in the presence of habitats with permanent water flow and larger substrates, which may be the reason why more critical rheophilic (flow-loving) fish prefer 2SC over 1SC.

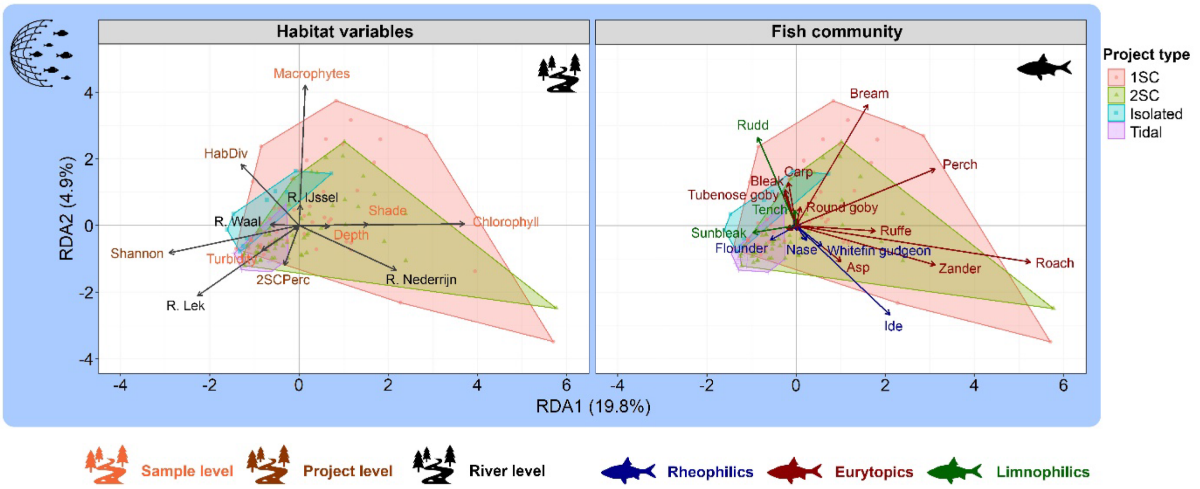

Figure 1. Redundancy Analysis (RDA) for YOY fish abundances (right panel) in 1SC and 2SC in relation to habitat variables (left panel) on different spatial scales in restoration projects of the lower river Rhine.

Abundances of YOY fish were most explained by 10 habitat variables (Figure 1; left panel). On sample level water depth, presence of macrophytes, chlorophyll and turbidity levels of the water, and shade were important. On project level the frequency of two-sided connectivity (2SCPerc), the Shannon habitat diversity index (Shannon), and shoreline habitat heterogeneity (HabDiv) were important. Eurytopics were more abundant in habitats with high levels of chlorophyll, shade and in the rivers Nederrijn and IJssel (Figure 1; right panel). The eurytopic species bream, common carp (*Cyprinus carpio)*, and bleak (*Alburnus alburnus*) and the limnophilic species rudd (*Scardinius erythrophthalmus*) were positively affected by the presence of macrophytes and high levels of habitat heterogeneity. On the other hand, abundances of rheophilic species nase, ide and whitefin gudgeon (*Romanogobio belingi*) were negatively affected by habitat heterogeneity. Rheophilic fishes mainly prefer habitats/projects with a high frequency of two-sided connectivity.

The role of spatial habitat heterogeneity in nursery habitat of riverine fishes is therefore ambiguous. Increased levels of shoreline habitat diversity and the Shannon index had a positive effect on abundances of many eurytopic and limnophilic species, whereas most rheophilic species were negatively affected by habitat diversity. For abundances of rheophilic to increase, first habitat conditions on a higher spatial scale (project level), such as permanent two-sided connectivity with the main channel, should be in order. If this criteria is not met, rheophilic fish abundances will be low or even non-existent. Eurytopic fishes show a high preference for a wide range of habitat variables on the smallest spatial scale (sample level), which probably explains their overall dominance in YOY fish communities in Dutch floodplain restoration projects. For the effective management and evaluation of floodplain restoration projects it is essential to take different spatial scales into account, as different components of the YOY riverine fish community may respond differently to habitat variables on different scales.

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