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Do human disturbance variables influence more on fish community structure and function than natural variables in the Wei River basin, China?

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ABSTRACT

Quantifying how human disturbance affects biotic communities in the context of other natural and spatial factors is a vital precursor to develop environmental management strategies to effectively conserve and restore ecosystem. This is particularly so for freshwater ecosystems in heavily populated and increasingly disturbed regions such as the Wei River basin in north-west China. In this paper, we employed both species' abundance and functional metrics (displaying species diversity, habitat, trophic level, tolerance and abundance) to quantify the effect of human disturbance using canonical correspondence analysis. The results showed that spatial, natural and human disturbance variables can explain 40.1% and 33.7% of the total variation in fish abundance without rare species and with all species, respectively. 37.1% and 37.9% variation can be explained in fish metrics without rare species and with all species. Human disturbance variables explained most of the total variations in the four fish matrices. Inclusion or exclusion of rare species will influence the total explained variation from three factors in fish metrics, but little in fish abundance. Rare species will highlight this relationship with human disturbance gradient. For fish metrics, removing rare species will reflect some wrong information for human disturbance gradient. We recommend to include rare species for fish metrics to assess the impact of environment.

1. Introduction

Aquatic ecosystem is of great importance to provide many goods, services and long-term benefits to human society, and the intense human activities, such as flow regulation, water pollution, and land use practices, make it become highly stressed and degraded (Meyer, 1997; Rapport et al., 1998). Growing concern about human disturbance on aquatic ecosystem health has led to increasing recognition of assessing ecosystem health and monitoring biotic responses to environmental degradation. Under the pressure of human activities such as dams construction (Marchetti and Moyle, 2001), sewage effluents (Figuerola et al., 2012), and land use (Saalfeld et al., 2012), many freshwater species have become extinct or are highly endangered (Darwall et al., 2008). In addition, the distribution, abundance and functional attributes of fishes are often simultaneously influenced by a variety of environmental factors operating by spatial position (Schlosser and Angermeier, 1995), and regional climatic condition (Magnan et al., 2010). Longitudinal position is an important factor for fish-assemblage composition and structure (Esselman et al., 2006). At present differences in fish abundance may relate more to changes in local microhabitat features than to any pervasive effect of stream order or longitudinal position in stream systems (Matthews, 1986). Understanding how natural and human disturbance shape the present-day diversity and composition of fish community is needed to effectively manage and conserve freshwater ecosystem in the future (Olden et al., 2010).

This is even more necessary in the rapidly developing countries with heavily human disturbance, such as the Wei River basin in the northwest China. The Wei River, located in the north-west China, is the transitional area between arid and humid zone. Over the past 30 years, intensified human activities made a huge negative impact on the Wei River basin, characterized by decreasing annual runoff, heavy pollution and high sediment concentration (Song et al., 2007;

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Wu et al., 2012). All of the above changes lead to fish decreasing dramatically, and make fish species highly vulnerable to human disturbance.

Several researches focused on partitioning variation of fish species abundance or traits into spatial, temporal and environmental factors (Anderson and Cribble, 1998; Sternberg and Kennard, 2013; Stewart-Koster et al., 2007). However, few studies distinguish the variation of human disturbance from that of natural and spatial variables to fish community. Ecologists traditionally have used fish occurrence and abundance as the descriptor of fish community. However, fish metrics describing fish compositions, native, migration, habitat preference, trophic guild and tolerance, are used to represent fish community. These metrics are improved based on original one developed by Karr, which reflect insights from several perspectives to fish study. Although these metrics are sometimes redundant because several may be sensitive to the same impact, in the aggregate they appear to be responsive to changes of relatively small magnitude as well as to broad ranges of environmental degradation (Karr et al., 1986). In this highly human disturbed river, it is vital to quantify the role of spatial, natural and human disturbance, and interactive impacts of them that influence different aspects of the fish communities. Most researches on assessing the ecosystem health exclude the rare species in order to reduce the noise from them (Hermoso and Linke, 2012), but if the abundance of sensitive species is low and spatial and temporal heterogeneity is high, it will increase the probability of failing to detect an impact or underestimating one (Cao et al., 2001; Ford, 1989). Identifying the importance of rare species will help to improve the probability of assessing ecosystem health. We hypothesize that human disturbance variables have a high impact on fish community structure and function, and rare species in the Wei River are important to estimate the impact of human disturbance, and it should be included when using fish as indicators to evaluate ecosystem health.

The aim of the present study was to quantify the impact of human disturbance, natural and spatial variables on fish abundance and metrics. First, we quantify how human disturbance affects fish abundance and functional metrics in the context of other natural and spatial drivers, and try to identify the noise of rare species to the quantification. Second, we understand how human disturbances influence different aspects of the fish communities, i.e., which species and/or which metrics are correlated with particular disturbance gradients. By these analyses, we aim to identify the indicator species or metrics that will response sensitively to particular human disturbance gradient, which will be a great reference for ecosystem protection and restoration.

2. Method

2.1. Study area and sample sites

The Wei River originates from Niaoshu Mountain, and flows through Gansu, Ningxia and Shaanxi province with a watershed area of 134,800 km^2. The Wei River is the largest tributary of the Yellow River, where the annual flow flux and annual sediment discharge account for 16.5% and 2.5%, respectively, of the total amount of the Yellow River basin (Song et al., 2010). The Wei River is located in the central part of China, which is the transition area of arid and semi-humid climate. The majority of rainfall occurs in the summer months from July to October. The flow regime of this river is highly variable both inter-annually and seasonally and low and high flows may occur any time of year. With progression downstream, the Wei River is increasingly disturbed by urban development, intensive agriculture, non-point source pollutants, flow alteration and major barriers to fish movement caused by numerous large dams and reservoirs (China, 2001; Song et al., 2007; Zhan et al., 2011). Industrial wastewater effluents and domestic disposal plant effluents arising from big cities in the Guanzhong area (Fig. 1) are causing high nutrient and organic pollution and runoff from agricultural areas is causing high sediment concentrations and loss of aquatic habitat quality and quantity (Song et al., 2007; Zhan et al., 2011).

Sixty study sites (Fig. 1) were distributed widely throughout the catchment to encompass as much of the natural biological and environmental variation as possible. Each site was sampled in the wet season (October 2012) and dry season (April 2013) to encompass a wide range of hydrological conditions.

2.2. Fish information

Fishes were collected for 30 min in three habitats (i.e., pools, riffles, and runs) within 200–300 m at each site, and the individuals in the three habitats were combined to represent the fish community at each site. Fish collection in wadeable streams (<1.5 m maximum depth) was performed by two people, i.e., one individual used the backpack electrofisher with two hand-held electrodes and one was responsible for netting fish with dip nets. In the unwadeable streams, seines (mesh sizes of 30 mm and 40 mm) were used for fish sampling by boat, and electrofishing equipment was employed to ensure a good representation of the fish at the site. All of the individuals (with a total length longer than 20 mm) collected were identified by species, counted, and recorded on field data sheets. Individuals with a total length less than 20 mm were not identified or included in the standard samples. Specimens that could not be identified in the field were preserved in a 10% formalin solution and stored in labeled jars for subsequent laboratory identification. The fish were identified according to Fishes in the Qinling Mountains area (Chen et al., 1987).

We characterized fish communities at the study sites using individual species' abundances and summary metrics of fish community structure and function. Fish metrics were derived from a functional guild classification of each species based on their ecological characteristics (see Appendix I). The 39 metrics describe the species diversity, migration, reproductive guild, habitat, tolerance and abundance (Table 1) (Jia et al., 2013; Karr, 1981). Functional attributes were based on a number of sources of information, including ichthyography (e.g. Fishes in Qinling Mountain area), existing literature, state agency reports, graduate theses and electronic databases available on the World Wide Web (e.g. FishBase). Functional traits with no information were inferred from closely related species (Olden et al., 2006).

Using this information, four fish matrices were derived to quantify the response of fish community to different environmental gradients: (1) fish abundances without rare species; (2) fish abundances with all species; (3) fish metrics without rare species; and (4) fish metrics with all species. Rare species were considered as species present in less than 5% of localities, and non-catching species in the sampling time were excluded in the analysis (see Appendix I).

2.3. Environmental data

We assembled three sets of explanatory variables for use in the variance partitioning analyses: spatial, natural environment and human disturbance (Table 2).

2.3.1. Spatial data

In order to investigate the influence of spatial arrangement of study sites on fish communities, geographical coordinates (longitude and latitude) were estimated for each site and centered on their means to reduce collinearity in the spatial variables. We calculated all terms of a cubic trend surface regression, consisting of