Original Research

The Effects of Bridge Abutments on the Benthic Macroinvertebrate Community

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Abstract

A river ecosystem is a treasure that is home to a wide variety of wetland species. The construction of bridges might have a deep impact on diversity of such an ecosystem. The ecological consequence of bridge abutments was studied by monitoring the benthic macroinvertebrate community at six main bridges on the Tuhai and Majia rivers in eastern China. We collected samples of macroinvertebrates from upstream to downstream during the summer hight-water period, and we monitored water quality at each site. The macroinvertebrate community of under-bridge sites was significantly correlated with that of reference sites in abundance, biomass, and richness. The benthic macroinvertebrate communities were not significantly different between under-bridge sites and reference sites in terms of abundance and biomass, while they were significantly different in terms of richness and the Shannon-Wiener index. This pattern outlined a major impact of bridge abutments on benthic macroinvertebrate communities for the first time, indicating the importance of habitat restoration after river construction was finished. Suitable measures should be taken to minimize the impact of bridge abutments.

Keywords: alluvial bank, benthic macroinvertebrate, bridge abutment, river ecosystem, sediment deposition

Introduction

An aquatic ecosystem can be impacted and fragmentized by a variety of stressors, including excess input of nutrients, geomorphological alterations, land use changes, hydrological stress, invasive species, and pathogens [1-4]. Fine-grained sediment has long been recognized as a major pollutant source that causes degradation of surface water bodies [5, 6]. Excessive transport of sediment-bound nutrients to surface waters causes eutrophication of streams, rivers, and lakes, decreasing their recreational value. These fluvial sediments are important not only because of the massive amounts of chemicals and nutrients delivered with the sediments, but also the morphological changes [7-11].

Studies of sediment flux, its dispersal pattern, and geomorphological impact have also increasingly received attention [12-15]. Intensive studies about the impacts of hydraulic engineering have been conducted, i.e., the effects of the Three Gorges Reservoir on the macroinvertebrate community has been carried out over the past several

years [4, 16]. Different processes that could contribute to sedimentation problems include erosion of uplands and channel bank collapse/erosion [17]. The linkage among upland erosion, sediment mobilization, and downstream sediment yield is complex due to uncertainties associated with sediment retention and storage at intermediate locations such as floodplains, streambeds, and foots of hill slopes [18]. The increase in deposition and storage of fine sediment on stream beds could result in the degradation of the physical, chemical, and biological status of watersheds [19, 20]. Fine sediment deposition on streambeds can cause damage to salmonid spawning beds by reducing the oxygen supply to hatching ova and invertebrates [21]. Only a few studies have focus on impacts of fine sediment deposition on macroinvertebrates [22].

Bridge abutments, the inevitable artificial structures across rivers, are places that easily collect deposits. During the low-water period, the sluices are shut down to meet the need of irrigation water demand. The sediments easily deposit around the abutments because of the low flow velocity. Water scour leads the migration of the substrate from abutments to river bed and the bottom materials deposit along the river bed. The river bank becomes alluvial and bare, which is different from the normal one. However, until now, dredging has been the most popular way to solve this problem in China. As a consequence, biodiversity decline is one of the greatest ecological problems threatening aquatic ecosystems [23], while no research has been done about the effects of bridge abutment construction.

The most seriously polluted rivers, the Tuhai and Majia, are located in the most densely populated province of Shandong, China. The population density is more than 550 per km^2 and the crops and residential land occupy more than 95% [24]. Freshwater is a finite resource which is irreplaceable in life, development, and environment. The Tuhai and Majia mainly provide irrigation for the farmland. However, they are contaminated and their water is not fit for it intended use. Previous studies in this region have been carried out by the chemical field

regarding heavy metal risk assessment [25], polycyclic aromatic hydrocarbons ecological risk [26], and organic carbon distribution [27], as well as economic studies [24]. No study has been carried out about the effects of bridge abutment construction on the macroinvertebrate communities in rivers.

In China there is an increasing trend to use macroinvertebrate communities in rivers, lakes, and wetlands as indicators of environmental quality [4, 16, 28-31]. Biomonitoring has the advantage that it can detect cumulative physical, chemical, and biological impacts of adverse activities on an aquatic system. Aquatic macroinvertebrates are often preferred for biomonitoring for the following three reasons: firstly, they are not very mobile and therefore they are representative of the area from which they are collected; secondly, they have relatively short life cycles and therefore can reflect environmental changes quickly through changes in their community composition; and thirdly they respond to pollutants in both the water column and sediments [32]. As a monitoring indicator of aquatic ecosystem health, how do macroinvertebrate perform in such seriously polluted rivers?

The aim of this study in the Tuhai and Majia rivers is to explore the impacts of two sorts of anthropogenic activities: water pollution and bridge abutments on the macroinvertebrate community. And to exam whether macroinvertebrates could be an indicator in severely contaminated water or be used in other ways to evaluate river health.

Material and Methods

Study Area Sites

The study area, the Tuhai Majia Basin, lies in northern China from 35°41′N to 38°08′N and from 114°51′E to 118°58′E (Fig. 1). It is an alluvial plain of the Yellow River with an area of 30,945 km^2, including an agricultural

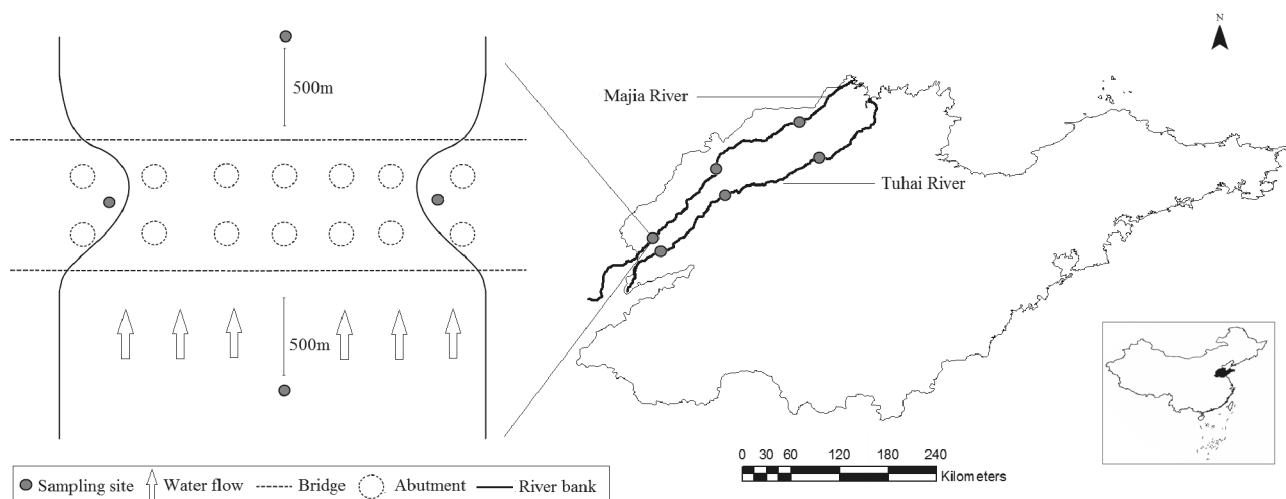● Sampling site ⇧ Water flow ------ Bridge ○ Abutment —— River bank

Fig. 1. Location of Tuhai River, Majia River and the sampling sites.

Table 1. Biological and chemical characteristics in the Tuhai and Majia rivers.

Location	Tuhai River			Majia River		
	Upstream	Mid-stream	Down Stream	Upstream	Mid-stream	Down Stream
Abundance (ind)	416	2744	39	371	109	92
Richness	8	8	6	6	3	6
Biomass (g)	69.37	621.51	61.04	55.5	55.06	17.33
Shannon-Wiener index	1.43	0.33	1.73	1.76	1.05	2.11
COD (mg L^{-1})	26.66	27.18	22.70	36.00	30.20	29.76
NH$_4$-N (mg L^{-1})	0.46	1.16	0.70	0.78	1.02	1.12
Dissolved oxygen (mg L^{-1})	7.08	4.82	7.23	7.51	6.87	7.32

region with great demand for water resources. However, the basin stands in an area of China with a serious water shortage [33]. For this paper we investigated 24 sites distributed along the rivers. We also investigated potential physicochemical and anthropogenic stressors in the rivers.

Macroinvertebrate Sampling and Community Analysis

Macroinvertebrate communities were sampled from June to September in 2013, following a multi-habitat scheme (Fig. 1, four sampling at each site: two sites sampled at a silted riverbed under the bridge; two sites sampled along the riverbank 500 m upstream and downstream from the bridge as reference samples) upstream, mid-stream, and downstream of the rivers. A 0.3m×0.3m surber net (0.25mm) was the main sampler. The surber net was put on the shallow bottom of the river and then the substratum was agitated by hand to collect benthic macroinvertebrates into the net. Other sample methods were also used to make sure that most macroinvertebrate individuals were collected in sample quadrats. The collected individuals at each site were put into plastic bottles filled with 75% ethanol to preserve the samples. Taxa were identified at the family level in a laboratory. Then a list of taxa, abundance, and biomass was made from the 36 sites. Based on the list, the following indices were calculated for each site: 1) abundance, 2) richness, 3) biomass, and 4) Shannon-Wiener index.

Chemical Parameters

A suite of chemical parameters, including dissolved oxygen (mg L^{-1}), NH$_4$-N (mg L^{-1}), and chemical oxygen demand (mg L^{-1}) were analyzed monthly from the surface water of the research sites at the monitoring station. Average data from May to September was used for analysis.

Statistical Analyses

Between-site differences in concentration of NH$_4$-N, chemical oxygen demand, dissolved oxygen, abundance

of macroinvertebrates, richness, biomass, and Shannon-Wiener index (Eq. 1) were tested using Pearson correlation analysis [34]. For each biological variable, comparisons between reference sites and under-bridge sites were performed using paired-samples T test. Statistical analyses were performed with SPSS 18.0. Maximum type-I error rates were set at α = 0.05.

$$\mathrm{H}' = -\sum_{i=1}^{R} p_i \log_2 p_i \quad \text{(Eq.1)}$$

…where p_i is the proportion of individuals belonging to the ith species in the related dataset.

Results

The main values of water quality (NH$_4$-N, chemical oxygen demand, and dissolved oxygen) and macroinvertebrate community (abundance, richness, biomass, Shannon-Wiener index) for each of the two rivers and three sampling sites (upstream, mid-stream, and downstream) are reported in Table 1.

The mean values of dissolved oxygen ranged from 4.82 mg L^{-1} downstream of the Tuhai to 7.51 mg L^{-1} in the headwaters of the Majia (Table 1). Table 2 presents Spearman's correlation coefficients between chemical and biological metrics. Only some macroinvertebrate metrics such as abundance and biomass were significantly correlated to dissolved oxygen (Table 2). Conversely, neither Chemical oxygen demand nor NH$_4$-N was correlated to any biological characteristics (Table 2).

In 2013 a total of 3,748 macroinvertebrate individuals belonging to 16 species were collected from the studied sites. The total number of individuals present at each site ranged from 39 to 2,744 (Table 3). There were eleven and nine species in the Tuhai and Majia, respectively. We reviewed how many taxa were represented in each site. The mean Shannon-Wiener index values at each site were 0.84±0.38 in the Tuhai and – a little higher – 1.15±0.48 in the Majia. Richness at most reference sites was higher than that at under-bridge sites as well as the Shannon-Wiener index (Fig. 2). The richness at reference sites 3 and 4 was comparatively higher than average, but H' was

Table 2. Pearson correlation analysis between biological metric chemical parameters in the Tuhai and Majia rivers.

Metrics	Chemical parameters	R	p-value
Abundance	Chemical oxygen demand	-0.156	0.768
	NH$_4$-N	0.153	0.773
	Dissolved oxygen	-0.882	0.020
Richness	Chemical oxygen demand	0.028	0.958
	NH$_4$-N	0.087	0.870
	Dissolved oxygen	-0.323	0.532
Biomass	Chemical oxygen demand	-0.089	0.867
	NH$_4$-N	0.661	0.153
	Dissolved oxygen	-0.957	0.003
Shannon-Wiener index	Chemical oxygen demand	0.365	0.477
	NH$_4$-N	0.493	0.320
	Dissolved oxygen	0.327	0.527

Fig. 2. Richness a) and Shannon-Wiener index b) in under-bridge site (UBS) and reference site (RS).

the lowest among all sampling sites. H' of UBS at sites 5 and 7 was a little higher than that of RS, while richness assumed the opposite trend, illustrating that the bridge affected richness more than H' (Fig. 2).
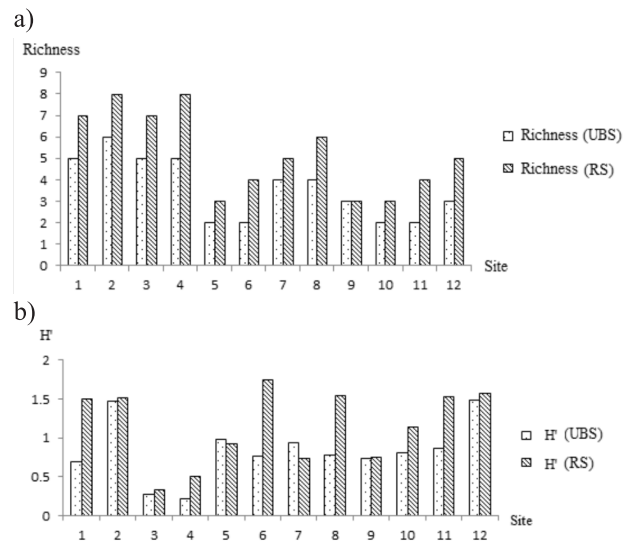
We conducted a sequence of analysis among biological characteristics. There were no significant differences between under-bridge sites and reference sites in abundance (p = 0.487) and biomass (p = 0.485), while richness (p<0.001) and Shannon-Wiener index (p = 0.019) both showed significant difference (Table 4). Pearson correlation drew very significantly between under-bridge sites and reference sites (abundance: R = 0.961, p<0.001;

Table 3. Numbers, names, and locations of macroinvertebrates.

Species	TUS	TMS	TDS	MUS	MMS	MDS
Limnodrilus claparedianus		2				
Branchiura sowerbyi	37	13				3
Chironomidae sp.1	18	20				
Chironomidae sp.2				22		7
Cipangopaludina catnayensis	308	34	19	302	81	58
Corixa substriata	3				9	
Glossiphonia sp.		3	3			
Lamprotula sp.1			1			
Lamprotula sp.2		24				
Limnodrilus hoffmeisteri	5			3		1
Odonata sp.				10		
Palaemon sp.			1			
Planorbidae sp.	15					
Radix swinhoei	2	9	1	4		18
Semisulcospira cancellata					19	
Tubifex sinicus	28	2639	14	30		5
Total	416	2744	39	371	109	92

Table 4. Pearson correlation analysis and paired-samples T test between reference sites (RS) and under-bridge sites (UBS) in abundance, biomass, richness, and Shannon-Wiener index.

Metrics	Correlation			Paired-samples T test
	N	R	Sig.	Sig.
Abundance	12	0.961	<0.001	0.487
Biomass	12	0.931	<0.001	0.485
Richness	12	0.930	<0.001	<0.001
Shannon-Wiener index	12	0.603	0.038	0.019

biomass R = 0.931 p<0.001; richness R = 0.930, p<0.001 – Table 4).

Discussion

Aquatic macroinvertebrates are often preferred for bio-monitoring because they can detect cumulative impacts of an aquatic system [35-37]. In the present study, no measured chemical parameters were significantly correlated to biological variables except dissolved oxygen. This might be because that tolerant species dominates the study area as a result of impacts of agriculture and industry. NH_4-N and chemical oxygen demand were the main water quality measurements in China. In addition to other frequent human activities, agricultural land use occupied a great proportion in the catchment area of the two rivers, leading to the degradation of riparian habitats and loss of biodiversity. Thus macroinvertebrates cannot be suitable indicators for monitoring such a polluted river ecosystem.

In both rivers, the macroinvertebrate communities were dominated by Oligochaeta, Diptera, and mollusks, which belong to the tolerant taxa that could somewhat endure water pollution. No sensitive taxa such as Ephemeroptera, Plecoptera, and Trichoptera were found in our study. Furthermore, compared to the upstream Hai River basin with good water quality, the total number of families (n = 16) observed in the present study was much lower than that in the headwaters (n = 90) [38]. In the

upstream Tuhai and Majia rivers, (Fig. 3 TUS and MUS), the macroinvertebrate community was dominated by mollusks (78.7%, 82%) followed by Oligochaeta (16.9%, 14.8%), which were similar to downstream figures (TDS and MDS). Combined with chemical variables, the results indicate that the Tuhai and Majia are seriously polluted along their entire length.

In Shandong, with a population of 100 million, bridges are essential for transportation. There is on average one bridge every three kilometers along the Tuhai (436.35 km, 157 bridges in total) and Majia (521km, 180 bridges in total). The effects caused by bridges on macroinvertebrate communities cannot be ignored, and bridge construction will never stop. What we are generally concerned about is the stability of bridges navigation safety during flooding. Not only the substrate but also the river bank is changed by turbulent flow and deposition. The investigation results indicated that the riverbed under the bridge is consistently added to by silt deposits. Insect species such as Ephemeroptera, Plecoptera, and Trichoptera were the most vulnerable to adverse changes of the river bank. Few
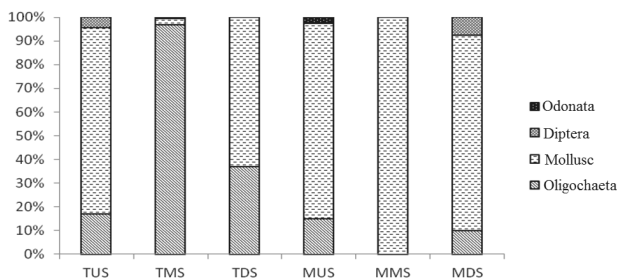

Fig. 3. Relative abundance of the main taxonomic groups of macroinvertebrates at each sampling site in 2013 (TUS = Tuhai upstream, TMS = Tuhai middle stream, TDS = Tuhai downstream, MUS = Majia upstream, MMS = Majia middle stream, MDS = Majia downstream).
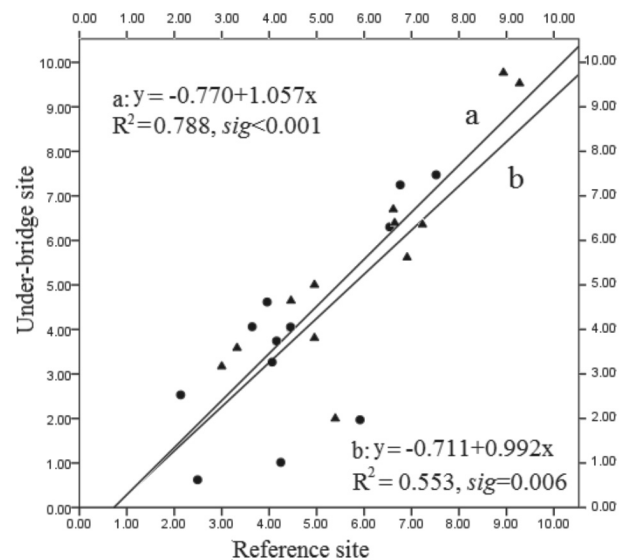

Fig. 4. Abundance and biomass correlation between under-bridge sites and reference sites. a▲: correlation of log-transformed abundance between under-bridge sites and reference sites; b●: correlation of biomass between under-bridge sites and reference sites.

insect species can reproduce in such a degraded ecosystem without vegetation except Chironomidae and Diptera (Fig. 3).

The difference of richness between the normal sites and the under-bridge sites is significant mainly because of the absence of insects at under-bridge sites. Conversely, the relationship of abundance and biomass between under-bridge sites and reference sites demonstrated that the tolerant species Oligochaetes (contributing to abundance) and mollusks (contributing to biomass) were barely affected by such habitat degradation. Moreover, correlation of log-transformed abundance and biomass between under-bridge sites and reference sites had nearly the same slope and intercept (Fig. 4).

Conclusions

River bank ecosystem degradation on account of sediment deposition and scouring around bridge abutments evidently affects the macroinvertebrate community structure and diversity. It is not suitable to use only macroinvertebrate diversity as an indicator of river ecosystem health, but sensitive species should be given more attention – especially in a polluted river system.

Acknowledgments

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