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REPORT

Navigation disturbance and its impact on fish assemblage in the East Tiaoxi River, China

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Abstract We provide the first evidence for navigation impact on resident river fish in China. The survey was conducted in the East Tiaoxi River that discharges into Lake Taihu near Shanghai, on which cargo ship traffic has dramatically increased in the recent economic development period. Water turbidity, ship traffic and other environmental factors were evaluated at 29 sites on the river. In a multiple regression model with the stepwise method, turbidity was significantly correlated with ship traffic ($R^2 = 0.53$). Another survey was conducted at 46 sites in the same area of the river, in which environmental factors were evaluated and fish individuals were electrofished. A generalised linear model with the stepwise method was applied to predict ecological indicators of the fish assemblage (species richness, individual density and Shannon's diversity index) based on environmental factors. The results showed that the indicators were negatively correlated with turbidity and presence of artificial shore embankment structures. Another analysis further showed that the negative effect of turbid water was especially considerable for fish of smaller size. In conclusion, cargo ship traffic has a negative impact on fish assemblage, especially on smaller individuals, in the East Tiaoxi River. A higher profile for conservation actions and consideration of environmental impacts of such traffic should be given increasing focus for this and other similar East Asian water courses.

Keywords Cargo ship traffic · Embankment · Lake Taihu · Navigation bottleneck hypothesis (NBH) · Turbidity · Water pollution

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Introduction

In ecological engineering, the response of wild organisms to artificial disturbance is a key area of study. In large rivers or lakes under regular use as shipping routes, the issue of how disturbance induced by navigation affects fish assemblage has been often discussed. Wolter and Arlinghaus (2003) suggested a navigation bottleneck hypothesis (NBH) in which they mainly focussed on chronic physical water movement which exceeds the fish's swimming ability to counteract (Morgan et al. 1976; Holland and Sylvester 1983; Killgore et al. 1987, 2001; Gutreuter et al.

2003). Navigation also increases water turbidity (Hilton and Phillips 1982; Garrad and Hey 1987; Kucera-Hirzinger et al. 2009), where chronic turbid water affects growth and survival rate (Herbert et al. 1961; Herbert and Merkens 1961; Goldes et al. 1988; Reynolds et al. 1989; Sutherland and Meyer 2007; Rosso et al. 2010) as well as other behaviours such as feeding (Barrett et al. 1992) of fish individuals. Macrophytes are also impacted by navigation activities, which, in turn, affects their ecological functions as fish habitats and shelters (Willby and Eaton 1996; Ali et al. 1999). The impact upon survival of eggs or young is because navigation disturbances prevent fish from nest-guarding (Mueller 1980) or can dislodge eggs (Jude et al. 1998).

Whilst such general reviews are helpful, actual direct studies of navigation impacts remain largely unreported (Gutreuter et al. 2006), as most studies have focussed simply on the direct effects due to waves (NBH; Wolter and Arlinghaus 2003). Additionally, these studies have been conducted exclusively in European (Willby and Eaton 1996; Lindholm et al. 2001; Arlinghaus et al. 2002; Kucera-Hirzinger et al. 2009) or North American (Morgan et al. 1976; Holland and Sylvester 1983; Smart et al. 1985; Holland 1986; Jude et al. 1998; Gutreuter et al. 2003, 2006) river or channel fish. Studies and further information regarding navigation impacts on fish in the context of East Asia, currently one of the fastest developing areas in the world, remain notably absent.

The East Tiaoxi River is one of the largest rivers that flow into Lake Taihu in China. Lake Taihu is the third largest lake in China, being situated near Shanghai. Thus, the river and lake are economically and socially essential as a source of water supply for Shanghai and its surrounding area. In the rapid economic development of Shanghai, the environment of the river has been drastically altered in recent years. The main alteration of the river has been caused by the quarrying and mining that were actively conducted in the 2000s (Sato et al. 2010). Use of massive cargo ships to transfer these mineral sediments has been almost continuous over this period. In addition, construction of artificial shore embankment structures along the river shore has also been often introduced to protect against bank erosion induced by navigation waves (Sato et al. 2010). All such disturbances and environmental changes are likely to pose a high risk of impact to aquatic organisms inhabiting the river (Sato et al. 2010).

In this study we mainly focus on navigation impact on the fish assemblage in the East Tiaoxi River on the basis of in situ surveys. We firstly clarify how water turbidity is correlated with cargo ship traffic and other related environmental factors. Second, we show that some ecological indices of the fish assemblage in the river (species richness, individual density and diversity index) are affected by water turbidity and other environmental factors such as the presence of artificial embankment structures. Third, we examine whether the impact of turbid water differs by individual fish size. We also discuss future perspectives and conservation of fish biodiversity in the river.

Methods

Study river and its environment

The study was conducted from the lower to middle reaches of the East Tiaoxi River, China [0.5–75 km, beginning at the mouth (30°56′N, 120°08′E; 1 m above sea level) to middle reaches (30°24′N, 119°58′E; 8 m above sea level) of the river; Fig. 1]. The river width ranged from roughly 200 m at the downstream sections to approximately 70 m in the middle reaches. Cargo ships (ship length 20–50 m) often traverse the river to carry both ore and sediment (Fig. 2a).

In 2009, 48% of the river bank remained natural (Fig. 2b) while 52% was artificially protected by concrete barriers or boulders (Fig. 2c) (Sato et al. 2010). There is little altitude difference between the mouth and middle reaches of the river (ca. 7 m), thus there is extremely slow water flow, and any wave action is exclusively generated by navigation activities (Sato et al. 2010).

Ship counting and turbidity

As many branched channels are linked to the main stream, the extent of cargo ship traffic in the main stream varies by location. To assess whether such traffic variation affects water turbidity, a survey was conducted from a small boat by travelling the river, measuring the turbidity and counting the cargo ships at various locations.

From 22 to 25 May 2010 (from 08:30 to 18:30 every day), the boat was driven upstream from the mouth (edge

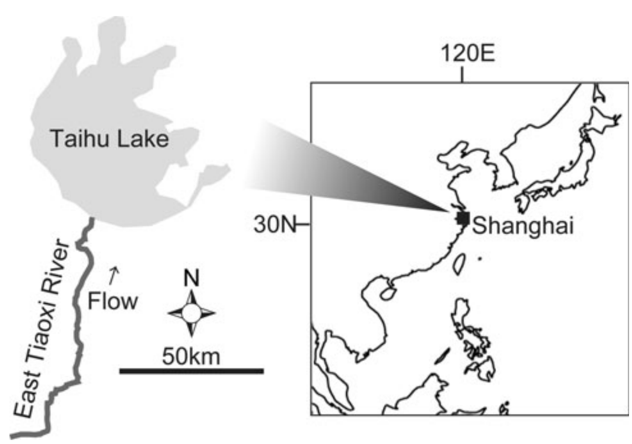

Fig. 1 Map of the survey area of the East Tiaoxi River, China

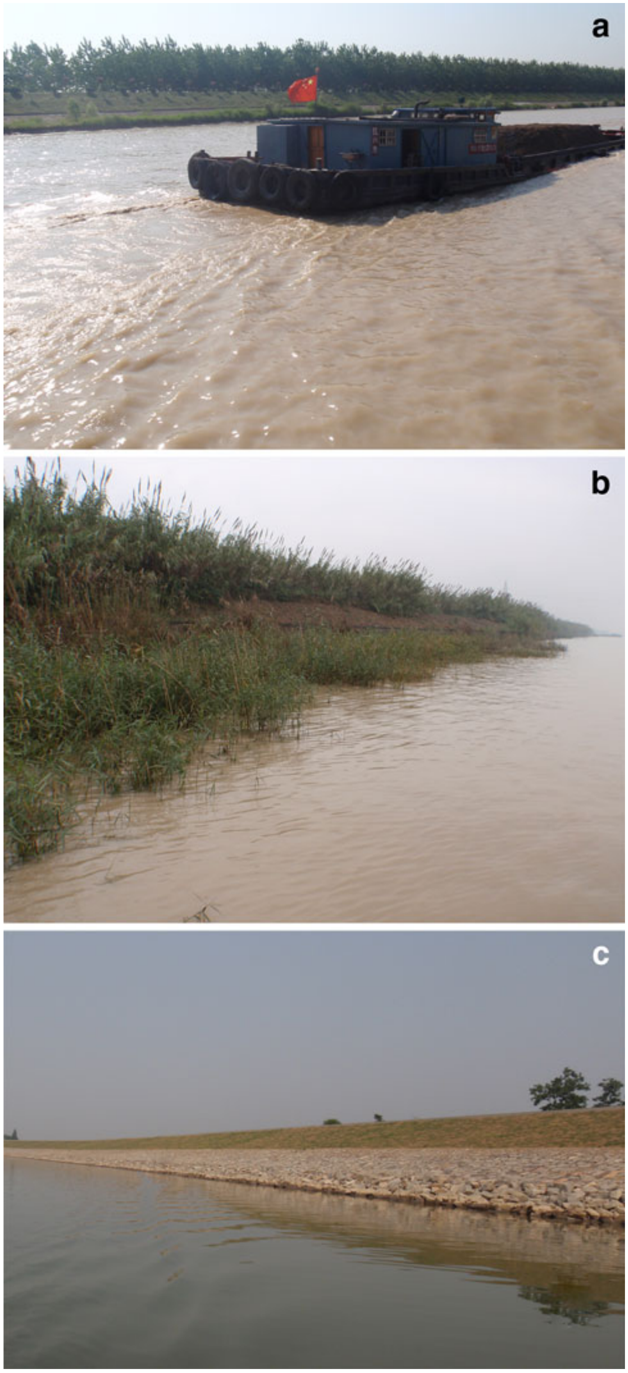

Fig. 2 Environment of the East Tiaoxi River; **a** a cargo ship disturbing the river with the screw, **b** natural bank with emergent plants and **c** artificially protected bank without water or plant cover

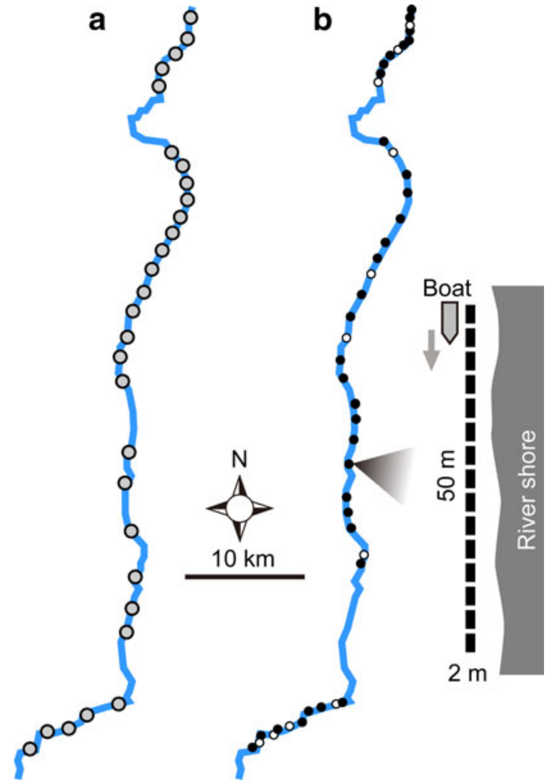

Fig. 3 Study sites on the East Tiaoxi River. **a** The turbidity was measured at 29 sites indicated by *gray circles*. **b** Fish individuals were caught at 46 sites shown in *solid* (natural bank) and *blank* (artificially protected bank) *circles* for a 2 × 50 m^2 range (*broken line*) at each site

of Lake Taihu) to middle reaches of the river, covering a distance of 75 km in the process. Ship traffic and turbidity were evaluated and measured en route at 29 randomly selected sites (Fig. 3a). Average distance (±standard deviation, SD) between adjacent sites was 2643 ± 1895 m. At each site, the boat was halted at the bank and remained moored there for a period of ca. 30–60 min. Then, the traffic of cargo ships was counted and recorded. The cargo ship traffic was evaluated as the accumulated ship number divided by the stay time. The turbidity at the bank was measured using a portable water quality meter (HI93703-B; HANNA Instruments Japan, Tokyo) every 10–15 min, and the values were averaged to calculate a representative value for each site. Attention was taken that our survey boat did not disturb the water or alter the precise turbidity measurement. The weather was fine without precipitation throughout the survey.

Fish assemblage and habitat assessment

From 19 to 22 November 2009, the fish assemblage and the river environment were assessed by boat at 46 sites at the same survey areas as above (from the mouth of the river to 75 km upstream). The average distance (±SD) between adjacent sites was 1670 ± 2132 m (Fig. 3b).

At each site, fish individuals were caught using a locally purchased electrofisher (Weibociliji, 12 V, 6000VA; Caifu), which has been generally used by local fishermen around the East Tiaoxi River and Lake Taihu. The boat was driven slowly (10 m/min) along the river shore (within

0–5 m from the river edge in axial section) for 50 m, and fish individuals were caught within a width of 2 m (Fig. 3b). The length of 50 m along the river was measured using a laser range finder (TruPulse 200; Laser Technology Inc., Centennial, CO). The catchment rate of this method was 0.32 in another study on the same river (Kano et al. unpublished data). Captive individuals were identified to species level, and their weight measured. Most individuals were released at the same site where they were caught, while some were fixed with formalin where further identification was required. Identification was based on Moa and Xu (1991), Chu et al. (1999), Wu and Zhong (2008), and Nakajima et al. (unpublished data).

Water turbidity was measured at each site using the portable water quality meter. Water depth was measured every 5 m along the 50 m line using a measuring pole, and the values were averaged to calculate a representative water depth for the site. The river bank environment of each site was categorised as natural (Fig. 2b) or artificially embanked (Fig. 2c) (Sato et al. 2010).

Data analysis

The data of the ship-counting survey (Fig. 3a) were analysed to elucidate the effect of cargo ship traffic on water turbidity. A generalized linear model (GLM; McCullagh and Nelder 1989) was performed to detect factors that influence turbidity. In the model, the dependent variables were water turbidity for each surveyed site, while the independent variables were ship traffic, river width and distance from Lake Taihu. Water turbidity was log-transformed for homoscedasticity. River width and distance from Lake Taihu were obtained using Google Earth (http://earth.google.com). The Gaussian distribution was applied for the model. The stepwise selection (forward–backward stepwise) was applied for the choice of effective predictors, in which the threshold P value ($P_{\text{in–out}}$) was set to 0.05 (Murtaugh 2009).

Data of the fish assessment survey (Fig. 3b) were analysed to elucidate the relationship between river environment and fish assemblage. A GLM was performed to predict three ecological indices of the fish assemblage based on environmental predictors. The indices (dependent variables) were species richness, number of individuals and Shannon's diversity index, while the independent variables were water turbidity, embankment, water depth and distance from Lake Taihu as spatial autocorrelation considering the longitudinal fish distribution along the river. For embankment, a dummy variable was applied. Poisson, negative binomial and Gaussian distributions were adapted for species richness, number of individuals and Shannon's diversity index, respectively. Shannon's diversity index (H') was calculated as

$$H' = -\sum_{i=1}^{S} (p_i \ln p_i),$$

where S is the number of species and p_i is the ratio of individuals of a given species to the total number of individuals in the community. Stepwise selection (forward–backward stepwise) was applied for the choice of effective parameters, with $P_{\text{in–out}}$ set to 0.05.

We also ascertained whether the impact of turbidity differed by fish size. A single regression model associated with turbidity was tested for average, minimum and maximum fish weights at respective sites. Both parameters were log-transformed for homoscedasticity. Sites where no individuals were caught were eliminated from the analysis. Further, as it is likely that the impact of turbidity differs by species, the GLM (Poisson distribution) was applied for each species, in which the dependent variable was individual number of each species and the independent variable was turbidity. The analysis was conducted for those species for which more than or equal to 5 individuals were caught at a minimum of 5 sites.

These analyses were conducted using R (version 2.9.2) statistical software and its optional package "MASS" and self-made scripts.

Results

Ship counting and turbidity

In total 368 cargo ships were counted, with ship traffic varying from 0 to 67.2 ships per hour (average ± SD = 25.6 ± 18.4). River width and distance from Lake Taihu varied from 59.9 to 215 m (116.3 ± 41.7 m) and from 0.48 to 74.5 km (34.9 ± 23.0 km), respectively. Water turbidity varied from 8.7 to 3228 nephelometric turbidity units (NTU) (335 ± 557 NTU).

Table 1 presents the results of the multiple regression model to predict water turbidity, in which the predictors ship traffic, river width and distance from Lake Taihu were selected by the stepwise method. As a result, ship traffic

Table 1 Results of multiple regression model to predict water turbidity in the East Tiaoxi River, China, in which the effective predictors were selected by the stepwise method ($R^2 = 0.53$)

Predictor	Coefficient	SE	t value
Intercept	1.55	0.14	10.7***
Ship traffic (ships/h)	0.025	0.005	5.6***
River width (m)			
Distance from Taihu Lake (km)			

Probability level: ***$P < 0.001$

was selected by this method, while river width and distance from Lake Taihu were eliminated from the model. The value of the correlation coefficient (R) was 0.73 ($R^2 = 0.53$).

Fish assemblage and habitat assessment

A total of 28 species (499 individuals) were caught in the survey (Table 2). The values of water turbidity and water depth for sites where fish were caught ranged from 12.6 to 656 NTU (average ± SD: 193 ± 166 NTU) and from 0.37 to 1.55 m (average ± SD: 0.74 ± 0.24 m), respectively. Turbidity value exceeded 100, 200 and 400 NTU at 29, 18 and 5 sites, respectively. Of 46 sites, 11 sites were evaluated as having embankment.

Table 3 shows the results of GLM analysis with the stepwise selection. Species richness and Shannon's diversity index were negatively affected by water turbidity and embankment. The number of individuals was negatively affected by water turbidity, embankment and water depth. Distance from Lake Taihu was not selected in any models. Figure 4 shows the relationships between the turbidity and the three fish ecological indices, discriminated by embankment type.

Figure 5 shows the relationships between turbidity and minimum, average or maximum weight of fish individuals caught at respective sites. The single regression model indicated significant positive correlations for average weight (Fig. 5a; $N = 40$, $P < 0.0001$, coefficient: 0.65, $R^2 = 0.29$) and minimum weight (Fig. 5b; $N = 40$,

Table 2 Summary of the sampling survey and the results of generalized liner model (GLM) analysis, in which the dependent variable is the individual number of each species and the explanatory variable is turbidity (NTU)

Family	Sub-family	Scientific name	N	Sites	Average weight (g) (±SD)	Coefficient of turbidity by GLM[a]
Salangidae	–	*Neosalanx tangkahkeii* (Wu 1931)	1	1	1.0	
	–	*Protosalanx chinensis* (Basilewsky 1855)	1	1	7.6	
Cyprinidae	Acheilognathinae	*Acheilognathus imberbis* (Günther 1868)	20	7	0.7 (0.7)	−0.058**
		Acheilognathus macropterus (Bleeker 1871)	3	3	7.4 (6.6)	
		Acheilognathus tonkinensis (Vaillant 1892)	10	5	4.3 (2.7)	−0.012*
		Rhodeus fangi (Miao 1934)	131	10	0.4 (0.2)	−0.141***
		Rhodeus ocellatus (Kner 1866)	3	1	0.3 (0.0)	
		Rhodeus sinensis (Günther 1868)	161	8	0.5 (0.4)	−0.094***
	Cultrinae	*Chanodichthys dabryi* (Bleeker 1871)	4	2	12.5 (4.0)	
		Chanodichthys erythropterus (Basilewsky 1855)	2	1	43.6 (20.9)	
		Culter alburnus (Basilewsky 1855)	22	8	12.5 (17.6)	0.002 NS
		Hemiculter bleekeri (Warpachowski 1887)	11	7	11.8 (3.9)	−0.001 NS
		Hemiculter leucisculus (Basilewsky 1855)	35	14	8.0 (8.6)	−0.003*
		Megalobrama amblycephala (Yih 1955)	1	1	498.4	
	Cyprininae	*Carassius auratus* (Linnaeus 1758)	9	7	31.8 (22.0)	−0.004 NS
		Cyprinus carpio (Linnaeus 1758)	1	1	180.4	
	Gobioninae	*Abbottina rivularis* (Basilewsky 1855)	7	2	3.0 (4.1)	
		Hemibarbus maculatus (Bleeker 1871)	1	1	15.8	
		Pseudorasbora parva (Temminck & Schlegel 1846)	6	6	3.6 (2.7)	−0.001 NS
	Labeoninae	*Cirrhinus cirrhosus* (Bloch 1795)	2	2	25.4 (14.6)	
	Rasborinae	*Opsariichthys bidens* (Günther 1873)	3	2	6.2 (5.1)	
	–	*Pseudobrama simoni* (Bleeker 1865)	2	2	21.8 (0.3)	
Bagridae	–	*Pseudobagrus fulvidraco* (Richardson 1846)	1	1	16.8	
Poeciliidae	–	*Gambusia affinis* (Baird & Girard 1853)	18	7	0.1 (0.0)	−0.028**
Hemiramphidae	–	*Hyporhamphus intermedius* (Cantor 1842)	37	9	2.1 (1.9)	−0.002 NS
Synbranchidae	–	*Monopterus albus* (Zuiew 1793)	1	1	127.9	
Anabantidae	Macropodinae	*Macropodus ocellatus* (Cantor 1842)	2	2	5.9 (5.6)	
Gobiidae	–	*Rhinogobius giurinus* (Rutter 1897)	4	4	0.7 (0.3)	

[a] The analysis was conducted only for those species for which more than or equal to 5 individuals were caught at a minimum of 5 sites

Probability levels: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Table 3 Results of GLM with stepwise method ($P_{\text{in-out}} = 0.05$) to predict ecological indices of the fish assembly in the East Tiaoxi River

Index	Coefficient (±SE)			
	Turbidity (NTU/1000)	Embankment (dummy variable)	Water depth (m)	Distance from Lake Taihu (km)
Species richness	−2.45 (0.69)***	−0.62 (0.22)**		
Number of individuals	−5.08 (0.98) ***	−1.02 (0.31)**	−1.92 (0.66)**	
Shannon's diversity index	−1.33 (0.36) ***	−0.36 (0.12)**		

Probability levels: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

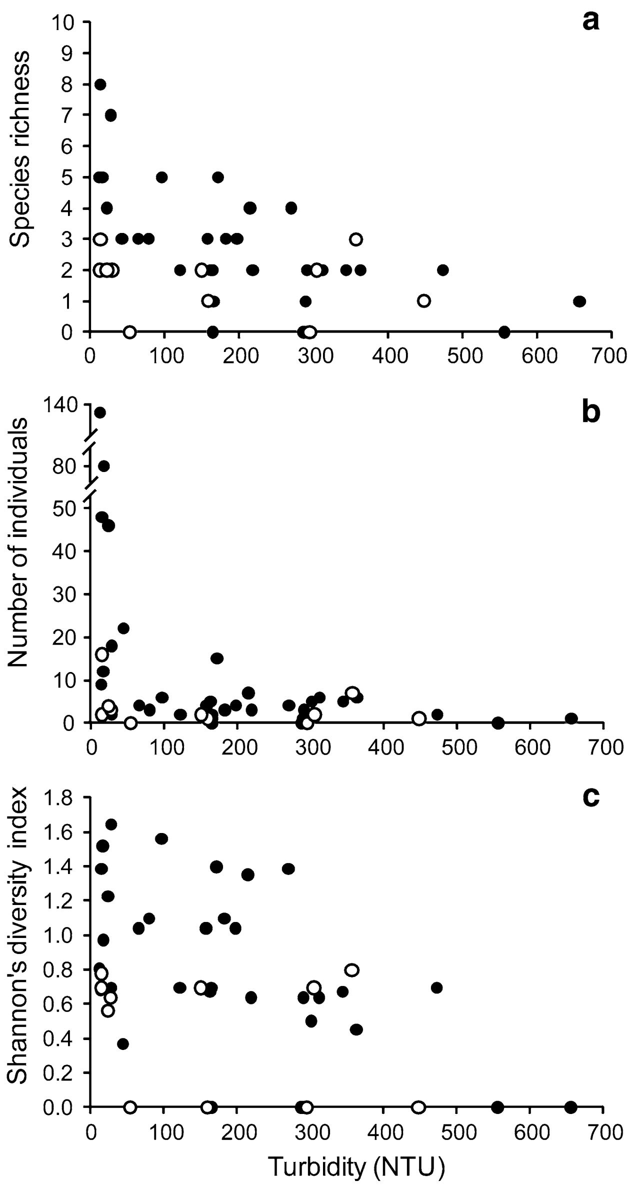

Fig. 4 Relationships between turbidity and **a** species richness, **b** number of individuals and **c** Shannon's diversity index. *Solid* and *blank circles* correspond to natural and artificially protected banks, respectively

$P < 0.0001$, coefficient: 1.03, $R^2 = 0.45$), whilst no significant correlation was found for maximum weight (Fig. 5c; $N = 40$, $P > 0.05$).

Table 2 presents the results of GLM in which the effect of turbidity was validated for each species. Turbidity significantly negatively affected six species (*Acheilognathus imberbis*, *Acheilognathus tonkinensis*, *Rhodeus fangi*, *Rhodeus sinensis*, *Hemiculter leucisculus* and *Gambusia affinis*), which had relatively low average weights. On the other hand, no significant negative effect was found on 5, relatively large species (*Culter alburnus*, *Hemiculter bleekeri*, *Carassius auratus*, *Pseudorasbora parva* and *Hyporhamphus intermedius*). No species showed significant positive effect of turbidity.

Discussion

Our results clarify the approximate picture of the water environment and the fish assemblage inhabiting the study area during the survey period, although such a picture might not always hold true. Cargo ship traffic induced water disturbance, provoking sediment suspension and increasing turbidity. Previous studies have confirmed that ship traffic increases turbidity in rivers and lakes (Hilton and Phillips 1982; Smart et al. 1985; Garrad and Hey 1987; Lindholm et al. 2001; Kucera-Hirzinger et al. 2009). Kucera-Hirzinger et al. (2009) reported, for example, that with the passing of a cargo ship in the Danube River in Austria, turbidity peaked at 550 NTU 2 min after ship passage and levelled off after approximately 7 min. However, the levelling-off time varied according to ship size and speed, as well as sediment size and river scale. In this study, concrete values of levelling-off time were not elucidated and remain to be determined. It also remains undetermined how ship traffic fluctuates according to time of day. In the river, however, a ship came past roughly every 2 min on average, and in such locations the turbidity may be persistently kept high without allowing a sufficient period for levelling off, at least from morning to evening.

Species richness, number of individuals and Shannon's diversity index were all decreased at locations where turbidity was high (Table 3; Fig. 4). Chronic high turbidity would physiologically affect fish individuals, because suspended sediment directly damages fish gills, resulting in

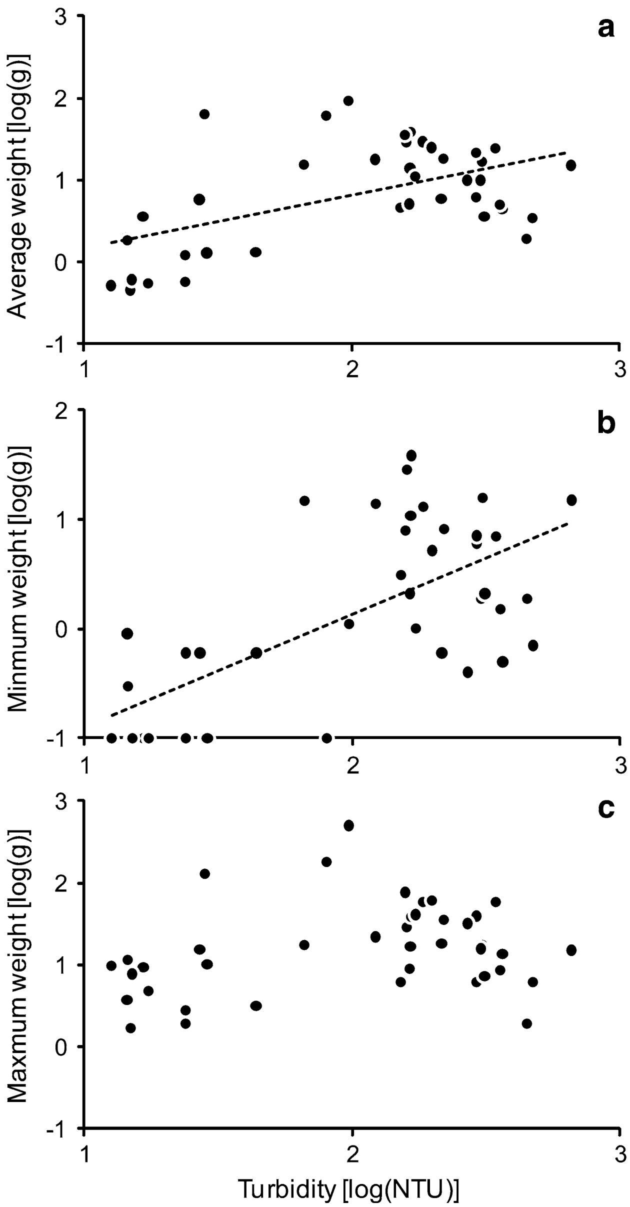

Fig. 5 Relationships between turbidity and **a** average, **b** minimum and **c** maximum weights for respective sites. *Broken lines* indicate approximate curves

suppression of growth and lower survival rates (Herbert et al. 1961; Herbert and Merkens 1961; Goldes et al. 1988; Reynolds et al. 1989; Sutherland and Meyer 2007; Rosso et al. 2010); for example, post-larvae of spotfin chub (*Erimonax monachus*) in 26, 46, 87 and 411 NTU turbid water (control 0 NTU) showed significant reduction in growth rate and increased gill thickness (Sutherland and Meyer 2007). Conversely, growth of larval lake whitefish (*Coregonus artedii*) was not affected by turbid water (6–28 NTU) (Swenson and Matson 1976). It is likely that the effect of turbid water differs by species (Sutherland and Meyer 2007). In this study, significant negative effect was detected in some species but not in others (Table 2). Nevertheless, significant positive effect of turbid water was not detected in any species.

Turbidity indicates the quantity of suspended material, so it also indirectly indicates the relative degree of physical water perturbation. Continual environmental perturbations have a major influence on fish composition at community level (Magoulick and Kobza 2003). There exists only an extremely slight geographical gradient in the middle to lower reaches of the East Tiaoxi River (7 m over 75 km), and a correspondingly extremely slow water flow. Thus, water oscillation induced by navigation would have a considerable effect on fishes that have adapted to such a slow flow, low natural turbidity environment. Water velocity tolerance and swimming performance have been studied for many species (Houde 1969; Brett and Glass 1973; Stahlberg and Peckmann 1987; Heggenes and Traaen 1988; Young and Cech 1994; Flore and Keckeis 1998); for instance, Kucera-Hirzinger et al. (2009) reported that water flow induced by ship passage exceeded maximum swimming performances of juvenile *Chondrostoma nasus* in the Danube River. In the East Tiaoxi River, as well as in these other studies, fish may be negatively impacted by such water perturbation. However, direct evidence of this was not shown in this study.

It is well known that water movements induced by navigation cause bank erosion (Fagerholm 1975, 1978; Rönnberg 1975). In the East Tiaoxi River, due to the increase of cargo ship traffic as well as for flood control, construction of concrete/boulder embankments increased rapidly in the 2000s (Sato et al. 2010). Such bank engineering, however, negatively affected the fish assemblage in the river (Table 3; Fig. 4). Artificial embankment is a major anthropogenic impact factor for aquatic ecosystems (Shields et al. 2000). Fish in the river are affected not only by disturbance of navigation but also by structural change in the river bank. Unfortunately, shoreline development is still proceeding at a dramatic pace on the East Tiaoxi River (Sato et al. 2010).

Fish size was small for low turbidity but larger for high turbidity (Fig. 5a). This does not necessarily mean that large individuals prefer high turbidity or that individuals in high turbidity grow larger. Rather, it is more likely an indication that small individuals could not survive, locate or distribute in high-turbidity habitats (Fig. 5b). On the other hand, large individuals were distributed in both low- and high-turbidity habitats (Fig. 5c). The species-specific analysis of the effect of turbidity also showed that species with small body tend to be negatively affected by turbid water, while species of large body do not (Table 2). Several studies have indicated that turbid water and persistent perturbation have an especially high impact on young and small individuals (Holland and Sylvester 1983; Sigler et al. 1984; Holland 1986; Flore and Keckeis 1998; Wolter and

Arlinghaus 2003; Kucera-Hirzinger et al. 2009). Our results correspond to these studies. Shallow shoreline zones serve as important nursery habitats for fish (Keckeis et al. 1997; Winkler et al. 1997). Ship-induced wake and splash will have an extremely strong effect on such sensitive zones, leading to drastic dislocation of microhabitats for young or small individuals (Arlinghaus et al. 2002; Wolter and Arlinghaus 2003; Kucera-Hirzinger et al. 2009).

Some other negative factors should also be considered. Navigation and embankment also have impacts on aquatic plants. In cases of high wave/turbidity disturbance, colonies of floating vegetation will be physically displaced and washed away, emergent vegetation may be uprooted or disturbed and photosynthesis of submerged vegetation may be prevented due to the increased turbidity (Mason and Bryant 1975; Garrad and Hey 1987, 1988; Ali et al. 1999; Boedeltje et al. 2001, 2003). Likewise, natural bank-side vegetation may be severely inhibited when subject to wave erosion, leading to stem breakage, and erosion and fragmentation of the root mat (Ali et al. 1999). Severe erosion may result in root exposure for bank-side trees, in extreme cases leaving only bare mud at the lower bank-side level. This in itself can add to water turbidity, as the exposed mud is easily washed into the water. Mechanical damage by drag and tearing can also result for more firmly rooted species. All such aquatic and bank-side plants have an ecological function as fish habitats and shelters (Randall et al. 1996; Willby and Eaton 1996). They may serve as shelter from predation, or shade from sunlight; they may provide a direct food source for fish or aquatic habitats with abundant invertebrate food sources; they may also provides spawning/egg-laying substrate. Thus, fish in the river may be indirectly affected by navigation through such ecological links. Diffusion of pollution from livestock and poultry (Gu et al. 2008; Huang et al. 2008) and agrochemicals washed into water courses (Wang et al. 2010) would likely worsen the situation. Likewise, overfishing (Wang 2009; Wang et al. 2009) around the region would further exacerbate the status of the fish assemblage.

In this survey, disturbance and impact by navigation were quantitatively elucidated by field surveys, with special focus on turbidity, at least during the survey period. Most previous studies regarding navigation impact have focussed on physical water forces generated by moving ships as typified by NBH (Wolter and Arlinghaus 2003). However, we suspect that physiological effects of turbid water may also be essential for consideration along with such direct physical forces. Additionally, study of navigation impact has been hitherto primarily conducted in Europe or North America, as reviewed by Wolter and Arlinghaus (2003). Our study is the first to indicate the navigation impact in China, where economic development is progressing at a speed rarely represented in the West. Although surveys were conducted only during a short-term period, the results mostly correspond to past studies of negative navigation impact on fish. We suspect that similar results could be obtained if surveys were conducted during other seasons, and that our snapshot results indicate the general aspects of the East Tiaoxi River.

There is an essential difference between our study and past studies conducted in Europe and North America in terms of biodiversity conservation. In Europe and North America, the economy has already developed and river environments have been relatively stabilized, regardless of whether the river environment has been artificially developed or left in a more natural state. In contrast, river environments in China have undergone, and continue to undergo, rapid change. We predict that navigation-related aquatic biodiversity loss will soon be widespread for Chinese (and other East Asian) navigable rivers. However, there remain primary natural habitats in China, particularly at higher altitudes and closer to river and stream sources. In such cases there is still a chance to retain or rehabilitate some of these natural primary or secondary channels (as in Gutreuter et al. 2006), and to specially protect shallow zones (as highlighted in Willby and Eaton 1996; Boedeltje et al. 2001, 2003).

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References

Ali MM, Murphy KJ, Langendorff J (1999) Interrelations of river ship traffic with aquatic plants in the River Nile, upper Egypt. Hydrobiologia 415:93–100

Arlinghaus R, Engelhardt C, Sukhodolov A, Wolter C (2002) Fish recruitment in a canal with intensive navigation: implications for ecosystem management. J Fish Biol 61:1386–1402

Barrett JC, Grossman GD, Rosenfeld J (1992) Turbidity-induced changes in reactive distance of rainbow-trout. Trans Am Fish Soc 121:437–443

Boedeltje G, Bakker JP, ter Heerdt GNJ (2003) Potential role of propagule banks in the development of aquatic vegetation in backwaters along navigation canals. Aquat Bot 77:53–69

Boedeltje G, Smolders AJP, Roelofs JGM, Van Groenendael JM (2001) Constructed shallow zones along navigation canals: vegetation establishment and change in relation to environmental characteristics. Aquat Conserv 11:453–471

Brett JR, Glass NR (1973) Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. J Fish Res Board Can 30:379–387

Chu X, Zheng B, Dai D (1999) Fauna sinica, osteichthyes, siluriformes. Science, Beijing

Fagerholm HP (1975) The effects of ferry traffic on the rocky shore macrofauna in the southern Åland archipelago: 1. The cladophora zone. Merentutkimuslaitoksen Julk Havsforskningsinst Skr 239:331–337

Fagerholm HP (1978) The effects of ferry traffic (artificial wave action) on rocky shore macrofauna in the Northern Baltic. 2. The fucus zone (a quantitative study). Kiel Meeresforsch 4:130–137

Flore L, Keckeis H (1998) The effect of water current on foraging behaviour of the rheophilic cyprinid *Chondrostoma nasus* (l.) during ontogeny: evidence of a trade-off between energetic gain and swimming costs. Regul Rivers Res Manage 14:141–154

Garrad PN, Hey RD (1987) Boat traffic, sediment resuspension and turbidity in a Broadland river. J Hydrol 95:289–297

Garrad PN, Hey RD (1988) River management to reduce turbidity in navigable Broadland rivers. J Environ Manage 27:273–288

Goldes SA, Ferguson HW, Moccia RD, Daoust PY (1988) Histological effects of the inert suspended clay kaolin on the gills of juvenile rainbow trout, *Salmo gairdneri richardson*. J Fish Dis 11:23–33

Gu P, Shen RF, Chen YD (2008) Diffusion pollution from livestock and poultry rearing in the Yangtze Delta, China. Environ Sci Pollut R 15:273–277

Gutreuter S, Dettmers JM, Wahl DH (2003) Estimating mortality rates of adult fish from entrainment through the propellers of river towboats. Trans Am Fish Soc 132:646–661

Gutreuter S, Vallazza JM, Knights BC (2006) Persistent disturbance by commercial navigation alters the relative abundance of channel-dwelling fishes in a large river. Can J Fish Aquat Sci 63:2418–2433

Heggenes J, Traaen T (1988) Downstream migration and critical water velocities in stream channels for fry of four salmonid species. J Fish Biol 32:717–727

Herbert DWM, Alabaster JS, Dart MC, Lloyd R (1961) The effect of china-clay wastes on trout streams. Int J Air Water Pollut 5:56–74

Herbert DWM, Merkens JC (1961) The effect of suspended mineral solids on the survival of trout. Int J Air Water Pollut 5:46–55

Hilton J, Phillips GL (1982) The effect of boat activity on turbidity in a shallow Broadland river. J Appl Ecol 19:143–150

Holland LE (1986) Effects of barge traffic on distribution and survival of ichthyoplankton and small fishes in the upper Mississippi River. Trans Am Fish Soc 115:162–165

Holland LE, Sylvester JR (1983) Distribution of larval fishes related to potential navigation impacts on the upper Mississippi River, pool 7. Trans Am Fish Soc 112:293–301

Houde ED (1969) Sustained swimming ability of larvae of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*). J Fish Res Board Can 26:1647–1659

Huang W, Xu G, Wu Q, Qin B (2008) Pollution and eutrophication. In: Qin B (ed) Lake Taihu, China. Springer Science + Business Media B.V., pp 23–42

Jude DJ, Tesar FJ, Tin HT (1998) Spring distribution and abundance of larval fishes in the st. Marys River, with a note on potential effects of freighter traffic on survival of eggs and larvae. J Great Lakes Res 24:569–581

Keckeis H, Winkler G, Flore L, Reckendorfer W, Schiemer F (1997) Spatial and seasonal characteristics of 0+ fish nursery habitats of nase, *Chondrostoma nasus* in the River Danube, Austria. Folia Zool 46:133–150

Killgore KJ, Maynord ST, Chan MD, Morgan RP (2001) Evaluation of propeller-induced mortality on early life stages of selected fish species. North Am J Fish Manage 21:947–955

Killgore KJ, Miller AC, Conley KC (1987) Effects of turbulence on yolk-sac larvae of paddlefish. Trans Am Fish Soc 116:670–673

Kucera-Hirzinger V, Schludermann E, Zornig H, Weissenbacher A, Schabuss M, Schiemer F (2009) Potential effects of navigation-induced wave wash on the early life history stages of riverine fish. Aquat Sci 71:94–102

Lindholm T, Svartstrom M, Spoof L, Meriluoto J (2001) Effects of ship traffic on archipelago waters off the Långnäs harbour in Åland, SW Finland. Hydrobiologia 444:217–225

Magoulick DD, Kobza RM (2003) The role of refugia for fishes during drought: a review and synthesis. Freshw Biol 48:1186–1198

Mason CF, Bryant RJ (1975) Changes in ecology of Norfolk Broads. Freshw Biol 5:257–270

McCullagh P, Nelder J (1989) Generalized linear models (2nd edn). Chapman and Hall, London

Moa J, Xu S (1991) Fauna of Zhejiang, freshwater fishes. Zhejiang Science and Technology, Beijing

Morgan RP, Ulanowicz RE, Rasin VJ, Noe LA, Gray GB (1976) Effects of shear on eggs and larvae of striped bass, *Morone saxatilis*, and white perch, *Morone americana*. Trans Am Fish Soc 105:149–154

Mueller G (1980) Effects of recreational river traffic on nest defence by longear sunfish. Trans Am Fish Soc 109:248–251

Murtaugh PA (2009) Performance of several variable-selection methods applied to real ecological data. Ecol Lett 12:1061–1068

Randall RG, Minns CK, Cairns VW, Moore JE (1996) The relationship between an index of fish production and submerged macrophytes and other habitat features at three littoral areas in the Great Lakes. Can J Fish Aquat Sci 53:35–44

Reynolds JB, Simmons RC, Burkholder AR (1989) Effects of placer mining discharge on health and food of arctic grayling. Water Resour Bull 25:625–635

Rosso JJ, Sosnovsky A, Rennella AM, Quiros R (2010) Relationships between fish species abundances and water transparency in hypertrophic turbid waters of temperate shallow lakes. Int Rev Hydrobiol 95:142–155

Rönnberg O (1975) The effects of ferry traffic on rocky shore vegetation in the southern Åland archipelago. Merentutkimuslaitoksen Julk Havsforskningsinst Skr 239:325–330

Sato T, Kano Y, Huang L, Li J, Shimatani Y (2010) Assessment of river environment in the East Tiaoxi Basin, China using GPS-logger, Google Earth and Landsat images. Adv River Eng 16:47–52 (in Japanese with English abstract)

Shields FD, Knight SS, Cooper CM (2000) Warmwater stream bank protection and fish habitat: a comparative study. Environ Manage 26:317–328

Sigler JW, Bjornn TC, Everest FH (1984) Effects of chronic turbidity on density and growth of steelheads and coho salmon. Trans Am Fish Soc 113:142–150

Smart MM, Rada RG, Nielsen DN, Claflin TO (1985) The effect of commercial and recreational traffic on the resuspension of sediment in navigation pool 9 of the upper Mississippi River. Hydrobiologia 126:263–274

Stahlberg S, Peckmann P (1987) The critical swimming speed of small teleost fish species in a flume. Arch Fur Hydrobiol 110:179–193

Sutherland AB, Meyer JL (2007) Effects of increased suspended sediment on growth rate and gill condition of two southern Appalachian minnows. Environ Biol Fish 80:389–403

Swenson WA, Matson ML (1976) Influence of turbidity on survival, growth, and distribution of larval lake herring (*Coregonus arttedii*). Trans Am Fish Soc 4:541–545

Wang D (2009) Population status, threats and conservation of the Yangtze finless porpoise. Chin Sci Bull 54:3473–3484

Wang ZS, Shi JQ, Xu CR, Lei GC (2009) Degradation of icefishes (salangidae) in the Yangtze River Basin of China: threats and strategies. Environ Biol Fish 86:1090–1117

Wang F, Tian P, Yu J, Lao G, Shi T (2010) Variations in pollutant fluxes of rivers surrounding Taihu Lake in Zhejiang Province in 2008. Phys Chem Earth (in press)

Willby NJ, Eaton JW (1996) Backwater habitats and their role in nature conservation on navigable waterways. Hydrobiologia 340:333–338

Winkler G, Keckeis H, Reckendorfer W, Schiemer F (1997) Temporal and spatial dynamics of 0+ *Chondrostoma nasus*, at the inshore zone of a large river. Folia Zool 46:151–168

Wolter C, Arlinghaus R (2003) Navigation impacts on freshwater fish assemblages: the ecological relevance of swimming performance. Rev Fish Biol Fisher 13:63–89

Wu H, Zhong J (2008) Fauna sinica, osteichthyes, perciformes (v) gobioidei. Science, Beijing

Young PS, Cech JJ (1994) Optimum exercise conditioning velocity for growth, muscular development, and swimming performance in young-of-the-year striped bass (*Morone saxatilis*). Can J Fish Aquat Sci 51:1519–1527