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SUBSTRATE PREFERENCE OF PARAZACCO SPILURUS AND CIRRHINUS MOLITORELLA: ROLE OF SEDIMENTS IN RIVER ECOLOGICAL RESTORATION

YAO WANG(1) & ONYX W. H. WAI(2)

(1) Department of Civil and Environmental Engineering, the Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
wyeureka@gmail.com

(2) Department of Civil and Environmental Engineering, the Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
onyx.wai@polyu.edu.hk

ABSTRACT

In natural rivers, fish have certain preference for bottom substrate types and will select where they prefer to stay. To investigate the substrate preference of target fish – predaceous chub (*Parazacco spilurus*) and mud carp (*Cirrhinus molitorella*), four duplicated experimental trials were carried out in laboratory. A rectangular test flume (7.2 m long×0.6 m wide×0.3 m deep) was divided into four equal areas and paved with four different bottom materials. Each striped substrate is 1.8 m long and 0.6 m wide. A natural part (NA) was set up at upstream of the flume to represent habitat in natural rivers. By deploying artificial turf, sand, pebbles, cobbles and vegetation (Winged star fern) randomly in this part, heterogenous flow conditions and habitat were then created. As most of urban streams have been channelized and concrete-lined, it is hoped to study fish preference for such surface. Therefore, at the end of the flume, an artificial part (AR) was characterized by polymethyl methacrylate (PMMA). Besides, two other bottom materials were tested, including the sediment-dominant substrate (SED) and the pebble-dominant substrate (PEB). To maintain the physical properties of sediments, natural sediment (<2 mm) collected from rivers was paved on one of the four sections. And the PEB region was covered with pebbles ranging from 31 to 64 mm. Flow rate in the flume was set at 3 L/s and water depth was kept at 25 cm by adjusting a tail gate. A group of 10 fish individuals (including 3 *Parazacco spilurus* and 7 *Cirrhinus molitorella*) were released into the flume and recorded by a monitoring system for one hour. Fish preference for various part of the flume was estimated by the distribution on every one-min video footage. Results show that fish population spent 34%-35% of the entire time on both NA and SED. On AR, the percentage of time is approximately 22%, while fish show little interest on PEB (~9%). The findings reveal the significance of sediments on fish habitat conservation. To better understand the role of sediments in fish habitat re-establishment, in addition to fish laboratory experiments, future research should also include numerical simulation of sediment transport and physical habitat modeling.

Keywords: Fish experiment, substrate preference, sediment, river restoration, habitat conservation

1 INTRODUCTION

In Hong Kong, for the purposes of flood control, most local rivers have been channelized into straight, wide, deep forms and lined with concrete. From an ecological perspective, the river system and fish habitat in the nullahs are greatly sacrificed by river regulation. As mentioned in the Water Framework Directive (WFD), the preservation and establishment of fish spawning habitats (Harby et al., 2004) should be considered as one of the major objectives in river ecological restoration (Hauer et al., 2008). A variety of factors may affect the assemblage of fish species including the composition of substrate, canopy cover, shading, interstitial pore space and water temperature gradients (King 2017). Among these factors, substrate types affect the spatial distribution of fish in rivers due to various grain size, organic content, food source and so forth (Szedlmayer & Howe 1997). For fish spawning or egg deposition, a suitable mixture of particles (sand, gravels, pebbles, cobbles) is required (Kondolf et al., 2000). If the substrate is too coarse to be moved, the ability of fish to excavate nests will be limited. While the accumulation of excess fine sediment may reduce oxygen supply for fish. And scouring of bed material below the depth where eggs are buried can expose and put the eggs in danger (Cienciala & Hassan, 2013). Also, smaller substrate such as sand and silt due to erosional processes may fill the interstitial spaces where fish species (especially those on early life history stage) use as shelter to hide from predators. Moreover, specific substrate may be necessary for the presence of macrophytes which will affect the fish species depending on them (King 2017).

During field surveys, it is relatively difficult to determine the fish preference to various substrate types as other environmental factors, e.g. vegetation cover, water temperature, flow depth and velocity may also interfere their selection (Yu & Lee 2002). In a controlled laboratory environment, it is possible to monitor which substrate fish prefers. It is assumed that target fish have certain preference for bottom materials. And when fish are provided with different categories of substrate types, they will selectively choose where they like to stay. Traditional habitat preference tests have been widely applied on mammals since they are regarded as animals with preference or avoidance features. In addition to this, fish have been successfully employed as experimental object for preference tests as they also present active choice when facing different conditioning places (Delicio et al. 2006). And the most widely used methods for determining fish habitat preference in freshwater are underwater observation, electrofishing and fish marking techniques such as passive integrated transponder (PIT) (Ban et al. 2013).

The first objective of this research is to investigate the substrate preference of two freshwater fish species by carrying out a series of fish laboratory experiments. Here, we hypothesized that the bare surface is the most unfavorable substrate compared with other three substrate types (i.e., pebble-dominant, sand-dominant and mixing natural substrate). Through duplicated tests, it is then aimed to explore the potential of certain substrate types for the enhancement of fish habitat. By comparing between sediment and pebble, it is hoped to find a better alternative for the concrete-lined surface in the nullahs. Considering the significance of particles to fish spawning, the third objective of this study is to better understand the role of sediments in fish habitat re-establishment and river ecological restoration.

2 MATERIALS AND METHODS

2.1 Target fish and acclimation conditions

Two fish species were selected as target fish in this research, i.e. the predaceous chub (*Parazacco spilurus*) and the mud carp (*Cirrhinus molitorella*). The first one is a typical widespread endemic fish species in Hong Kong and one of the dominant fish species in the local freshwater environmental (Figure 1 (a)). It is worthy to mention that *Parazacco spilurus* are vulnerable and are indicator species since they are quite sensitive to the habitat. The second one *Cirrhinus molitorella* are commercially valuable (Figure 1 (b)). And the two fish species belong to the same family “Cyprinidae” and have similar size, appearance and behavior mode.

The individuals of *Parazacco spilurus* were collected in the natural reach at the middle course of Tung Chung River in Hong Kong. Fish were then transported to the Eco-hydraulic Research Center at the Hong Kong Polytechnic University to adapt to laboratory environment. The mean body length±SE of captured *Parazacco spilurus* is 11.6±0.4 cm. Taking the harvest difficulty into consideration, we employed another fish species *Cirrhinus molitorella* in our fish experiment. The test fish were provided by local supplier in the fish market, with sizes ranging from 8.6 to 12.9 cm. The mean size of the *Cirrhinus molitorella* is 10.4±1.2 cm. All the test fish were cultured in a fish aquarium in the laboratory with continuous aeration and recirculating system through a biological filter. Dechlorinated water was supplied into the tank every other day. Fish were properly and regularly fed with general fish food and the water quality in the fish tanks was kept within standards.

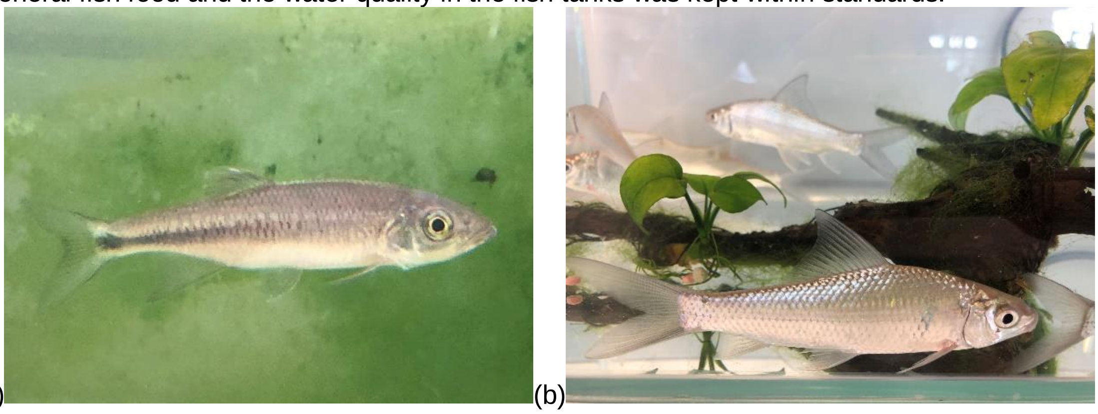
(a)  (b)

Figure 1. Photo of (a) *Parazacco spilurus*, and (b) *Cirrhinus molitorella*

Earlier pre-experimental tests were carried out on the two fish species. When no less than 3 fish individuals take concerted actions (e.g. same swim path in close distance, similar sharp turn), they are considered as a fish group; otherwise, fish are regarded as casual individual exhibiting random behaviors. According to observations, most of the time, both fish species ascended or descended in single (<3) or in group (≥3). The phenomenon of fish swimming as a group is regarded as the gregarious feature of fish. *Parazacco spilurus* showed certain leadership since their total body length is larger than *Cirrhinus molitorella*. When fish group follows the leader of certain fish individuals, this phenomenon is defined as herd immunity. However, sometimes, individual fish suddenly changed the original swimming direction and followed other fish population for no reason. The likely reason is instinctive vigilance to danger or blind following ability of animals (for foraging or avoiding enemies).

2.2 Experimental setup

The fish experiments were carried out in a 10 m long, 1 m wide, 0.45 m deep hydraulic flume in the Eco-hydraulics Research Center at the Hong Kong Polytechnic University. The effective testing region is 7.2 m long by 0.6 m wide by applying the polymethyl methacrylate (PMMA) baffles as sidewalls. At both ends of the flume, rigid fish net was put up to prevent fish from leaving the test area. To verify the hypothesis and investigate the importance of sediments for the enhancement of fish habitat, the rectangular test flume was divided into four equal areas paved with different bottom materials (Figure 2).

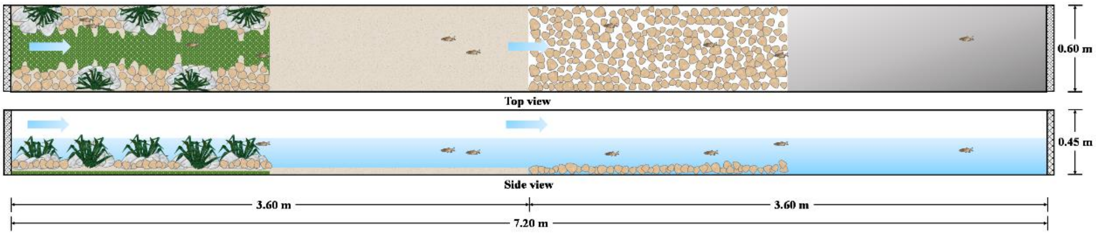


Figure 2. Geometric dimensions of test flume with banded substrate pavement (from upstream to downstream: NA, SED, PEB and AR)

Note: NA refers to natural part, SED refers to sediment part, PEB refers to pebble part and AR refers to artificial part.

Each area installed with striped substrate is 1.8 m long and 0.6 m wide. The upstream natural area (NA, Figure 3 (a)) was mimicked by placing artificial grass turf, sand, pebbles, cobbles and vegetation (Winged star fern) randomly on the bottom to create heterogeneous flow and diversified habitat. The second sediment-dominant substrate area (SED, Figure 3 (b)) was covered with natural sediment (<2 mm) collected from rivers to maintain its physical properties. The third pebble-dominant substrate area (PEB, Figure 3 (c)) used pebbles with sizes ranging from 31 to 64 mm. And the last area was an artificial region (AR, Figure 3 (d)) covered with smooth polymethyl methacrylate (PMMA).

Flow rate was regulated by pump as 3 L/s and water depth was controlled by the tail gate at 25 cm. Lighting was restricted to daylight (light intensity: near to window 600-4,000 lux; near to door 500-800 lux) and static overhead light in laboratory. Two overhead cameras were set up during the experiment to record the fish behavior with 720 p resolution and 60 FPS (frames per second) in a near field of view. The bottom of the artificial part in the flume was covered with 20 cm×20 cm grid for visually identification through video footage. In this research, fish bait was not employed to avoid man-made interference and to capture the most natural daily activities of fish.

(a) (b) (c) (d)

Figure 3. Photos of the four different substrate (a) NA, (b) SED, (c) PEB, and (d) AR

Water used in the flume was conditioned municipal tap water with an average temperature of ~20 ℃. The chlorine (Table 1) in the tap water was removed before the experiment with dose of chemicals as directed by the manufacturer. Water was also left for overnight before a new experiment. And the flume including the pump parts were rinsed thoroughly once a month for the benefit of fish wellbeing.

The water temperature (WT), pH, dissolved oxygen (DO), chlorine (CL2) of different water samples were analyzed in the Water and Waste Research Laboratory at the Hong Kong Polytechnic University. pH and DO values were measured using the PHS-3C pH Meter and the YSI5000 Dissolved Oxygen Meter, respectively. Total chlorine was measured by using the HACH Pocket Colorimeter and the DPD Total Chlorine Reagent Powder (Cat No. 21056-69). The readings are tabulated in Table 1. It can be noticed that after using chemicals and leaving the water overnight, chlorine in water was reduced from 0.09 mg/L to a relatively lower level (0.02-0.03 mg/L).

Table 1. Comparison of water quality of water samples involved in fish experiment

Sample	WT (℃)	pH	DO (mg/L)	CL2 (mg/L)
Running municipal tap water	25.0	8.04	8.10	0.09
Tap water let stand for two days	21.5	7.74	8.85	0.05
Fish tank water	25.6	7.60	6.80	0.04
Flume water (with pump shut down)	21.1	7.69	9.48	0.03
Flume water (with pump started)	20.8	7.71	9.75	0.02

2.3 Experimental trials

In this research, four repeated experimental trials were carried out on the two fish species, predaceous chub (*Parazacco spilurus*) and mud carp (*Cirrhinus molitorella*). A total of 10 fish individuals (including 3 *Parazacco spilurus* and 7 *Cirrhinus molitorella*) were selected randomly as a group for each experiment without bias. They were introduced into a transfer jar prior to experimentation to acclimate to the temperature of the water in the flume. Then, the fish group were released into the test flume while being recorded by monitoring system. The time duration of fish staying in each substrate area was estimated by every one-min video footage to analyze the fish preference for the substrate. After the experiment, fish were transferred to the jar again to adjust themselves to the water in the fish tank. Fish would get at least 24-hour rest after a 1-hour (3:00 p.m. to 4:00 p.m.) experiment.

3 RESULTS AND DISCUSSION

The test trials of fish preference for different categories of substrate were carried out in the slow-moving water (~0.02 m/s). Froude number was controlled in a relative minimal stage (<0.05). Because of the original slope of the test flume, it will cost energy for fish to ascend towards the upstream natural part (Figure 4 (a). And energy can be saved at the downstream artificial part (Figure 4 (b) since it is the lowest point of the potential energy. Here, the behavior of fish ascends represents their yearning for better habitat. While the performance of group descends implies their desire for resting. When fish individuals stay still or calf round on a small scale at the downstream artificial region over 30 s, they are considered as in fatigue status. Moreover, small-sized fish were monitored leaning on the intercept net at the downstream end (Figure 4 (b)), which is regarded as in exhausting status.

In the experiments, *Parazacco spilurus* show more preference to the upstream natural habitat over the downstream man-made substrate. With staggered real plants (Winged Star Fern) in the natural part, *Parazacco spilurus* demonstrat more swift and brisk activities in this region, and sometimes they were observed racing with burst or sprint speed. In contrast, *Cirrhinus molitorella* prefer to stay at the downstream artificial part rather than the upstream natural region. When fish individuals of *Cirrhinus molitorella* reach the natural region, they normally hide behind the plants or swim through those plants.

(a)  (b) 

Figure 4. (a) fish ascend to the upstream natural part, and (b) fish rest at the downstream artificial part

Regarding the trajectory of fish population, it was concluded based on the experiments that fish swimming mode is characterized by body size. *Parazacco spilurus* choose the middle pathway (main flow) to move from one region to another, while *Cirrhinus molitorella* prefer to swim along the wall boundary where the flow velocity is near zero. Here, we assume that frequent transiting of fish implies the seeking for preferable habitat in the flume. If fish stay in one region for relatively longer time, they are considered have preference for certain substrate. Figure 5 shows the transits of fish from pebble-dominant substrate to sediment-dominant substrate observed during the preference tests. This is probably because they want to make a choice between the two substrate types and look for a more suitable place to stay.

(a)  (b) 

(b)

Figure 5. Fish transit from the pebble-dominant to sediment-dominant substrate (a) sideview, (b) planview

Fish monitoring in the local streams indicate that target fish prefer to inhabit in environment with mixed sediment-gravel substrate. By comparing between the pebble-dominant and sediment-dominant substrate, fish were observed hiding on the surface of both substrate types as seen in Figure 6. The likely reason is the color similarity of fish and the substrate. For the purposes of avoiding enemies, animals tend to find camouflage in which their color matches the surroundings to make themselves difficult to be seen (red circle in Figure 6).

(a)  (b) 

Figure 6. Fish hide on the surface of (a) pebble-dominant substrate, and (b) sediment-dominant substrate

Fish preference for various substrate types was tested in the flume and recorded by a monitoring system for one hour. The video-processing results of the four duplicated experiments are illustrated in Figure 7.

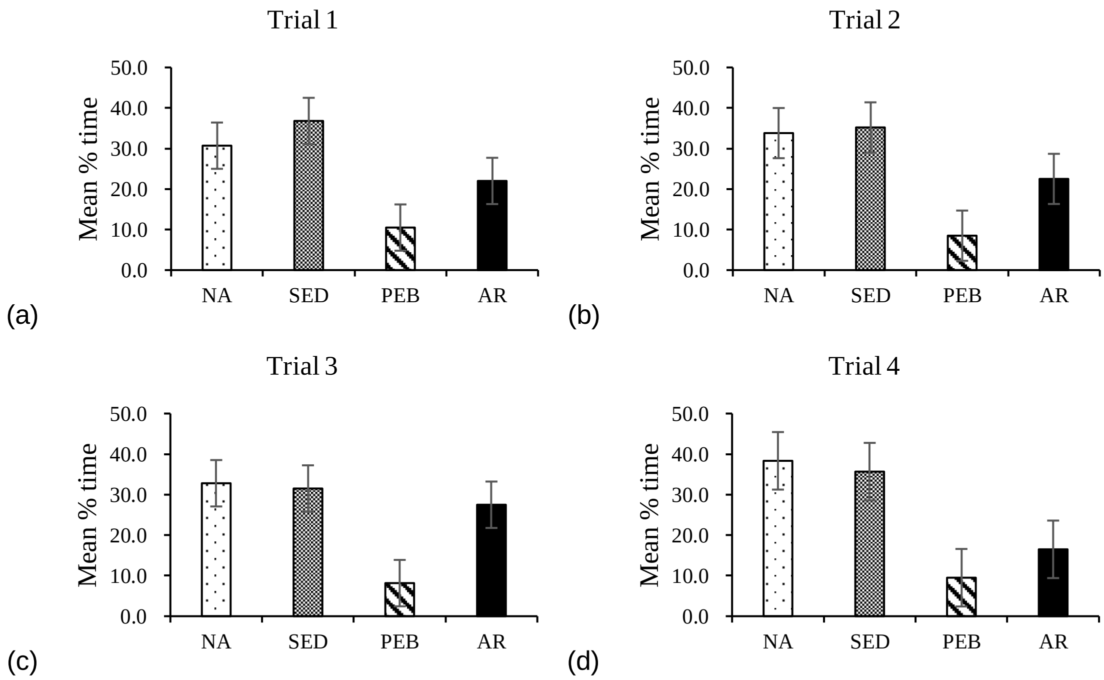


Figure 7. Percentage of time on different substrate types

As expected, fish prefer natural part over man-made part without the existence of sediment or vegetation. It is revealed in this study that the percentage of time on natural part (NA) and artificial part (AR) are nearly 33.9% and 22.1%, respectively. More time spent on the upstream natural part of fish population can be partly explained by their preference for better living environment or rheotaxis attribute. If we hope to find alternatives for the concrete-lined surface, the best option is to transform the man-made flood channel into its original natural state. The actions to return river into a pre-disturbance condition are defined as river restoration. However, a prominent concern on river restoration designs is how the restored channel will convey floods. The desirable natural fish habitat is at the sacrifice of flood flow accommodation (Morris, 1996). In addition, it takes more effort to include every element into river restoration activities. Therefore, we hope to find other easy alternatives for the concrete-lined surface which is not suitable for fish to live. During the fish experiments, we tested the fish preference for both sediment-dominant substrate (SED) and pebble-dominant substrate. It is estimated that *Parazacco spilurus* and *Cirrhinus molitorella* spend even more time on the sediment-dominant substrate (~34.8%) than the upstream natural region. Early research findings show that most fish (e.g. juvenile flatfish, sturgeon) demonstrate strong preference for sediments. Similar conclusions were draw in our research as well. The preference for sediment-dominant substrate implies the significance of sediments for the rehabilitation of fish habitat. Despite the pebble-dominant substrate (PEB) can provide sheltering for fish with similar color, this region is the least preferred substrate of our target fish (~9.2%). Similar with Nile tilapia and sturgeon, *Parazacco spilurus* and *Cirrhinus molitorella* avoid gravel or pebble and prefer smaller substrate (i.e. sediment). This may be explained by the turbulence created by the pebbles which will drive individual fish away.

4 CONCLUSIONS

In summary, it is revealed from the experiments that the two fish species *Parazacco spilurus* and *Cirrhinus molitorella* prefer natural region and sediment-dominant substrate rather than pebble-dominant substrate or artificial region. To return the river into a natural state approximately near its situation before disturbance, a variety of modifications to river as well as its adjacent riparian zones and floodplains, not this merely but also the water, sediment and solute inputs (Bennett et al., 2011) should be included. And these modifications of river restoration share the same objective for the improvement of hydrologic, geomorphic and ecological process within a degraded watershed and replacement of the lost, damaged or compromised elements of the natural system (Wohl et al., 2005). The other option to restore the fish habitat is to embrace the sediment regime concept (Wilcock, 2012). As is commonly acknowledged, the transport of river sediments is a fundamental factor in the movement of river. Different kinds of bed morphology (e.g. riffles, pools and runs) are the consequences of sediment transport and river bed evolution. And a mixture of bed morphology types provides a variety of habitats to support fish and invertebrate life. Moreover, the dispersion of sediment also has fundamental impact on river water quality and ecosystems since it is the carrier of pollutants and nutrients. Therefore, in a river system, either sediment excess or sediment deficit is probably to have some negative effect on the process and form of rivers, leading to the degradation of ecosystems (Wohl et al., 2015). Given the complex nature of sediment-transport processes (Noack, 2012), it is difficult to include sediment dynamics into the research of river ecological restoration. To better understand the role of sediments in fish habitat re-establishment, further studies should also include numerical simulation of sediment movement and fish habitat.

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