RESEARCH ARTICLE

Study of intertidal biological channels during the construction of the Qiantang River seawall

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Received: June 6, 2023; **accepted:** July 31, 2023.

As China enters a new stage of high-quality ecological development, higher demands are placed on the ecological effects of coastal protection projects. Because the traditional hard seawall pays little attention to its impact on the coastal ecological environment, the construction of seawalls along the line cuts off the habitats inside and outside the pond, which makes the regional habitats fragmented, and hinders the migration of organisms. In order to restore and protect the coastal zone, build an ecological seawall, improve the seawall's ability to resist typhoon, storm surge, and other marine disasters, and protect the beach wetlands, water quality, and biodiversity along the seawall, this project started with the study of biological channels, and then systematically carried out the investigations, research, and analysis on the biological resources inside and outside the seawall and along the seawall. The results of research and field investigation showed that there were mainly natural plant communities such as *Bolboschoenoplectus mariqueter* and *Phragmites australis* on the beach of Jianshan section. The back slope of the pond was the soil slope with human afforestation as the main vegetation, and the foot of the slope was the protection pond river. Crab was the dominant species in beach and intertidal zone. Referring to the domestic and international biological channel cases, we proposed to set up 8 biological channels in the Jianshan section of the pond as a test section without affecting the structural safety of the seawall, and set up video monitoring equipment to evaluate the use of the channels and provided data support for future design or optimization of the channels.

Keywords: seawall; biological channel; ecological seawall; Qiantang river; migrate.

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Introduction

Coastal protection works are essential to prevent coastal zone erosion and maintain ecosystem integrity and diversity. Traditional hard seawalls are less considered for their impact on the coastal zone ecology. As China enters a new stage of high-quality ecological development, higher demands are placed on the ecological effects of coastal protection projects [1]. Since the 1950s, some countries in North America and Europe began to design and use wildlife channels, especially in the United States, Canada, the Netherlands, and other countries with a long history [2]. Many countries have gradually begun to pay attention to the impact of transport facilities on the ecological environment [3], and in the past 20 years, environmental impact assessment and wildlife channels design have been incorporated into the routine planning of transport facilities, and relevant laws and policies have been formulated. In these countries, wildlife passages, like sidewalks and overpasses in cities, have become an indispensable role in roads and railways [4]. However, in China, the research on traffic eco-environmental protection mostly focuses on the environmental pollution of traffic facilities [5], and the ecological impact of highway engineering construction. The research on the impact of road traffic on wildlife is still not comprehensive enough [6].

In past studies, some researchers believed that the wildlife movement corridor was a linear habitat, and its main function was to connect wildlife in more than two habitat areas. Beier and Loe suggested that wildlife migration channel was a kind of banded plaque that combined channel and habitat function [7]. Jordan also pointed out that an ecological corridor referred to an area that could connect habitats and enable specific species to migrate between habitats [8]. In addition, Clevenger and Waltho defined the wildlife channel as the channel located above or below the road to assist the migration of wildlife [9]. From those studies, we can summarize that the wildlife channel should have two main functions with one to connect the fragmented natural environment caused by man-made obstacles such as roads and two to make wild animals capable migrating freely between connected habitats by means of channels. In 1955, Florida, USA built an underground channel for black bears, which was the first wildlife channel in the world [10]. Subsequently, Europe and North America also built a variety of wildlife channels. According to the location, shape, and materials, these wildlife channels were mainly divided into four types including tubular culverts, box culverts, bridge wildlife channels, and road wildlife channels. The tubular culverts are relatively small in size and often use fences to guide animals to the entrance of the channel, so as to prevent them from running directly to the road and causing road fatal accidents. They are mainly designed for small animals. Box culverts are usually larger than tubular culverts, and also play a drainage role when there is plenty of water. Compared with tubular culverts, box culverts provide more space and are cheaper than bridge channels. Bridge wildlife channels are mainly designed for medium or large animals, and it is one of the best channel forms in mountainous areas and river sections. It is a relatively common channel form. Road wildlife channels are mainly designed for large mammals. Generally, a bridge is designed on a mountain divided by roads, so that the two sides of the mountain are connected together. At the same time, the surface of the bridge is covered with soil for planting native plants, and shrubs are planted on both sides of the bridge to make it similar to the surrounding natural environment, which can avoid the disturbance of animal vision and reduce the impact of road noise.

The purpose of this study was to design the biological passage in the intertidal zone of Qiantang River, Haining, Zhejiang, China. So that the habitats inside and outside the pond that were cut off due to the construction of seawall could be connected again, and the organisms could migrate between the broken regional habitats. This study could protect the wetland, water quality, and biodiversity along the seawall by constructing biological channels in intertidal zone, and also provide reference for the study of biological channel in seawalls in other regions.

Materials and Methods

Targeted study location
Haining, Zhejiang, China is located at the southern end of Hangjiahu Plain. It is about 120 km away from Shanghai, China and east of Hangzhou City and north of Qiantang River. The area of Haining is 744.8 km^2 with a length of 51.6 km and a width of 28.9 km. The Jianshan ecological beach in Haining, the targeted area of this study, is located in Jianshan reach of Haining.

On-site monitoring method
In order to find out the biological status of intertidal zones along the seawall, this field survey focused on the representative Haining

Table 1. Layout of biological survey sections in intertidal zone.

serial number	Sample number	Longitude	Latitude
1	S1	120.86093903	30.32428587
2	S2	120.81390381	30.29523927
3	S3	120.75262070	30.31850687
4	S4	120.74601173	30.35450889
5	S5	120.71545601	30.38575916
6	S6	120.63134193	30.40152861
7	S7	120.55902958	30.39993697
8	S8	120.46028137	30.39301490

seawall area that was on the north bank of the Qiantang River. Eight sections were arranged along the whole survey area, and each section was sampled in the high, middle, and low tide areas, which included 3 sections in Jianshan wetland, 1 section in old salt warehouse, 2 sections in ancient sea pond, and 2 sections in beach land on the lower north bank of Jianshan reach. The specificities of each location were shown in Table 1. The investigation was performed during the summer and autumn seasons with the summer investigation time from July 10th to 16th and the autumn investigation time from September 20th to 26th.

According to the requirements of Code for Marine Survey Part VI: Marine Biological Survey [11], when sampling organisms on the rocky shore, each station adopted a quantitative frame of 25 cm × 25 cm × 30 cm to take two quadrats. A quantitative frame of 10 cm × 10 cm was applied in the densely populated area. Four quadrats (0.25 m^2 in total) were taken from each station of mudflat and sandy beach with a quantitative frame of 25 cm × 25 cm × 30 cm. Eight quadrats (0.5 m^2 in total) were taken from each station on the beach with a quantitative frame of 25 cm × 25 cm × 30 cm. At the same time, one qualitative sample was taken from the high, middle, and low tide areas, respectively.

Results

Species composition of intertidal zone

27 species of 3 phyla were collected including 2 chordates, 4 annelids, 15 arthropods, and 6 mollusks accounting for 7.4%, 14.8%, 55.6%, and 22.2% of the total species, respectively. Arthropod was the main group of organisms in the intertidal zone (Figure 1). The biological dominant species in July 2021 were *Ilyoplax* sp., *Ilyoplax deschampsi*, *Grandifoxus cuspis*, and *Penaeus* sp., while, in September 2021, the biological dominant species in the intertidal zone were *Ilyoplax deschampsi*, *Fenneropenaeus* sp., *Grandifoxus cuspis*, and *Glauconome corrugate* (Table 2).

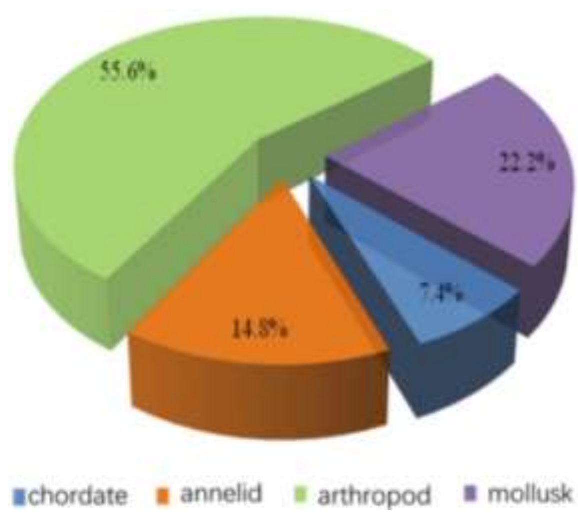

Figure 1. Species composition of intertidal zone.

Habitat density and biomass

In July 2021, the average habitat density of each section was 27 individual (IND)/m^2, while, in September 2021, the average habitat density of

Table 2. Biological list of intertidal zone in Haining section of Qiantang River estuary.

Serial number	Biological species	Latin	S1	S2	S3	S4	S5	S6	S7	S8
I	Chordate									
1		*Apocryptodon glyphisodon*	-	-	-	-	+	-	-	-
2		*Gobiidae*	+	-	-	-	+	-	-	-
II	Annelid									
3		*Nephtys oligobranchia*	-	-	-	-	+	-	-	+
4		*Paralacydonia paradoxa*	-	-	-	-	+	-	+	-
5		*Nephtys neopolybranchia*	-	-	-	-	-	+	-	-
6		*Mediomastus* sp.	-	-	+	-	-	-	-	-
III	Arthropod									
7		*Penaeus* sp.	-	-	-	-	+	-	+	-
8		*Corophium* sp.	-	+	+	+	+	-	+	+
9		*Grandifoxus cuspis*	-	+	+	+	+	+	+	+
10		*Neosarmatium meinerti*	+	-	-	-	-	-	-	-
11		*Neoepisesarma mederi*	-	+	-	+	-	+	+	+
12		*Ilyoplax* sp.	-	+	+	-	+	+	+	+
13		*Ampeliscidae*	-	-	-	+	-	-	-	-
14		*Ilyoplax deschampsi*	+	+	-	+	+	+	+	+
15		*Eriochier leptognathus*	-	-	-	+	-	-	-	-
16		*Bresedium* sp.	-	-	-	-	+	-	-	-
17		*Fenneropenaeus* sp.	+	+	+	+	+	-	+	+
18		*Helice tridens tientsinensis*	+	+	-	-	-	-	-	+
19		*Atypopenaeus* sp.	-	-	-	+	-	-	-	-
20		*Acetes chinensis*	+	-	-	-	-	-	-	-
21		*Perioculodes* sp.	-	-	-	-	-	-	-	+
IV	Mollusk									
22		*Glauconome primeana*	+	-	-	-	-	-	-	-
23		*Glauconome* sp.	+	-	-	-	-	-	-	-
24		*Mactra quadrangularis Deshayes*	+	-	-	-	-	-	-	-
25		*Assiminea violacea*	-	-	+	-	-	+	-	-
26		*Assiminea* sp.	+	-	-	-	-	-	-	-
27		*Glauconome corrugata*	+	-	-	-	-	-	-	-
Total species number			10	7	6	8	10	6	7	9

each section was 42 IND/m^2. The average habitat density in autumn was higher than that in summer. In July 2021 and September 2021, the average habitat density of each tidal area showed the trend of middle tidal area > low tidal area > high tidal area. The average biomass of each section was 5.82 g/m^2 and 10.57g/m^2 in July 2021 and September 2021, respectively. The average biomass in autumn was higher than that in summer. The average biomass of each tidal area showed the trend in July 2021 and September 2021 as high tidal area > middle tidal area > low tidal area (Figure 2).

Diversity index

Margalef's richness, Shannon-Wiener diversity index, Pielou's evenness index, and Simpson's diversity index were applied for data analysis to study the diversity. Margalef's richness is a method to measure species diversity in an

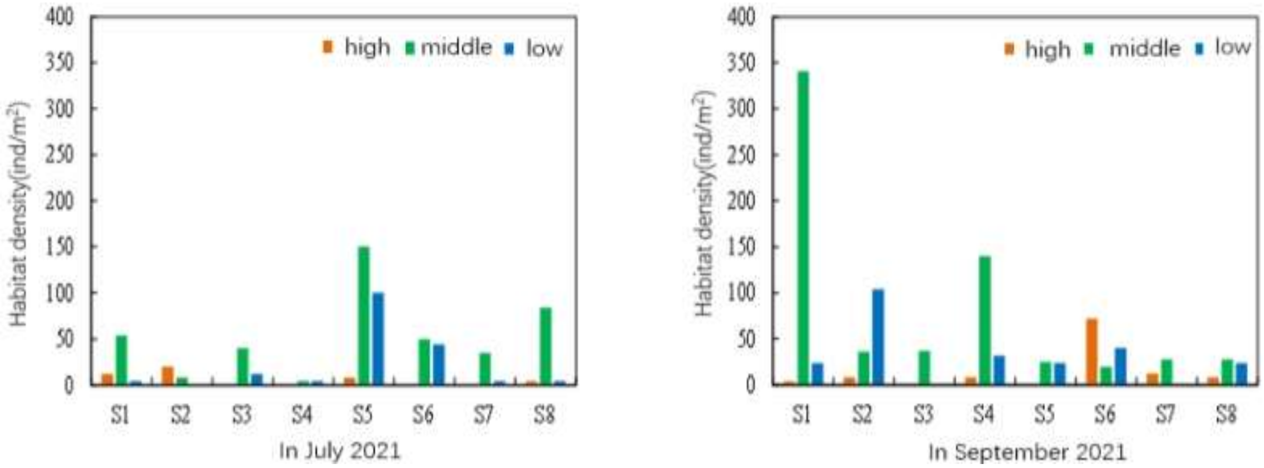

Figure 2. Spatial and temporal distribution of average habitat density in intertidal.

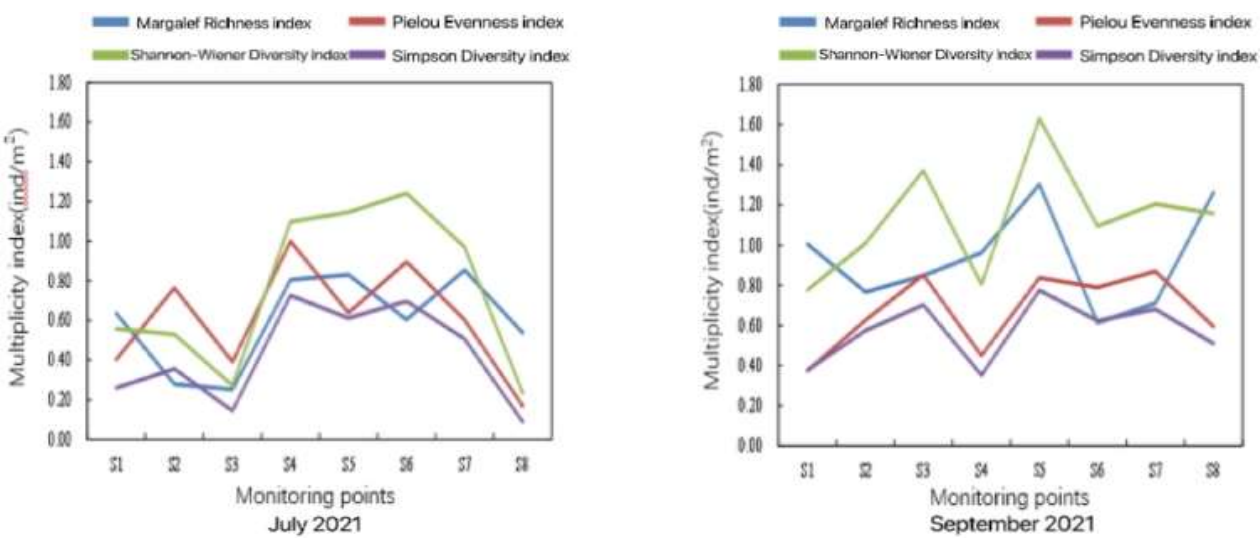

Figure 3. Spatial distribution of diversity index.

ecosystem, which can reflect the information of species quantity, species composition, and relative richness in a region or sample plot. Pielou's evenness index refers to the distribution of the number of individuals of all species in a group or environment, which is a measure of the closeness of different species in quantity. Shannon-Wiener diversity index is an index used to investigate the local diversity (α-diversity) of plant communities, which is often used together with Simpson diversity index, while Simpson diversity index describes the probability that the number of individuals obtained from two consecutive sampling of a community species belongs to the same species. In July 2021, the number of species ranged from 2 to 6 with an average value of 4. The Margalef's richness ranged from 0.25 to 0.85 with an average value of 0.60. The Pielou's evenness index ranged from 0.17 to 1.00 with an average value of 0.61. Shannon-Wiener diversity index ranged from 0.23 to 1.24 with an average value of 0.76. Simpson's diversity index ranges from 0.09 to 0.73 with an average value of 0.42. In September 2021, the number of species ranged from 4 to 8 with an average value of 6. The Margalef's richness ranged from 0.61 to 1.30 with an average value of 0.93. The Pielou's evenness index ranged from 0.37 to 0.87 with an average value of 0.67. Shannon-Wiener diversity index ranged from 0.78 to 1.63 with an average value of 1.13. Simpson's diversity index ranged from 0.35 to 0.78 with an average value of 0.57. The values of community ecological characteristic index were higher in autumn than that in summer (Figure 3).

Another field survey on the habitats along the same route was conducted during June and July of 2022. The results demonstrated that the habitat in front of the seawall in Jianshan section was basically bounded by Jiashao Bridge, and the front of the seawall on the upstream side of the bridge was seriously scoured. The beach area covered by vegetation was small with a longitudinal width of about 30~50 m. The front of the beach was mainly gravel, and the beach was mainly *Phragmites australis*. The beach area covered by vegetation on the downstream side of the bridge was larger than that on the upstream side with a longitudinal width about 120~150 m and the beach was mainly composed of *Bolboschoenoplectus mariqueter* and *Phragmites australis*. The back slope of seawall was soil slope, and the habitat of the back slope was basically the same as basically artificial vegetation. There was a pond protection river behind the slope. Bu combining the results of both intertidal biological surveys in 2021 and 2022, it could be known that crabs were the dominant species in this area with a large population. During the field survey, it was also found that a large number of crabs lived everywhere on the slope toe and beach in front of the seawall, and a large number of crab caves could be seen everywhere. At the same time, many crab bodies were found on the concrete cover in front of the seawall and on the top of the seawall, indicating that some crabs tried to cross the seawall and died because of long-term water shortage and physical exhaustion.

Discussion

At present, although some other countries have built animal channels, their utilization rate is still low, and these channels may have had the following problems when they were set up. In the pre-study of building animal channel, the location of the channel was not carefully investigated and set arbitrarily, resulting in low utilization rate of animals after the channel was built. Therefore, it is necessary to determine the best location and the best density ratio for the construction of the channels after a rigorous field survey to achieve the optimal protection effect with the minimum cost and to avoid wasting time and resources [12]. The different species have different preferences for the type of channel and design structure. For example, deer like an open-view environment, while cougars tend to use the channel under the road. It is difficult to design a channel that can meet the requirements of all animals. Therefore, only by combining the characteristics and living habits of local wildlife communities, the most suitable channel that conforms to the local ecosystem can be designed and built [13]. The design and construction of animal channels need to be combined with many disciplines, such as zoology, engineering, and ecology. The design of the channel is a complicated process. The professional technologies and experts from various disciplines need to be integrated and cooperated with each other for the design of the biological channel. After the completion of the animal channel, it is necessary to carry out long-term monitoring to determine whether the channel has an effect on the surrounding ecosystem, whether there are animals to use it, what kind of animals are using it, and how often it has been used [14]. After long-term monitoring, the effectiveness of the channel can be evaluated, and its disadvantages can be improved to truly meet the needs of animals. The maintenance of animal channels includes fences and channel structures, for example, some culvert channels with drainage function may be blocked by sand and silt, and the entrance will be eroded. These all depend on daily maintenance to ensure the normal use of the channel.

According to the results of field investigation, there were mainly natural plant communities such as *Bolboschoenoplectus mariqueter* and *Phragmites australis* on the beach of Jianshan section. The back slope of the pond was the soil slope with human afforestation as the main vegetation, and the foot of the slope was the protection pond river. Crab was the dominant species in beach and intertidal zone. The construction of seawalls along the line cut off the habitats inside and outside the pond, which made the regional habitats fragmented and hindered the migration of organisms [15], and brought great pressure to their survival, especially amphibians and reptiles, who were slow to move and weak in diffusion, and had a very high mortality rate when crossing the seawall. The construction of the biological channels could connect the fragmented habitats, promote the communication between species, and enable amphibious reptiles such as crabs to migrate through biological pathways rather than over the surface of road, which could effectively reduce the mortality rate.

Based on the current research status, there was no biological channel on seawalls both domestically and internationally. The main reasons were that (1) there was a great difference between the habitats inside and outside the seawall. The environment outside was saline water, while the environment inside was fresh water. So, there was little physiological demand for animal migration; (2) behind the seawall were generally urban areas, where wild animals were scarce and habitats for wild animals were also lacking; (3) the hydrodynamic conditions of the beach were complex and affected by storm surges. In addition, the geological conditions of seawalls are generally poor. If the biological channels are not set properly, the safety risks of seawalls will increase. Based on the domestic research status, data collection, and biological investigation results of this study, the setting of biological channels was explored. At present, amphibians such as crabs, terrestrial reptiles, and small mammals are mainly considered. Biological channels mainly provide places for such kinds of wild animals to inhabit, migrate, and avoid natural enemies.

According to the relevant cases of domestical and international biological channels, optimization was carried out. Due to the good conditions of the Jianshan section, it was taken as the experimental section. Aiming at the phenomenon of habitat fragmentation in intertidal zones, this study put forward some suggestions to build biological channels to help solve the problem of blocked biological migration. It was proposed to set up eight biological channels along the Qiantang River seawall, which was a domestic precedent, and further optimized the layout point and section structure type. One channel would be installed every 2 km along the seawall, and a total of 8 channels would be installed with a width of 1.0 m and a height of 0.8 m. The bottom elevation of the outlet on the inland river side was 0.96 m, which matched the normal water level on the inland river side. From the toe of the inner slope of the seawall to the outside of the pond, the biological channel was built in the seawall structure, and the foundation size should be appropriately increased in some sections to ensure that the setting of the biological channel would not affect the structural safety of the seawall. The top of the biological channel was covered with a partially light-transmitting cover plate and equipped with a rain shower system with one facility in every 5 m to ensure the humidity of the inner bottom of the ecological channel. The bottom of the biological channel adopted a large boulder cushion, which was covered with silty sand of about 0.3 m with the soil taken from the beach nearby. The plants such as low reeds were planted in the channel, so as to create the same habitat conditions as the outside of the pond (Figures 4 and 5). In addition, considering the monitoring and evaluation after the implementation of the biological channel, video monitoring equipment was set at the entrance, exit, and middle of the biological channel to facilitate future monitoring and management.

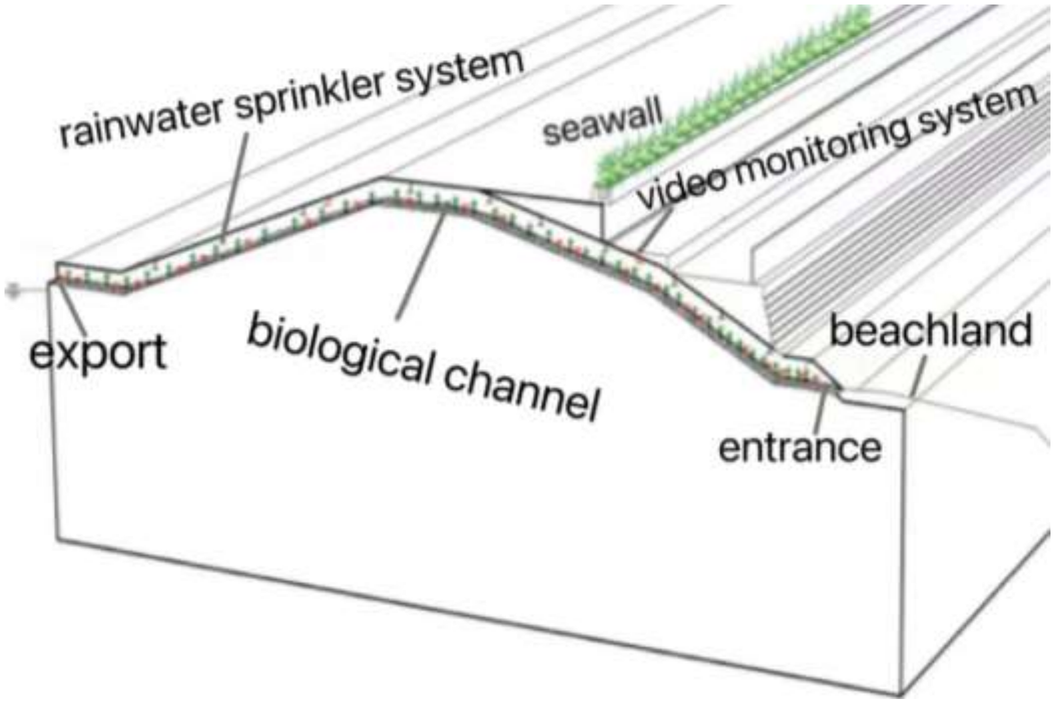

Figure 4. Longitudinal profile of biological channel.

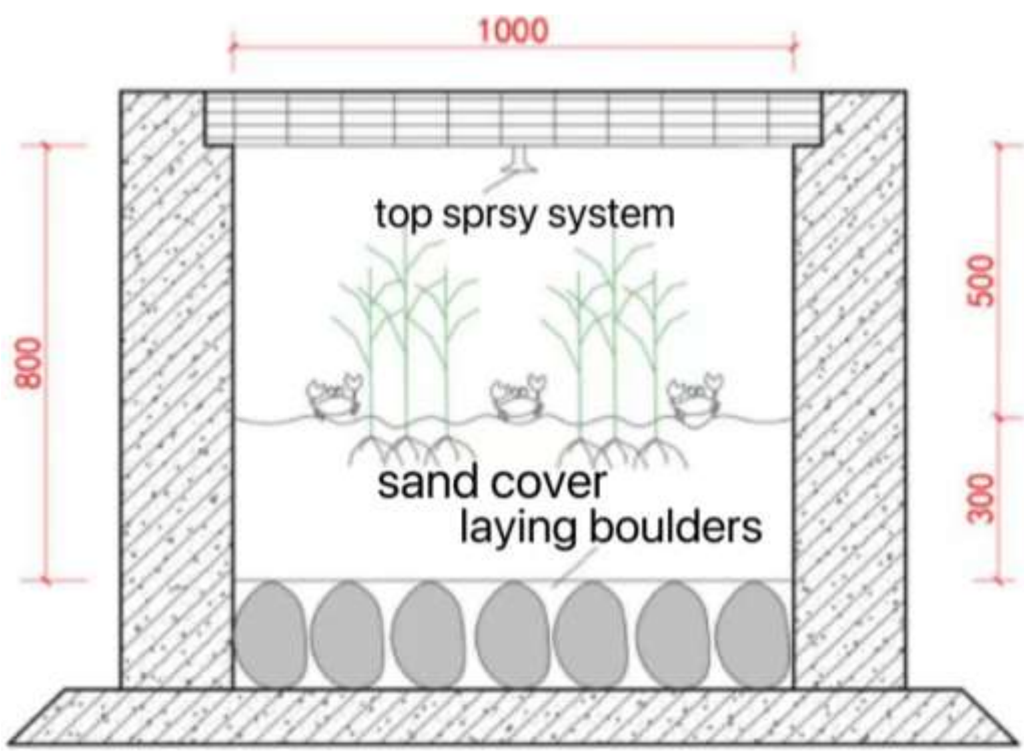

Figure 5. Cross section of biological channel.

Acknowledgement

This study was partially funded and supported by Science and Technology Plan project from Department of Water Resources, Zhejiang Province, China in 2022 (Granted: RC2250).

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