

Article

# The Importance of Providing Multiple-Channel Sections in Dredging Activities to Improve Fish Habitat Environments

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Academic Editor: John S. Schwartz

Received: 19 October 2015; Accepted: 14 January 2016; Published: 22 January 2016

**Abstract:** After Typhoon Morakot, dredging engineering was conducted while taking the safety of humans and structures into consideration, but partial stream reaches were formed in the multiple-channel sections in Cishan Stream because of anthropogenic and natural influences. This study mainly explores the distribution of each fish species in both the multiple- and single-channel sections in the Cishan Stream. Parts of the environments did not exhibit significant differences according to a one-way ANOVA comparing the multiple- and single-channel sections, but certain areas of the multiple-channel sections had more diverse habitats. Each fish species was widely distributed by non-metric multidimensional scaling in the multiple-channel sections as compared to those in the single-channel sections. In addition, according to the principal component analysis, each fish species has a preferred environment, and all of them have a wide choice of habitat environments in the multiple-channel sections. Finally, the existence of multiple-channel sections could significantly affect the existence of the fish species under consideration in this study. However, no environmental factors were found to have an influence on fish species in the single-channel sections, with the exception of *Rhinogobius nantaiensis*. The results show that providing multiple-channel sections in dredging activities could improve fish habitat environments.

**Keywords:** multiple-channel section; dredging engineering; habitat characterization; habitat use; binary logistic regression

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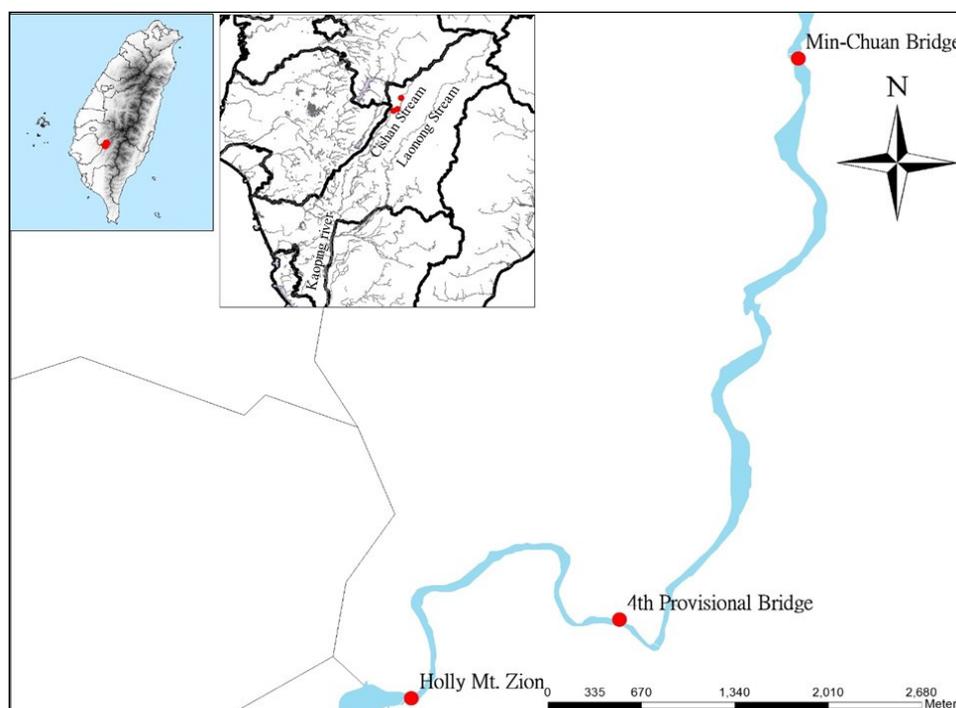
## 1. Introduction

Flow velocity, water depth and substrate are generally measured as environmental factors in order to explore relationships between aquatic organisms and habitat [1–4]. One reason for this is that these environmental factors can be directly and easily measured, and another reason is that they can be connected with some hydraulic parameters which are used to characterize physical habitat conditions [4]. These environmental factors have different presentations under different hydromorphological conditions [5]. For example, high flow events may cause faster velocity and more homogeneous substrate to be in the stream [6–11]. Furthermore, high flow events also reform the stream habitat, which include channel types [12,13]. However, channel types still can be affected by other factors. Leopold & Wolman (1957) [14] first classified three different channel types (straight, meandering and braided channels) according to the channel slope and bankfull discharge. Subsequent researchers provide additional factors which can be used to differentiate between these three channel types [15–17]. Braided channels were different from the others due to their multiple channels, and some research found braided channels contain high environmental variances [18–20]. Consequently, braided river restoration can provide habitat value [2].

Multiple-channel sections include one main channel and at least one secondary channel [2,21]. These channels are separated by bars or stable islands [2,22–24]. The shape of multiple-channel sections is rather unclear due to complex stream systems [2,12,18,21]. However, complex stream systems could potentially benefit aquatic organisms [25–28].

Habitats are more diverse in multiple-channel sections than in single-channel sections [2,29]. Generally, the main channel has greater depth, velocity and coarser substrates than the secondary channel [30]. In addition, multiple-channel sections could provide an excellent habitat to aquatic organisms both for spawning and survival [31–33]. Furthermore, multiple-channel sections also can provide suitable habitats to fish for spawning and survival due to the fact that these habitat environments are characterized by the low velocity and shallow water existing under different discharge conditions in the stream [34]. Generally, secondary channels have shallower water depth and slower flow velocity as compared to main channels. Therefore, these channels are key elements for aquatic organisms in streams [5,24,35,36].

Before Typhoon Morakot, the Cishan Stream (Figure 1) remained largely an area with very little human impact. During the three days of Typhoon Morakot, the habitat was completely destroyed in the Cishan Stream. Typhoon Morakot brought record-breaking rainfall to southern Taiwan, and the rainfall was more than 2500 mm in the mountainous area of Kaohsiung City, which resulted in landslides, debris flows and floods which caused damage to many roads and bridges. Consequently, a lot of sediment entered into the channel and raised the riverbed by more than 30 m in the Laonong Stream and 20 m in the Cishan Stream, respectively. After Typhoon Morakot, because the riverbed rose too much, government agencies continuously authorized the dredging and digging of ditches (the single-channel sections) to concentrate the flows to reduce the water surface elevation and flooding. After a period of time, some of the stream reach transformed from dredged single channels into multiple-channel sections creating different river depths, velocities and substrate conditions than found prior to the typhoon as a result of anthropogenic and natural disturbances.



**Figure 1.** The surveyed stations in Cishan Stream.

The aims of this study are (1) to compare the differences in habitat between multiple- and single-channel sections; (2) to compare the differences in fish assemblages between multiple- and single-channel sections; (3) to compare the differences in the habitat environments inhabited by fish

in both multiple- and single-channel sections; (4) to compare the differences in habitat use by fish species in both multiple- and single-channel sections; (5) to explore which environmental factors have the most influence on fish species. As described above, researchers in the past have studied the differences between multiple- and single-channel sections based on restoration [2,32]. Second, only a few studies have explored the relationship between environmental factors and fish assemblages in multiple-channel sections. In our study, the multiple-channel sections were not formed as part of the restoration. However, we assume they still provide diverse habitats and that many fish can live in these areas. Regardless of the purpose of the re-emergence of multiple-channel sections, this paper provides an evaluation of the effectiveness of these habitat types.

## 2. Methods

### 2.1. Area of Study

The study was conducted in the upstream of the Cishan Stream. The Cishan Stream is one of the important tributaries in the Kaoping River in the southern Taiwan, and its total length and catchment are 104 km and 741 km<sup>2</sup>, respectively [37]. The Cishan Stream remained largely undisturbed by humans until Typhoon Morakot in 2009. The storm produced copious amounts of rainfall and triggered enormous mudslides and severe floods in southern Taiwan, where stream habitats were destroyed. In addition, the Taiwanese government was concerned about human safety and about local structures, so dredging was used in the stream to form single-channel sections where stream habitats became homogenous. Dredging and the resulting homogenization of stream habitats may adversely affect habitat availability for aquatic organisms [38]. However, parts of the stream reach changed from single- to multiple-channel sections as a result of anthropogenic and natural disturbances in 2011. Anthropogenic disturbances included the influence of dredging and other engineering activities, and natural disturbances refers to the original characteristics in the Cishan Stream. The stream of multiple-channel sections is like braided rivers that consist of a main or primary channel and different secondary channels or side-channels [5,38]. In this study area, the stream with multiple-channel sections mainly includes a main channel and a secondary channel.

Field surveys of fish abundance and habitat measurements were conducted at three stream reaches, the Min-Chuan Bridge, the Holly Mt. Zion and the 4th Provisional Bridge areas (Figure 1). Each stream reach includes one multiple-channel section and one single-channel section that are of sufficient length to survey fish abundance and conduct habitat measurements. The single-channel section is located near the multiple-channel section. Generally, equidistant sample grids by the middle-channel bar length were placed within the main channel and the secondary channel, and the distance of the equidistant sample grids was also applied in the adjacent single-channel section. In total, 109 sample grids were placed during daylight hours between December 2012 and July 2014.

### 2.2. Fish Sampling

In this study, electrofishing devices with two 1-m sticks that frame a 1 m × 1 m rectangular electrode were used. After the placement of the electrofishing devices, the sample grids were not disturbed for at least 11 min [39]. The sample grids were placed on the adjacent shoreline because the shoreline is an important habitat for fish [12,40,41]. After this period of acclimation, the electrodes were charged for one minute, and samplers used dip-nets to collect immobilized fish downstream from the rectangular electrode frames. The caught fish were identified and standard length and wet weight were recorded. Then, they were released to their original collection location. Permission was obtained from the local community, the Agriculture and Marine Bureau of the Kaohsiung City Government, and the Forestry Bureau, Council of Agriculture before conducting this study.

### 2.3. Habitat Survey

The habitat survey data included the flow velocity (at 60% depth), water depth, substrate, pH, electrical conductivity (EC), salinity, dissolved oxygen (DO), turbidity, and chlorophyll *a*. The water depth and flow velocity were surveyed at nine points in each sample grid, and then the average of the nine values was used to represent the water depth and flow velocity of the sample grid (1 m × 1 m). A 1 m × 1 m plastic net was used to determine the percentage of substrate composition using a surface-visual-method [42]. This net was marked with one hundred grid cells (10 cm × 10 cm), with each cell's substrate size categorized as sand (<2 mm), gravel (2–64 mm), pebbles (64–256 mm), cobble (256–512 mm), and boulders (>512 mm).

### 2.4. Data Analysis

The mean, standard deviation, and coefficient of variation were calculated for each environmental factor. One-way ANOVA (Analysis of Variance) was used to examine the differences in physical and chemical properties among the channels. The Duncan post-hoc analysis was used to separate differences under a one-way ANOVA [43] (p. 473) [44] (pp. 49–50). The coefficient of variation (CV) can represent habitat diversity or heterogeneity, so it was used to determine and compare diverse differences among the channels [2,35].

Non-metric multidimensional scaling (nMDS) was used to examine the differences in habitat environments where fish inhabit multiple- and single-channel sections for each fish species. The Euclidean distance matrix is used in nMDS. nMDS plots provide a relative association between samples, so stress values are used as an indicator to evaluate the fitness of nMDS. Therefore, lower stress values represent less distortion and provide accurate information on an nMDS diagram [45].

Principal component analysis (PCA) [43] (p. 16) was used to examine the differences in habitat use by each fish species in the various channels. PCA uses the orthogonal transformation to convert the possibly correlated variables into a set of values of linearly uncorrelated variables. The parameters included all of the environmental factors occurring where fish live. Furthermore, the inhabited distribution of each fish species was also determined using a PCA [20,28]. A correlation matrix was used on all of the data to exclude the influence of inconsistent units under PCA.

A binary logistic regression [46] was used to interpret which environmental factors had the most influence on fish species. The data was separately analyzed in different channels (Braided main and secondary channels, and single-channel section). Differences in environmental factors having influences on local fish populations were determined in the various channel types using a logistic regression. In this study, the forward stepwise regression was used to analyze the data. Based on the Hosmer and Lemeshow Test ( $p > 0.05$ ) [47], each equation could pass hypothesis testing for each fish species among the various channels.

## 3. Results

### 3.1. Fish Abundance

*Acrossocheilus paradoxus*, *Candidia barbata*, *Hemimyzon formosanus*, *Cobitis sinensis*, *Rhinogobius nantaiensis*, *Gobiobotia kollerii*, *Onychostoma alticorpus*, and *Opsariichthys pachycephalus* (The ecological characteristics of the studied species could be found at the website: <http://fishdb.sinica.edu.tw/eng/home.php>) were captured, with a total of 51, 5, 291, 1, 122, 1, 44, and 2 individuals captured in the 109 sample grids, respectively. The most abundant fish species were *H. formosanus*, whose average standard length and wet weight were 3.7 cm and 1.0 g, respectively. The second most abundant fish species was *R. nantaiensis*, whose average standard length and wet weight were 3.4 cm and 0.9 g, respectively. The most uncommon fish species were *A. paradoxus* and *O. alticorpus*, whose average standard lengths were 3.6 cm and 4.0 cm, respectively, and for which the average wet weights were 1.3 g and 4.3 g, respectively. The abundances of *C. barbata*, *C. sinensis*, *G. kollerii* and *O. pachycephalus* were too low so these fish species were omitted from further analyses.

A higher density of *H. formosanus* appeared in the multiple-channel section where the most density appeared in the secondary channel (134 individuals) (Table 1). The most density of *R. nantaiensis* was in the multiple-channel section, but this fish species was not usually captured in the single-channel section (14 individuals) (Table 1). *A. paradoxus* was rarely captured in the main channel (5 individuals), but this fish species exhibited higher abundance in the secondary channel (26 individuals) and in the single-channel section (20 individuals) (Table 1). *O. alticorpus* had the least density, and this fish species only exhibited higher numbers in the single-channel section (25 individuals) (Table 1).

**Table 1.** The density (individuals/m<sup>2</sup>) of each fish species in the two sections.

Fish Species	Multiple-Channel Section		Single-Channel Section
	Main Channel	Secondary Channel	
<i>H. formosanus</i>	2.91	3.55	1.32
<i>R. nantaiensis</i>	1.58	1.59	0.55
<i>A. paradoxus</i>	0.15	0.83	0.77
<i>O. alticorpus</i>	0.21	0.38	1.00

### 3.2. Environmental Factors

Most of the environmental factors were not significantly different in the various channels, except for the flow velocity, water depth and bed area covered with pebbles (Table 2). According to the ANOVA results, the flow velocity in the multiple-channel section was higher than in the single-channel section (Table 2). The deepest water depth was in the single-channel section followed by that in the main channel of the multiple-channel section (Table 2). The shallowest water depth was in the secondary channel of the multiple-channel section (Table 2). The percentage of pebbles was higher in the multiple-channel section than in the single-channel section (Table 2).

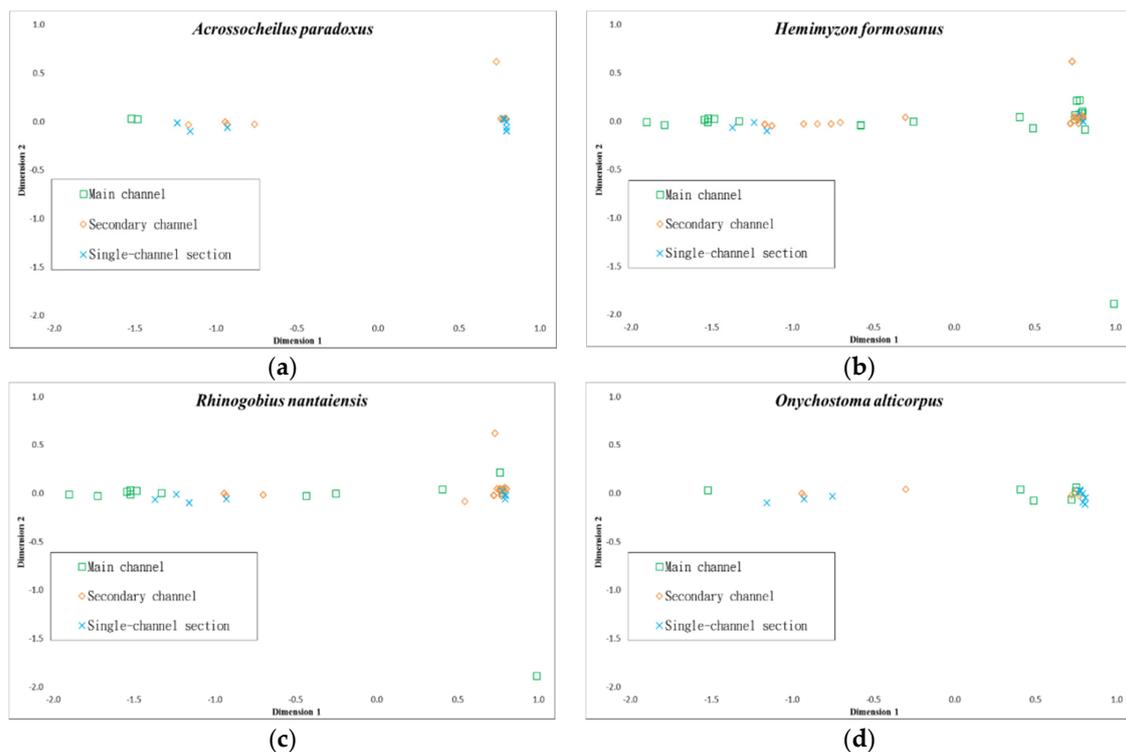
**Table 2.** Mean and CV for environmental factors in the two sections. The different letters are significantly different according to the Duncan post-hoc analysis ( $p < 0.05$ ) for the means, and the order is indicated by: a < b < c. “—” represents no value because the standard deviation is 0.

Environmental Factor	Multiple-Channel Section				Single-Channel Section	
	Main Channel		Secondary Channel		Mean	CV (%)
	Mean	CV (%)	Mean	CV (%)		
EC ( $\mu\text{s/cm}$ )	423.98 <sup>a</sup>	15.7	413.06 <sup>a</sup>	7.2	421.06 <sup>a</sup>	4.8
Turbidity (NTU)	123.96 <sup>a</sup>	161.1	78.03 <sup>a</sup>	182.3	71.17 <sup>a</sup>	213.7
Salinity (ppt)	0.2 <sup>a</sup>	11.1	0.2 <sup>a</sup>	8.2	0.2 <sup>a</sup>	—
DO (mg/L)	8.59 <sup>a</sup>	12.7	8.60 <sup>a</sup>	9.4	8.35 <sup>a</sup>	7.4
pH	8.34 <sup>a</sup>	2.0	8.33 <sup>a</sup>	1.9	8.38 <sup>a</sup>	1.5
Chlorophyll <i>a</i> (ppb)	0.676 <sup>a</sup>	68.8	0.534 <sup>a</sup>	59.1	0.501 <sup>a</sup>	69.1
Flow velocity (m/s)	0.7 <sup>b</sup>	37.6	0.6 <sup>b</sup>	54.4	0.5 <sup>a</sup>	50.8
Water depth (cm)	33.4 <sup>b</sup>	37.3	26.6 <sup>a</sup>	36.6	39.0 <sup>c</sup>	31.2
Sand	0.13 <sup>a</sup>	182.1	0.18 <sup>a</sup>	153.2	0.21 <sup>a</sup>	131.6
Gravel	0.28 <sup>a</sup>	98.9	0.33 <sup>a</sup>	86.5	0.34 <sup>a</sup>	73.9
Pebbles	0.21 <sup>b</sup>	111.7	0.18 <sup>b</sup>	103.6	0.08 <sup>a</sup>	105.3
Cobble	0.17 <sup>a</sup>	90.7	0.13 <sup>a</sup>	69.6	0.11 <sup>a</sup>	86.1
Boulders	0.20 <sup>a</sup>	137.3	0.18 <sup>a</sup>	117.6	0.26 <sup>a</sup>	83.9

Although most of the environmental factors were not significantly different in the channels, most of the environmental factors in the multiple-channel section had higher CV values, except for the turbidity, chlorophyll *a*, flow velocity, and pebbles and cobble content (Table 2). According to the CV results, the multiple-channel section had more diverse habitats than the single-channel section.

### 3.3. Habitat Characterization in Combination with Fish Species

The nMDS shows the differences in habitat characterization of fish in the multiple- and single-channel sections (Figure 2). The distribution of the plots is very extensive in the multiple-channel section, but the distribution of the plots is very intensive in the single-channel section for four fish species. Because each plot represents individual fish, the results by the nMDS suggest that the fish have more diverse habitat opportunities to inhabit or utilize the environment in the multiple-channel section. Oppositely, the habitat diversity is reduced in the single-channel section.

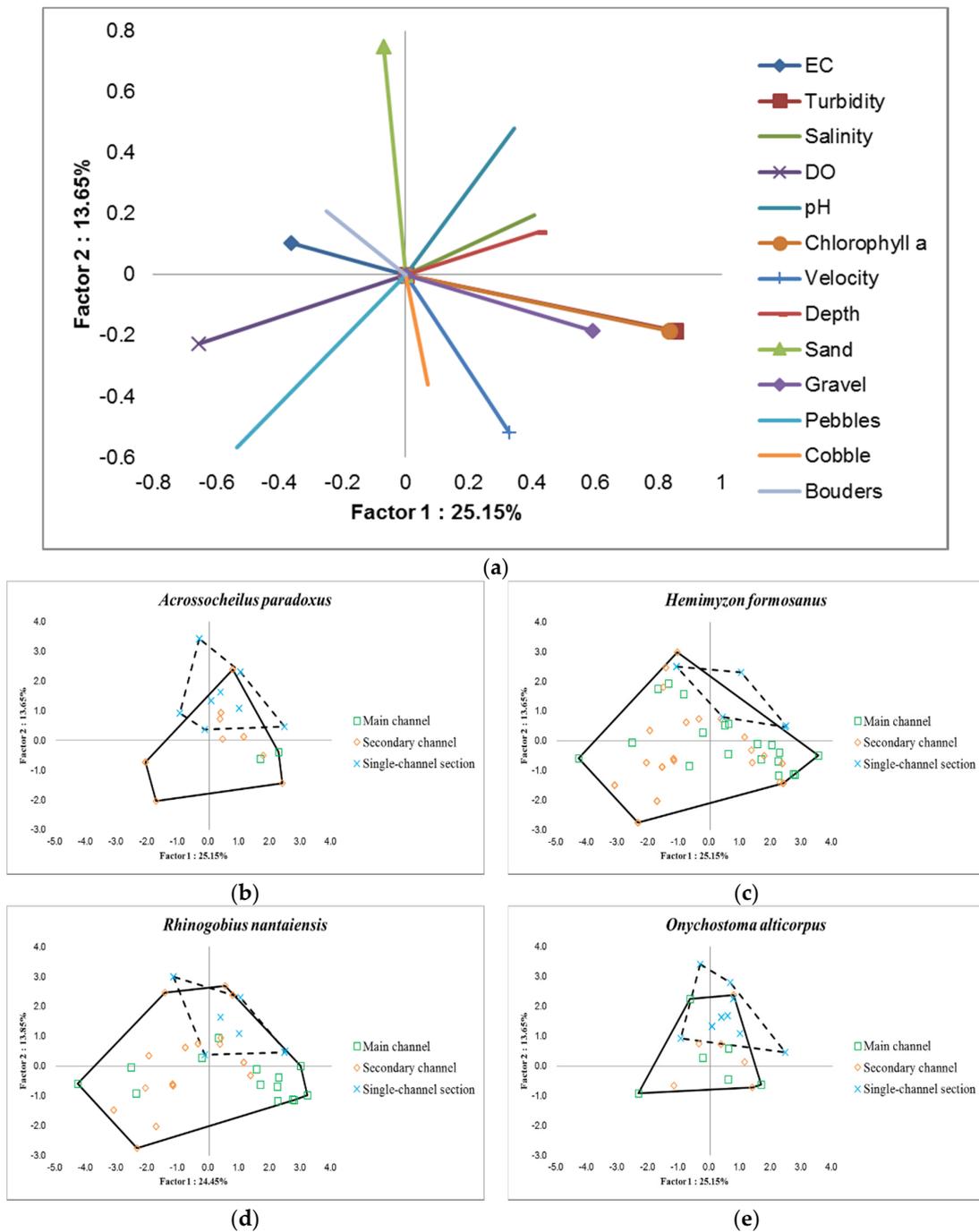


**Figure 2.** The plots from the environmental data indicating fish habitats as shown in the nMDS diagram. The stress value is 0.01. (a) The differences in habitat characterization of *Acrossocheilus paradoxus* in the multiple- and single-channel sections; (b) The differences in habitat characterization of *Hemimyzon formosanus* in the multiple- and single-channel sections; (c) The differences in habitat characterization of *Rhinogobius nantaiensis* in the multiple- and single-channel sections; (d) The differences in habitat characterization of *Onychostoma alticorpus* in the multiple- and single-channel sections.

### 3.4. Environmental Use for Fish Species

The first two axes account for 38.80% of the variance from the PCA (Figure 3). Axis 1 represents chlorophyll *a*, turbidity, DO, gravel, water depth and salinity characteristics; Axis 2 represents sand, pebbles, flow velocity, and pH characteristics. The density of *A. paradoxus* and *O. alticorpus* mostly increases with increasing water depth, salinity, and pH (Figure 3). Oppositely, the density of *H. formosanus* and *R. nantaiensis* mostly decreases the water depth, salinity and pH (Figure 3).

The areas of the range are similar for the multiple- and single-channel sections for *A. paradoxus* and *O. alticorpus* (Figure 3). However, the area of the range was much bigger in the multiple-channel section as compared to the single-channel section in the case of two fish species, *H. formosanus* and *R. nantaiensis* (Figure 3). We therefore conclude that the multiple-channel section can provide a diverse habitat for four fish species, especially *H. formosanus* and *R. nantaiensis*. The single-channel section can also provide a diverse habitat for *A. paradoxus* and *O. alticorpus*.



**Figure 3.** Thirteen environmental factors and four species in the first two principal component analysis axes. The full line is the range of the fish species in the multiple-channel section, and the dotted line is the range of the fish species in the single-channel section. (a) The distributions of thirteen environmental factors in the PCA diagram; (b) The preferred environments of *Acrossocheilus paradoxus* in the multiple- and single-channel sections; (c) The preferred environments of *Hemimyzon formosanus* in the multiple- and single-channel sections; (d) The preferred environments of *Rhinogobius nantaiensis* in the multiple- and single-channel sections; (e) The preferred environments of *Onychostoma alticorpus* in the multiple- and single-channel sections.

The logistic regression indicates which environmental factors have the most influence on fish species (Table 3). No environmental factors were found to affect the existence of the majority of fish

species in the single-channel section, with the exception of *R. nantaiensis*. Oppositely, no environmental factors were found to affect the existence of *O. alticorpus* in the secondary channel. According to the results of the logistic regression, the existence of the multiple-channel section will significantly affect the existence of the fish species under consideration. In the case of *A. paradoxus*, chlorophyll *a* and flow velocity affect their existence in the main channel, and salinity and pebbles affect their existence in the secondary channel. In the case of *H. formosanus*, boulders and water depth will affect their existence in the main channel, and pebbles affects their existence in the secondary channel. In the case of *R. nantaiensis*, chlorophyll *a* and salinity affects their existence in the main channel; flow velocity affects their existence in the secondary channel, and chlorophyll *a* affects their existence in the single-channel section. In the case of *O. alticorpus*, boulders are the only important environmental factor in the main channel.

**Table 3.** The equation using a logistic regression in the different channel types for each fish species. “ND” means no environmental factors are chosen in the equation. “LL” is the log likelihood.

Fish Species	Channel Type	−2 LL	Hosmer and Lemeshow Test		Equation
			Chi-Square	Sig.	
<i>Acrossocheilus paradoxus</i>	Main channel	0.00	0.00	1.00	−46.769 + 78.016 Chlorophyll <i>a</i> − 137.743 Flow velocity
	Secondary channel	28.90	5.07	0.54	46.796 − 233.323 Salinity − 5.258 Pebbles
	Single-channel section	ND	ND	ND	ND
<i>Hemimyzon formosanus</i>	Main channel	27.81	8.90	0.35	4.826 − 6.299 Boulders − 0.084 Water depth
	Secondary channel	17.79	4.27	0.64	−0.916 + 20.067 Pebbles
	Single-channel section	ND	ND	ND	ND
<i>Rhinogobius nantaiensis</i>	Main channel	25.32	7.01	0.54	42.776 +3.439 Chlorophyll <i>a</i> − 229.978 Salinity
	Secondary channel	25.64	5.03	0.66	3.974 − 4.964 Flow velocity
	Single-channel section	15.70	3.87	0.70	−2.529 + 3.648 Chlorophyll <i>a</i>
<i>Onychostoma alticorpus</i>	Main channel	26.55	2.63	0.62	−2.089 +3.154 Boulders
	Secondary channel	ND	ND	ND	ND
	Single-channel section	ND	ND	ND	ND

#### 4. Discussion

One-way ANOVA, CV, nMDS, PCA, and logistic regression approaches were used in this study to compare the differences between the multiple- and single-channel sections, and it was found that the two channel sections have great differences. There were many fish individuals in the multiple-channel section. *H. formosanus* and *R. nantaiensis* were more abundant in the multiple-channel section. Although *A. paradoxus* were rarely captured in the main channel, they were more abundant in the secondary channel. Oppositely, there were fewer fish individuals in the single-channel section, although three fish species (*H. formosanus*, *R. nantaiensis*, and *O. alticorpus*) were captured. However, most of the environmental factors were not significantly different between the multiple- and single-channel sections, especially environmental factors related to water quality (Table 2). This is not surprising because the water source was the same mountaintop [1]. Although most of the environmental factors were not significantly different among the three channels, they still exhibited higher diversity in the multiple-channel section. Only three environmental factors showed significant differences (flow velocity, water depth, and pebbles) in the analysis. (Table 2). Although we did not measure flow discharge, our sample grids were placed in three channels. The discharges were different in these channels, and habitat environment would be affected by the flow discharge. Consequently, habitats would form different environments in these channels. Multiple-channel rivers are complex systems resulting from the interaction of various discharge regimes and sediment loads, so they can produce complex hydromorphological conditions [18]. Therefore, multiple-channel rivers have higher diversity as compared to single-channel rivers [2,29,32].

According to past studies, there have been a large number of objectives related to the restoration of multiple-channel rivers. This is because many rivers have been multiple-channel rivers in the past, but they were changed to narrow, straightened rivers by human activities [2,4,48–50]. However, this study is different from previous studies. The multiple-channel sections in this study were formed by dredging and natural geomorphic processes after Typhoon Morakot, so they were not formed due to restoration purposes. Similarly, multiple-channel sections provide diverse habitats according to the results of this study (Table 2). The main difference between multiple- and single-channel sections is the presence of a secondary channel. The secondary channel is a critical habitat that can provide nursery habitats for a variety of fish species due to the amounts of seston and macroinvertebrate drift [24]. According to the results of Burge (2004) [5], secondary channel environmental factors are significantly different from those of single and primary channels. According to our results, only the water depth in the secondary channel was different from that in the main channel and the single-channel sections (Table 2), but there were a lot of fish individuals and fish species in the secondary channel (Table 1).

The results from the nMDS showed the differences in habitat characterization between the multiple- and single-channel sections (Figure 2). The plots have more extensive distribution on the nMDS diagram in the multiple-channel sections than in the single-channel for the four fish species. In the Czarny Dunajec River and the Polish Carpathians, Wyzga *et al.* (2012) [4] also used the nMDS to determine the differences between multiple- and single-channel sections. However, they used the average and CV of each environmental factor to analyze the data. In the present study, individual data was used to conduct the nMDS using Euclidean distance, but most of the CV values for the environmental factors were found to be higher in the multiple-channel sections as compared to the single-channel sections. Furthermore, our data also detailed the appearance of fish individuals so the data could provide insight into opportunities of fish species for environmental use or habitation. The causes of differences between the multiple- and single-channel sections are perhaps related to the presence of a secondary channel. This is because secondary channels usually exhibit different hydraulic and substrate conditions [4,24,35].

According to the results of the PCA for the habitat use and inhabited distribution for each fish in the multiple- and single-channel sections (Figure 3), *A. paradoxus* and *O. alticorpus* mostly exhibited a positive relationship with water depth, salinity and pH, but *H. formosanus* and *R. nantaiensis* mostly exhibited a negative relationship with the water depth, salinity and pH. *A. paradoxus* and *O. alticorpus* are less rheophilous fish species that they prefer deeper water, and *H. formosanus* and *R. nantaiensis* are the more rheophilous fish species that they prefer shallow water [51]. In our study, the mean water depths were 33.4 cm and 26.6 cm in the main channel and secondary channel, respectively (Table 2). The mean water depths of the channel types were significantly lower than the mean water depths in the single-channel sections, but there were high variances in the multiple-channel sections where the distribution of the four fish species under consideration occurred over a large area. Oppositely, the mean water depth was found to be 39.0 cm in the single-channel sections, but its CV was the lowest, and only *A. paradoxus* and *O. alticorpus* were distributed over a large area according to the results of the PCA. Although the four fish species have different preferences for pH and salinity, these two environmental factors had very low CVs in both the multiple- and single-channel sections. The pH value of the range was from 7.84 to 8.49, and the salinity value ranged from 0.1 to 0.2.

According to the results of the binary logistic regression, we were able to determine which environmental factors had the greatest influence on fish species in the three channel types. Some environmental factors had a great deal of influence on the fish species in both the main and secondary channels. Oppositely, no environmental factors influenced the fish species in the single-channel sections, with the exception of *R. nantaiensis*. This indirectly suggests that no environmental factors significantly affect the distribution of fish species in the single-channel sections, as compared to the multiple-channel sections. Four fish species eat algae [51], but chlorophyll *a* could have a great deal of influence on *A. paradoxus* and *R. nantaiensis* in the main channel and on *R. nantaiensis* in the single-channel sections. The food of *A. paradoxus* and *R. nantaiensis* includes algae, small fish and

invertebrates [52]. However, the Cishan Stream was treated after a serious disturbance by Typhoon Morakot in 2009, and the habitats and populations of fish and invertebrates perhaps have not fully recovered or become stable. Tew *et al.* (2002) [53] pointed out that fish fauna recovered to a pre-typhoon condition 14 months after Typhoon Herb impacted the Cishan Stream, but the destruction caused by Typhoon Morakot was greater than that caused by Typhoon Herb. Furthermore, the size of the fish caught was very similar in the case of all four fish species according to our sampling, so it could be concluded that *A. paradoxus* and *R. nantaiensis* were not able to eat other fish species. Therefore, chlorophyll *a* could be an important environmental factor for *A. paradoxus* and *R. nantaiensis*. Flow velocity and salinity affected distribution of *A. paradoxus* and *R. nantaiensis* whereas salinity had a low CV. *A. paradoxus* prefers slower-moving water [51], so it was difficult to catch *A. paradoxus* in the main channel. However, *R. nantaiensis* prefers fast-moving water [51]. Our reason for drawing this conclusion is that *R. nantaiensis* is a small-sized fish species so the body of the adults and young fish are very similar. However, at different life stages they have different preferences for flow velocity [54]. In this study, the fish were not separated into different life stages. *H. formosanus* prefers shallow water but avoids sandy substrate [51]. In this study, the water depth had a great deal of influence on *H. formosanus* in the main channel, with the highest CV. Although water depth was not found to be an important environmental factor in the secondary channel and in the single-channel sections, the density of *H. formosanus* was the highest in the secondary channel with the lowest mean water depth, and was the lowest in the single-channel sections with the highest mean water depth. In order to determine the influence of substrate on *H. formosanus*, Lee & Suen (2012) [51] used two methods (density and electivity) to determine preference, but they did not achieve consistent results. According to their research, pebbles may be a moderator with regard to substrate size. In our study, pebbles greatly influenced *H. formosanus* in the secondary channel. Boulders were the only environmental factor that affected the distribution of *O. alticorpus*. Lyu & Suen (2010) [49] found that adult and young *O. alticorpus* prefer large-sized substrate. This is related to their food source. Their major food source is the periphyton, which grows on rocks [55].

## 5. Conclusions

The multiple-channel sections provide more diverse habitats for fish species. Furthermore, some environmental factors were shown to have a significant influence on the distribution of fish species. In contrast, these multiple-channel sections were not shaped based on the restoration done after the typhoon. However, our determination is approximately consistent with other research based on the restoration. It was concluded that dredging could significantly destroy the stream habitat due to the creation of narrow, deeper and more homogeneous single channels. If the channels could be changed from single- to multiple-channel sections, this would benefit the fish species in the Cishan Stream.

**Acknowledgments:** The authors gratefully acknowledge the support for this research provided in part by the Ministry of Science and Technology, Taiwan, under grant number NSC 102-2221-E-006-246-MY3 and by the Headquarters of University Advancement at the National Cheng Kung University, which is sponsored by the Ministry of Education, Taiwan. We also thank field assistance of NCKU Ecological Water Resources Management Lab members. Electrofishing was approved by the Agriculture Council and Kaohsiung City Government Taiwan and fish handling followed the regulation of animal care and ethics committee.

**Author Contributions:** Hung-Pin Chiu performed data analysis. The manuscript was prepared by both authors.

**Conflicts of Interest:** The authors declare no conflict of interest.

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