On fish habitat diversity research with applications of numerical model analysis

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ABSTRACT

Two fish species, i.e. *Gobiidae*, *Cyprinidate,* are selected as the indicator species to investigate the hydraulic diversity and different fish habitats types with and without spur dikes in the tidal estuary.

A quasi-two-dimensional model, NETSTARS, and a horizontal two-dimensional model, TABS-2, were employed in this study.

The results in the normal discharge events reveal that the fish habitat area will increase with the less number and the shorter length of spur dikes. Installing spur dikes, nevertheless, will increase the hydraulic diversity and therefore create various flow conditions suited for different aquatics. The well-known Shannon diversity index was employed in this study to combine and calculate the different habitat type as an index value. It was therefore concluded that optimum habitat diversity take place while the number of spur dikes was 6-10 and 3-5 of PQI and Fr. no. method, respectively.

The spur dike is a hydraulic structure intended to protect the river bank by diverting the existing flow direction. River width is thus influenced by spur dikes. Proper utilization of spur dikes can also create near-natural flow conditions in both rivers and lakes. Moreover, we prove that suitable number of spur dikes can also create diverse aquatic habitat in regular discharge period.

Key Words: hydraulic diversity, spur dikes, numerical model, normal discharge event, sediment transport simulation

1. Introduction

This study considers the region between Ger-Ma-Lan Bridge and Lanyang Bridge (Fig. 1), and the impact of spur dikes on the habitat of *Cyprinidate* and *Gobiidae*. Following the storm damage by Nari typhoon in 2001, eight spur dikes were designed by the Water Resources Agency of the Ministry of Economic Affairs in order to protect the river bank. Dikes construction was completed in June 2002. Not only can the spur dikes protect the river bank, but they can establish different flow conditions and thereby increase fish habitat diversity.

Do-Wun Creek case study utilized a two dimensional numerical model TABS-2 (Hu et al. 2003) while Ker-Ya Creek (Chen 2001) and Chou-Shui Creek (Wu 2002) case studies applied a one dimensional numerical model PHABSIM. Both two papers were concentrated in the influence of hydraulic variation. Additionally, Ouillon and Dartus（1997）developed a three-dimensional numerical model to simulate the flow conditions of spur dikes installed in an experimental rectangular channel.

The diverse flow condition can provide various habitat types for different species (Yu and Peters, 1997). Many methods have been developed to evaluate flow requirements for fish (Wesche and Rechard, 1980; Rao et al., 1992; Thomas and Bovee, 1993; Yu and Peters, 1997). Several approaches are used to describe relations between physical habitat and probability of fish use (Yu and Peters' (1997) literature review of Sheppard and Johnson (1985), Lyons (1991) and Aadland (1993)). Some studies have been used as an objective method for classifying habitat types in streams (Jowett, 1993; Yu and Peters, 1997) and used to describe habitat preference benthos (Orth and Maughan, 1983; Statzner et al., 1988; Jowett et al., 1991).

2. Material and methods

A horizontal two-dimensional model, TABS-2, were used to simulate the hydraulic characteristics. Water depth, flow velocity and the sediment transport capability were among the Lanyang Estuary characteristics studied in both spur dikes and natural conditions. The results were applied to calculate the weighted usable area (WUA) of *Cyprinidate* and *Homalopteridae*.

2.1 Numerical model

The TABS-2 model is a two dimensional depth-averaged finite element hydrodynamic numerical model developed by the Waterways Experiment Station of U.S. Army Corps. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields. TABS-2 also computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated according to the Manning or the Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state problems can be analyzed. Please refer to SMS 7.0 Users Manual (2000) for more details. Fig. 4 illustrates the generated grid.

The flood discharge which exceeds the return period of one year was selected as the upstream boundary condition, while the corresponding water surface elevation of the river mouth was selected as the downstream boundary condition. The upstream discharge hydrograph and downstream water surface elevation are provided in Figs. 5 and 6, respectively. The concentration of the suspended sediments in the upstream boundary is estimated using the discharge-and-sediment concentration rating curve of the Lanyang Bridge, as established by Limin Consultant Company in 2000.

2.2 Weighted usable area (WUA)

Usable fish habitat area is affected by various factors, such as water depth, flow velocity, turbidity, temperature, dissolved oxygen and substrate types of river bed. In this study, water depth and flow velocity are utilized to quantify the total fish habitat area.

The habitat suitability curve can be derived from the recorded catch per unit of effort (CPUE). The CPUE is established form sampling and experimental results. The water depth and flow velocity suitability curves of *Cyprinidate* and *Homalopteridae* are considered in this study, and are plotted in Figs. 3,4,5 and 6, respectively. (Ya et al., 2000).

The weighted usable area (WUA) of fish habitat in a stream is evaluated as (Mihous, 1999):

$$WUA = \sum_i \left[f(V_i) \times f(D_i) \times A_i \right]$$

Where Ai is the stream area of element i and f (V_i, D_i) is the combined suitability factor (CSF) for Ai. Several methods have been proposed to determine CSF, but the most prevalent technique calculates the product of the corresponding suitability weights for flow velocity, depth and channel characteristics. WUA can therefore be determined by substituting the hydraulic simulation results into the WUA equation.

2.3 Habitat types

A range of physical habitat assessment methods have been developed in recent years, each relying on different knowledge of the river channel's physical and hydraulic attributes and biotic users, and operating over different spatial scales (Maddock, 1999). 1999). Many of these approaches are 'rapid assessment methods' analysing habitat performance at just a single discharge (e.g. reconnaissance level surveys; Thorne and Easton, 1994). Only the more complex appraisals, such as the physical habitat simulation system (PHABSIM; Bovee, 1982), require more detailed information on flow velocity variations over a range of river discharges. Some literature reviews (Azzellin and Vismara，2001, Bingham and Miller, 1989)show that diverse hydraulic condition can create different species habitat. Two scheme of fish habitat assessment were applied to evaluate habitat diversity: 1.PQI (pool quality index) method (Aadland, 1993) was used and habitat type was distinguished as pool and riffle (see also Table1); 2. Froude number method (Yu and Peters, 1997; Jowett, 1993) was applied and habitat type was divided into pool, run and riffle (see also Table2).

3. Results and discussion

The upstream and downstream conditions of numerical modeling were discharges of Lan-Yang Bridge from 1949 to 2003 and water surface elevations of river mouth form 1999 to 2004. Please see the detail of boundary conditions in Fig. 2.

The relationship between number of spur dikes and PUA of *Gobiidae* and *Cyprindae* with variation of Froude number were shown in Fig.7 and 8, respectively. The dynamic standard deviations of flow velocity were illustrated in Fig.9 and 10, respectively. The optimum PUA occurs in the set-up of no.00 (no spur dikes). In contrast, the results reveal that the most diverse fish habitat occurs when number of spur dikes is 10. In addition, the PQI and Fr. No. scheme results were also tabulated in Table 3 and 4. The well-known Shannon diversity index (Shannon and Weaver, 1949) was employed in this study to combine and calculate the different habitat type as an index value. It was therefore concluded that optimum habitat diversity take place while the number of spur dikes was 6-10 and 3-5 of PQI and Fr. No. method, respectively.

The spur dike is a hydraulic structure intended to protect the river bank by diverting the existing flow direction. River width is thus influenced by spur dikes. The slower velocity zone that is generated around the spur dikes has been provided to benefit the surrounding ecosystem (Hu et al., 2003). Proper utilization of spur dikes can also create near-natural flow conditions in both rivers and lakes (Shubun Fukudome et al., 2002). Besides those mentioned benefits, we prove that suitable number of spur dikes can also create diverse aquatic habitat in regular discharge period.

4. Figures & Tables

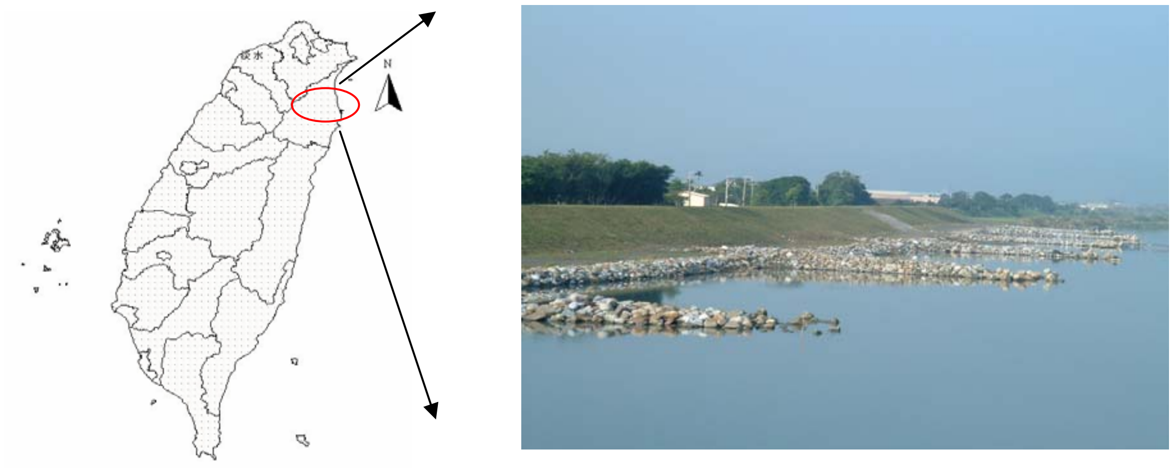


Fig.1 The installation of spur dikes in Lanyang Estuary

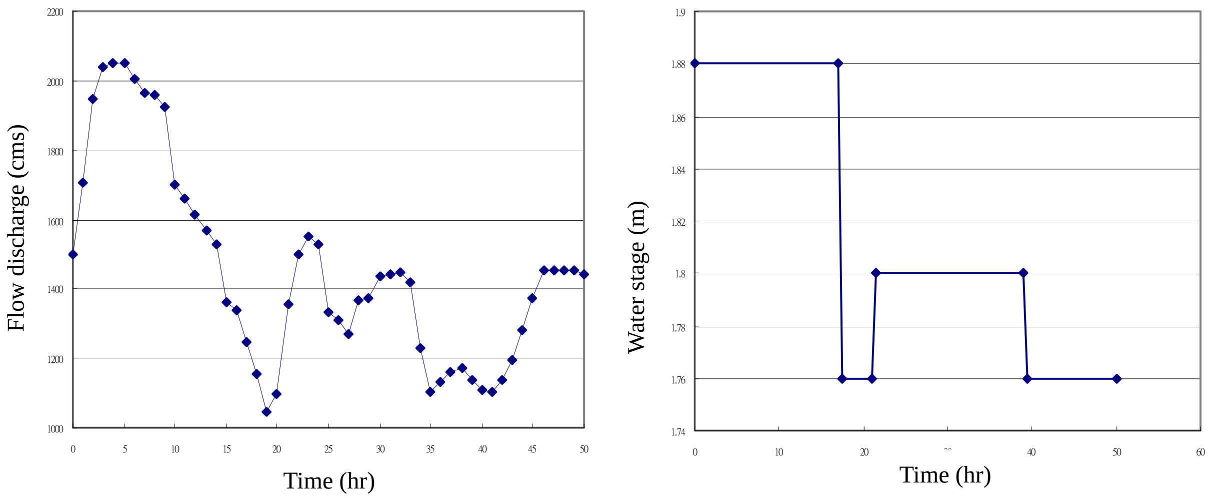
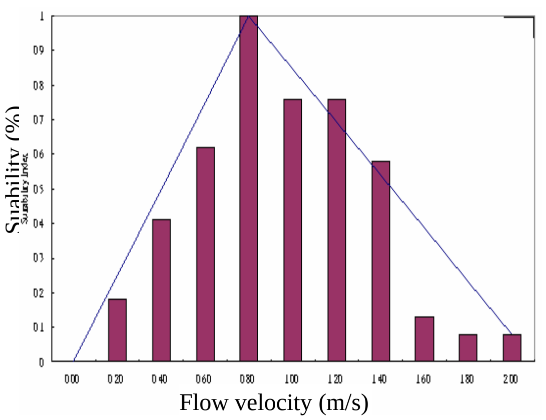


Fig.2 The upstream discharge hydrograph and downstream water stage hydrograph of study area



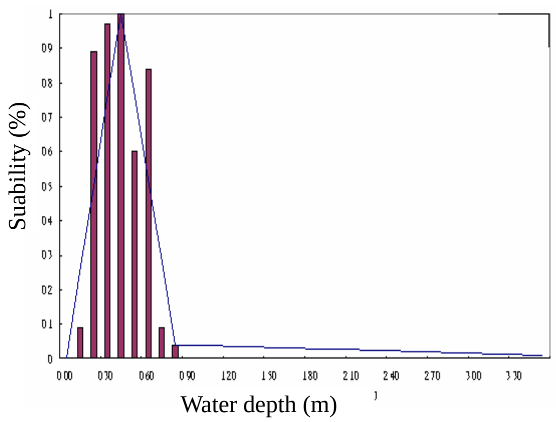


Fig.3 The flow velocity suitability curve of *Cyprinidate* (Ya et. al, 2000)

Fig.4 The water depth suitability curve of *Cyprinidate* (Ya et. al, 2000)

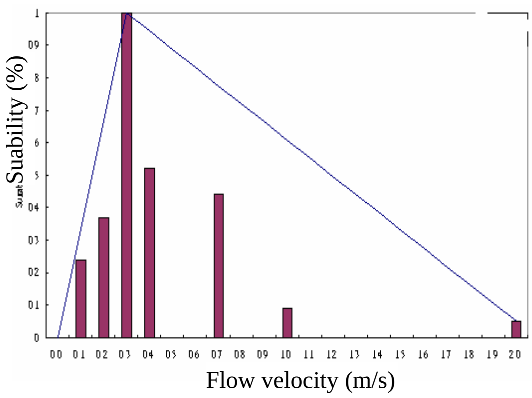


Fig.5 The flow velocity suitability curve of *Gobiidae* (Ya et. al, 2000)

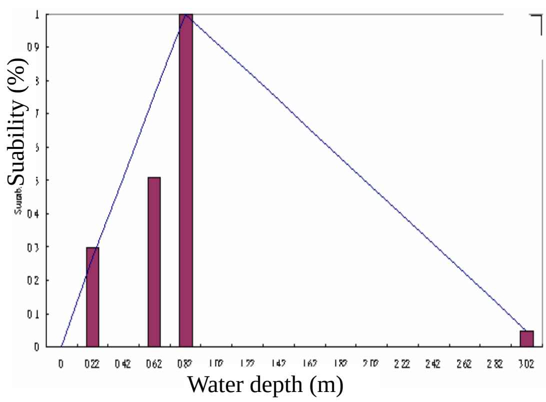


Fig.6 The water depth suitability curve of *Gobiidae* (Ya et. al, 2000)

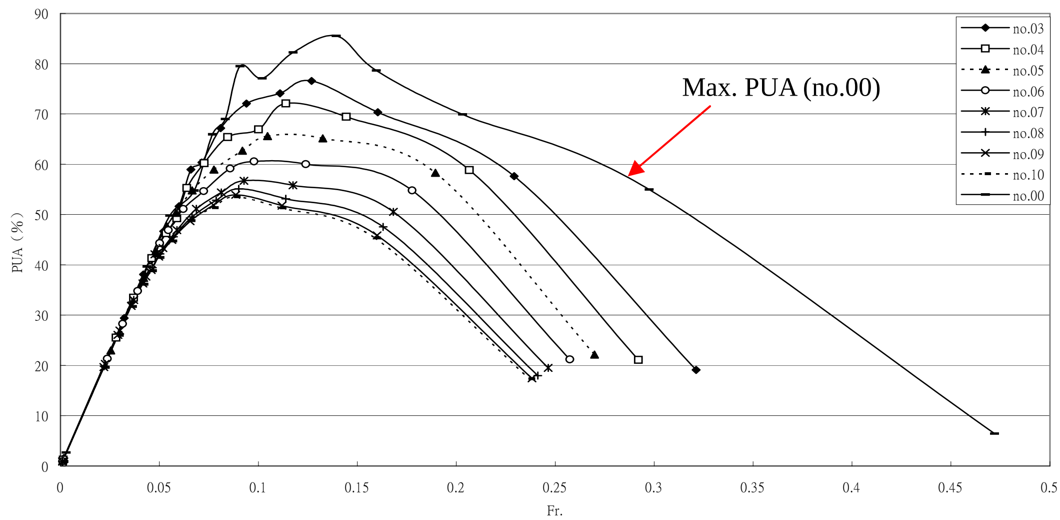


Fig.7 No. of spur dikes-PUA relationship of *Gobiidae* with variation of Fr. No.

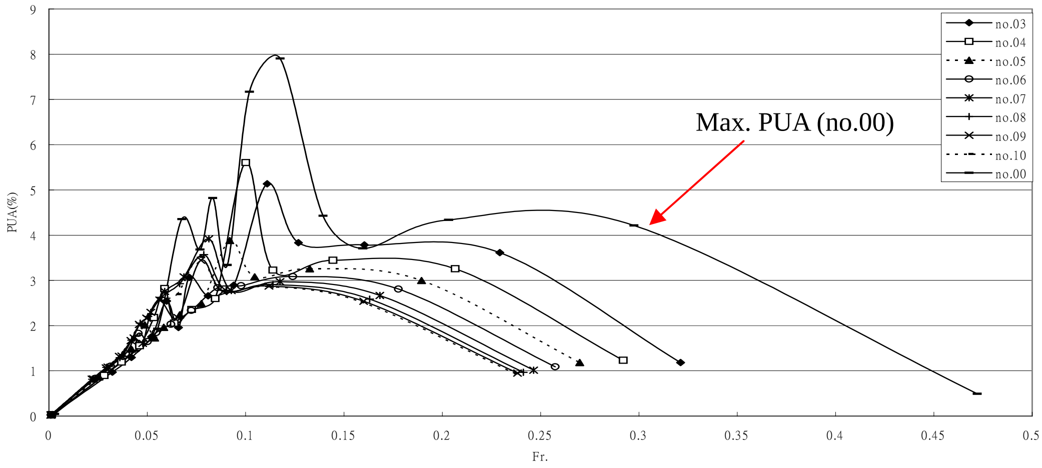


Fig.8 No. of spur dikes-PUA relationship of *Cyprinidate* with variation of Fr. No.

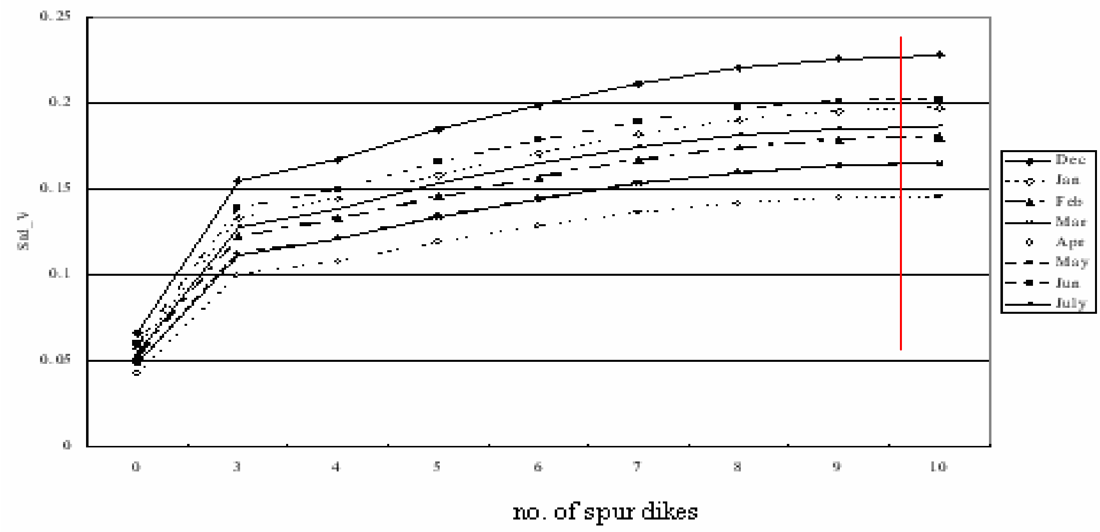


Fig.9 The dynamic standard deviation of flow velocity from December to July

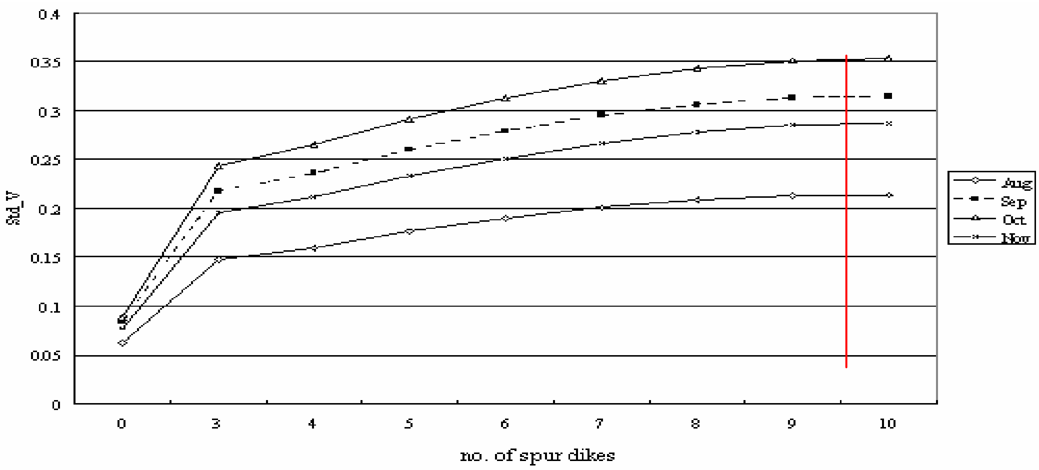


Fig.10 The dynamic standard deviation of flow velocity from August to November

Table1 PQI method for classification of fish habitat（Azzellin and Vismara, 2001）

Habitat type		**Flow velocity** (m/s)	**Water depth** (m)
Pool	Deep Pool (DP)	< 0.3	> 0.6
	Medium Deep Pool (MP)		< 0.6
Riffle	Slow Riffle (SR)	0.3 ~ 0.7	< 0.6
	Fast Riffle (FR)	> 0.6	

Table2 Fr. Number method for classification of fish habitat（Jowett, 1993）

Habitat type	**Fr. No.**
Pool	< 0.18
Run	0.18~0.41
Riffle	> 0.41

Table3 The relationship between habitat type and no. of spur dikes with PQI method

No. of spur dikes	**DP**(%)	**MP**(%)	**SR**(%)	**FR**(%)	**others**(%)	$\overline{H}$
0	0.00	0.00	18.67	0.00	81.33	0.481
3	7.68	3.85	7.42	0.00	81.05	0.686
4	11.31	4.99	5.47	0.00	78.23	0.747
5	20.94	4.26	5.50	0.00	69.30	0.876
6	27.59	5.41	4.05	0.00	62.95	0.934
7	31.00	5.33	4.08	0.00	59.60	0.958
8	33.05	4.76	4.10	0.00	58.09	0.957
9	34.06	4.79	4.00	0.00	57.15	0.961
10	33.79	4.89	4.03	0.00	57.29	0.963

Table4 The relationship between habitat type and no. of spur dikes with Fr. no. method

No. of spur dikes	**Pool**(%)	**Run**(%)	**Riffle**(%)	$\overline{H}$
0	100.00	0.00	0.00	0.000
3	94.17	5.83	0.00	0.222
4	94.84	5.16	0.00	0.203
5	95.06	4.94	0.00	0.197
6	96.50	3.50	0.00	0.152
7	96.60	3.40	0.00	0.148
8	96.81	3.19	0.00	0.141
9	97.16	2.85	0.00	0.129
10	97.27	2.73	0.00	0.125

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