堤防工程對於赤蘭溪生物多樣性衝擊

楊松岳 (1) **莊明德** (2)

摘　要

堤防工程是河川治理中經常採用的方法，但卻也同時威脅到淡水生態系。為了瞭解堤防工程對於淡水生態系的衝擊，經濟部水利署水利規劃試驗所於 2000~2004 年間在嘉義縣赤蘭溪進行一個長期的生態觀測計畫，項目包含鳥類、魚類、甲殼類、兩棲類與水生昆蟲。同時，在這觀測期間，有兩處堤防工程被興建。本研究採用 seasonal Kendall test 分析這五年期間物種豐富度與生物多樣性指標時間序列的變化，來評估堤防工程對於河川生物多樣性所造成的衝擊，並進一步比較不同生物種類對於衝擊的敏感程度。本研究成果顯示水生昆蟲對於棲地的改變最為敏感，依序為魚類、兩棲類與甲殼類，對於鳥類則沒有顯著的影響。而這樣的差異主要是與物種的移動能力，已及對於棲地的依賴程度有關。本研究顯示堤防工程會導致河川物種的消失與生態多樣性的劣化，特別是在施工的初期階段。即使後來逐漸復原，回復的程度仍然有限。

(**關鍵詞：**生物多樣性、堤防工程、seasonal Kendall test、淡水生態)

Impact of dike construction on biodiversity on the Chihlan River

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ABSTRACT

Dike work, a common measure in river regulation, threatens freshwater ecosystems. To understand the impact flood control work on aquatic ecosystem in Taiwan, the Water Resources Planning Institute, Water Resources Agency, Ministry of Economic Affairs instituted an ecological monitoring program for the Chihlan River in Chiayi County in 2000-2004. During this period, two dikes were constructed for flood control on the Chihlan River. Communities of birds, fish, crustaceans, amphibians and aquatic insects were monitored. This study used the seasonal Kendall test to analyze the 5-year time series trends of species richness, abundances, and biodiversity indices at each zone to identify the degree and scope of dike construction impact, and further compare the

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sensitivity of different creatures to the impact. Aquatic insects were most sensitive to the habitat alterations, followed by fish, amphibians, and crustaceans. The construction did not have significant impact to the biodiversity of bird. The sensitivity difference was related to creature mobility and habitat dependence. In conclusion, construction of dikes resulted in species disappearance and biodiversity degradation, especially during the initial construction stages. Although the ecosystem recovered, its resilience was limited.

(**Keywords**：biodiversity, flood control, seasonal Kendall test, freshwater ecology)

Introduction

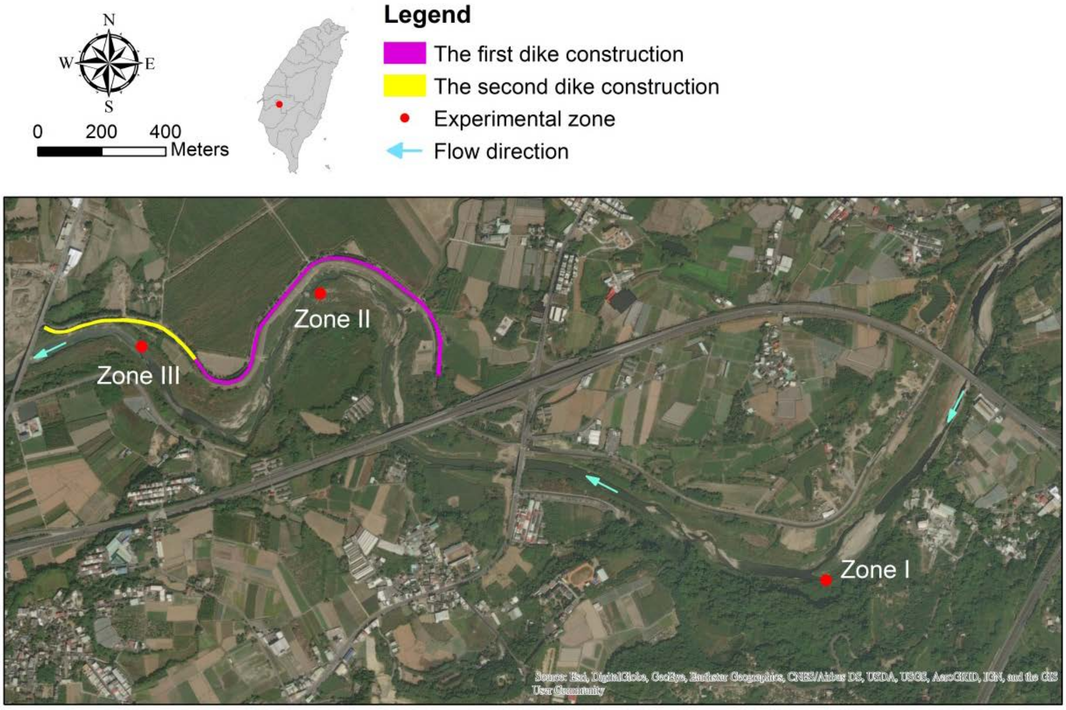
Surface freshwater habitats account for only about 0.01% of the world’s water and cover only approximately 0.8% of the Earth’s surface (Gleick, 1996). At least 100,000 species, roughly 6% of all describe species, rely on freshwater. For instance, over 10,000 fish species live in freshwater (Lundberg et al., 2000); freshwater habitat account for approximately 40% of the global fish diversity and one quarter of the global vertebrate diversity (Dudgeon et al., 2006). However, freshwater ecosystems are the most endangered ecosystems worldwide due to the disproportionate richness of inland waters as habitats for plants and animals. The destruction of biodiversity in freshwater ecosystems is more serious than that of terrestrial ecosystems (Sala et al., 2000). Five interrelated threats adversely affect global freshwater biodiversity; overexploitation; water pollution; flow modification; destruction or degradation of habitat; and, invasion by exotic species (Dudgeon et al., 2006).

Based on the growing demand for flood protection and water resources, hydrological engineering in running waters has been applied ubiquitously (Dynesius & Nilsson 1994; Voüroüsmarty et al. 2000; Nilsson et al., 2005). However, flow modification can significantly alter freshwater habitats, especially in regions with highly variable flow regimes. Many studies have investigated the effects of fragmented flow regulation on large rivers (Dynesius & Nilsson, 1994; Dudgeon, 2000; Nilsson & Bweggren, 2000; Nilsson et al., 2005). However, no study has investigated and assessed quantifiably the impact of dike construction on biodiversity in running water in Taiwan. To identify the extent and scope of the impact of hydrological work on biodiversity, the Water Resource Agency instituted a five-year ecological monitoring program during 2000-2004, that assessed the effects of two constructions flood-control dikes on the Chihlan River. The species monitored were birds, fish, amphibians, crustaceans, and aquatic insects. This study utilized the seasonal Kendall test, a nonparametric test for trends (Hirsch et al., 1982; Hirsch & Slack, 1984), to analyze the time series trends of species richness, abundances, and biodiversity indices. The aims of this study were (1) to identify the degree and scope of dike constructions impact on biodiversity (2) and compare the sensitivity difference with the impact on different species.

Materials and Methods

1. Study site

The experimental zone is on the Chihlan River in Chiayi County (23°26’05’’ N; 120°26’41’’ E). The basin area covers 111 km^2 and flatland occupies roughly 30 % of the total basin. The main stream is 21.5 km long and average slope of the riverbed is 1/60. Most land on both riverbanks have been developed. Because some cross sections of the midstream and downstream are insufficiently wide, flood disasters are frequent. Three typhoons, Toraji, Nari and Lekima, caused severe flooding in July and September 2001. To reduce the flood disasters, two dikes were constructed along the riverbanks. The first dike, constructed of reinforced concrete, was built on the right riverbank during September 2001 to April 2002. The second dike, a concrete frame dike along with vegetation, was built on the right riverbank between June 2003 and January 2004. Three sample zones were used, each 50 m long. Sample zone I was located upstream of zones II and III; zone II was located at the site of the first dike; zone III was located at the second dike (Fig. 1).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1 Map of three zones on the Chihlan River

2. Sampling method

The biological monitoring program was implemented between March 2000 and December 2004. Investigation frequency was once monthly. Sampling methods were as follows.

Birds: Birds were counted in the early mornings and evenings visually (with a telescope). Voice identification was used to determine bird species.

Fish: Sampling was performed principally by electrical collection. In sediment deposits and deep water (> 80 cm) area, sampling was done using a gill net. After sampling, fish species were identified and populations calculated.

Crustaceans: Crustaceans were collected via traps left in the river for 24 hr. Traps were separated by over 10 m. After sampling, species and populations were identified and calculated.

Amphibians: Researchers search with flashlight along the sandbars of the riverbank at night. Amphibian species were identified and populations counted.

Aquatic insects: Three samplings were carried out using a Suber Net (50 cm × 50 cm) in each sample zone. The collected samples were preserved in 70 % alcohol, brought to the laboratory, and insect families were identified.

3. Diversity index

Three diversity indices, commonly applied in Taiwan (EPA, 2003), were adopted to evaluate the biodiversity in each sample zone.

Simpson's dominance index

$$C=\sum_{i=1}^{S}\left(\frac{N_i}{N}\right)^2 \qquad (1)$$

Shannon-Wiener's diversity index

$$H'=-\sum_{i=1}^{S}\left(\frac{N_i}{N}\right)\log_{10}\left(\frac{N_i}{N}\right) \qquad (2)$$

Margelef's index

$$SR=\frac{(S-1)}{\log_{10}N} \qquad (3)$$

S: total number of species recorded

N_i: number of individuals in the ith species.

N: the total number of individuals for all species (population).

As the value of C decrease, the value of H and SR increase, and biodiversity increases.

4. The seasonal Kendall test

The seasonal Kendall test, developed by the US Geological Survey (USGS) for analyzing trends in surface-water quality, is a generalized version of the Mann-Kendall test. The seasonal Kendall test accounts for seasonality by applying the Mann-Kendall test in each season separately, and then computational results are combined (Hirsch et al., 1982; Hirsch & Slack, 1984). A 90% confidence level (p-value = 0.1) was used for all statistical tests in this study. Kendall.exe, a software developed by the USGS, was used for data analyses (Helsel et al., 2005).

This study used the seasonal Kendall test to analyze the 5-year time series trends of species richness, abundances, and biodiversity indices at each zone to identify the degree and scope of dike construction impact, and further compare the sensitivity of different creatures to the impact. Because the Zone III located at the downstream of Zone II, the ecology system at zone III was affected slightly during the period of first dike construction. The dike construction usually results in the degradation of water quality due to the disturbed sediment in the riverbed.

Results

Figures 2-6 present the time series diagrams of species (*S*) or families (*F*) and population (*N*) of birds, fish, crustaceans, amphibians and aquatic insects, respectively. Table 1 lists the trends and *p*-values of *S* or *F*, *N*, Simpson’s dominance index (*C*), Shannon-Wiener’s diversity index (*H*’) and Margelef’s index (*SR*) calculated using the seasonal Kendall test in three zones.

1. Birds

Notably, *S* in all three zones showed significant increment trends, and *N* in zones I and III increased significantly (Table 1 and Fig. 2).

In zone I, *H* and *SR* indicate increased diversity. In zones II and III, all three indices had trends of significant increases in biodiversity.

The biodiversity of birds in the three zones showed increased significantly during the monitoring period, and was not influenced by the dikes. That is, most birds did not rely solely on the aquatic habitat directly. Additionally, the birds could move to neighboring habitats when their main habitat was affected by the dikes.

2. Fish

In zones II and III, *S* decreased significantly, and *N* decreased significantly in all three zones (Table 1 and Fig. 3).

In zone I, *SR* diversity increased significantly. In zone II, all three diversity indices decreased; this reduction was insignificant. In zone III, all three diversity indices decreased significantly.

The flood control dikes influenced directly the biodiversity of fish at the dike sites. A comparison of zones II and III indicates that the degree of the biodiversity degradation in zone III was more severe than that in zone II. This experimental result was because the second dike was built later than the first dike. In zone II, the ecosystem had partially recovered after the initial adverse environmental impact, but did not recover completely until the end of the monitoring period.

3. Amphibians

Notably, *S* and *N* in zone II decreased significantly; other zones had no significant changes (Table 1 and Fig. 4). The variety of *C*, *H*’ and *SR* in the three zones was not significant.

In zone II, *S* and *N* decreased significantly; however, the biodiversity indices did not reflect biodiversity degradation. This result was due to the fact that during and after the periods of dike construction, no amphibian was found in many months. The biodiversity index values could not express this situation. Thus, the calculations for biodiversity indices using the seasonal Kendall test did not demonstrate biodiversity degradation;

however, the calculations for *S* and *N* indicate habitat degradation.

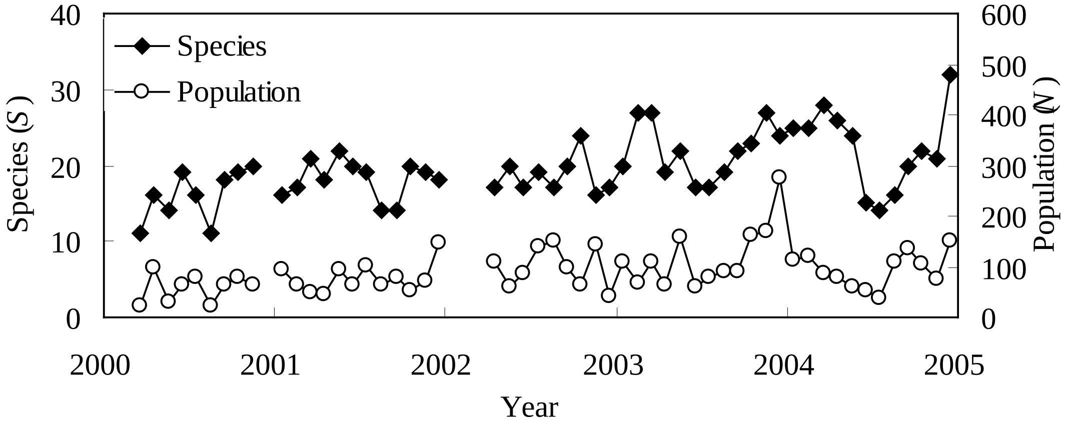
In zone III, *S* and *N* decreased insignificantly between March 2000 and December 2004. However, only one species was investigated twice after dike construction began. This study further calculated the trends for *S* and *N* between February 2002 and December 2004. The *p*-values of *S* and *N* were 0.0150 and 0.0289, respectively. Thus, amphibians were significantly sensitive to dike construction.

Table. 1 Trends and *p*-values of species or families, population and biodiversity indices

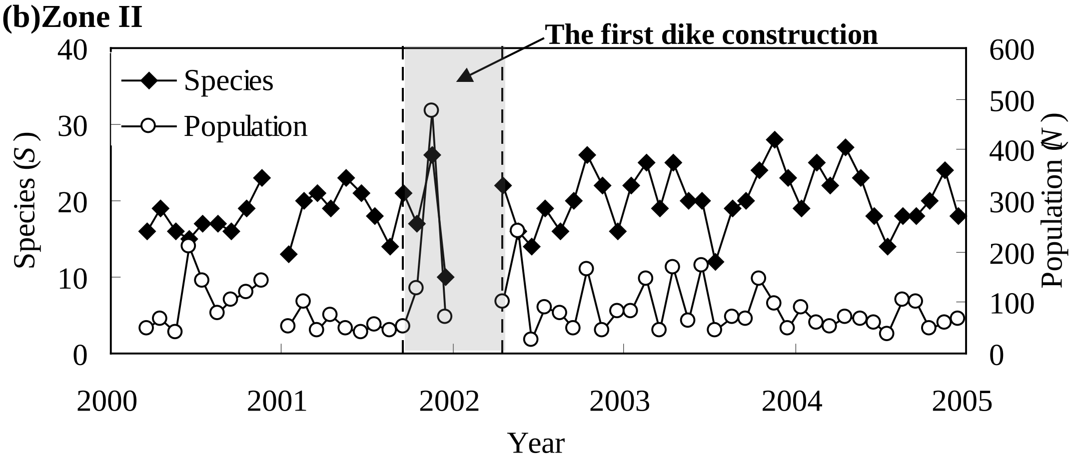
		Zone I		Zone II		Zone III	
	index	trend‡	*p*-value	trend	*p*-value	trend	*p*-value
Birds	*S*	U	0.0048 **	U	0.0236 *	U	0.0001 ***
	N	U	0.0317 *	U	1.0000	U	0.0032 **
	C	D	0.1762	D	0.0137 *	D	0.0210 *
	H'	U	0.0673 †	U	0.0948 †	U	0.0210 *
	SR	U	0.0317 *	U	0.0137 *	U	0.0137 *
Fish	*S*	D	0.8110	D	0.0798 †	D	0.0000 ***
	N	D	0.0000 ***	D	0.0150 *	D	0.0067 **
	C	D	0.4390	U	0.5005	U	0.0006 ***
	H'	U	0.2472	D	0.1778	D	0.0001 ***
	SR	U	0.0505 †	D	0.8662	D	0.0002 ***
Amphibians	*S*	D	0.4911	D	0.0097 **	D	0.7562
	N	D	0.3648	D	0.0420 *	D	1.0000
	C	D	0.5623	U	0.3613	D	1.0000
	H'	U	0.5623	D	0.3613	U	1.0000
	SR	U	0.4735	D	0.2012	U	1.0000
Crustaceans	*S*	U	0.0016 **	U	1.0000	D	0.0060 **
	N	U	0.4363	D	0.8533	D	0.0414 *
	C	D	0.1534	U	0.3454	U	0.0742 †
	H'	U	0.1127	D	0.8503	D	0.0460 *
	SR	U	0.1104	U	1.0000	D	0.1722
Aquatic insects	*F*	D	0.3064	D	0.0028 **	D	0.0006 ***
	N	U	0.0187 *	D	0.0119 *	D	0.0000 ***
	C	U	0.1679	U	0.0045 **	U	0.0214 *
	H'	D	0.4654	D	0.0004 ***	D	0.0574 †
	SR	D	0.0285 *	D	0.0057 **	D	0.0891 †

S: total number of species recorded;
F: total number of families recorded;
N: the total number of individuals summed for all species (population);
C: Simpson’s dominance index;
H: Shannon-Wiener’s diversity index;
SR: Margelef’s index;
‡U: upward; D: downward;
†: *p*-value<0.1; *: *p*-value<0.05; **: *p*-value<0.01; ***: *p*-value<0.001.

(a)Zone I



(b)Zone II



(c)Zone III

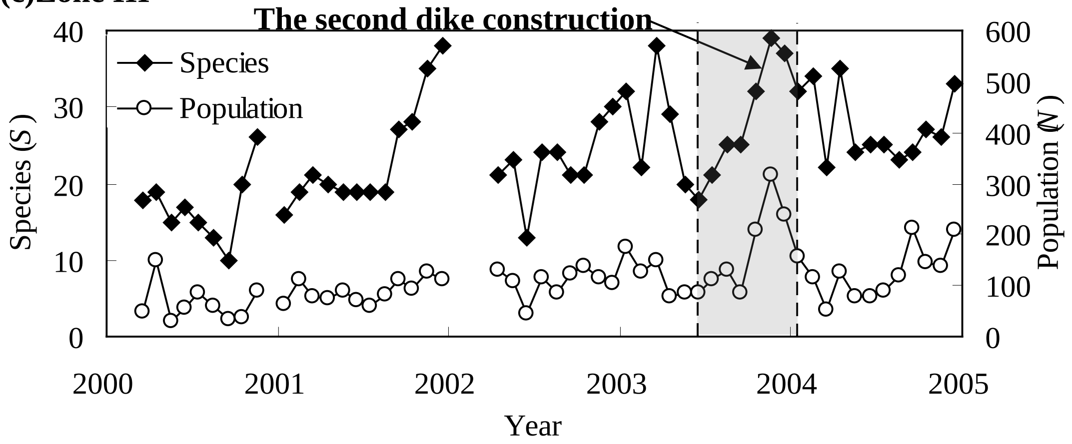
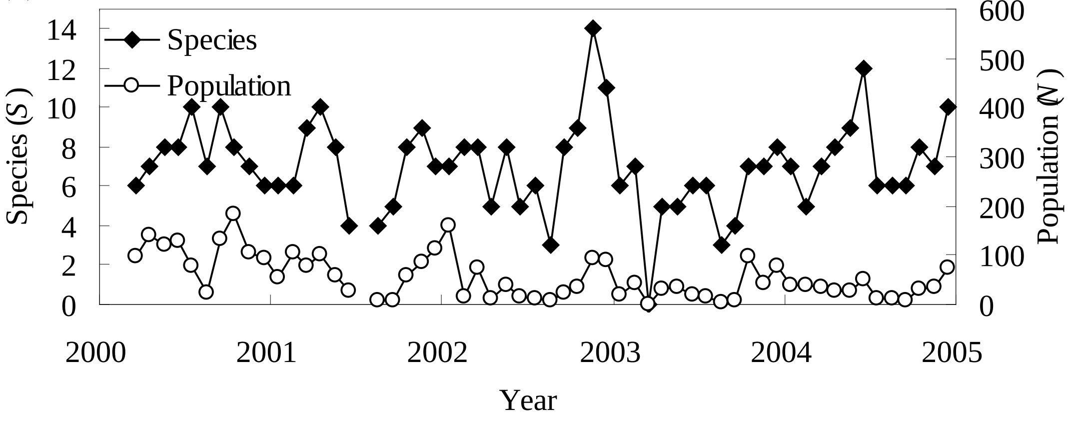


Figure 2. The time series of the species and population of birds

(a)Zone I



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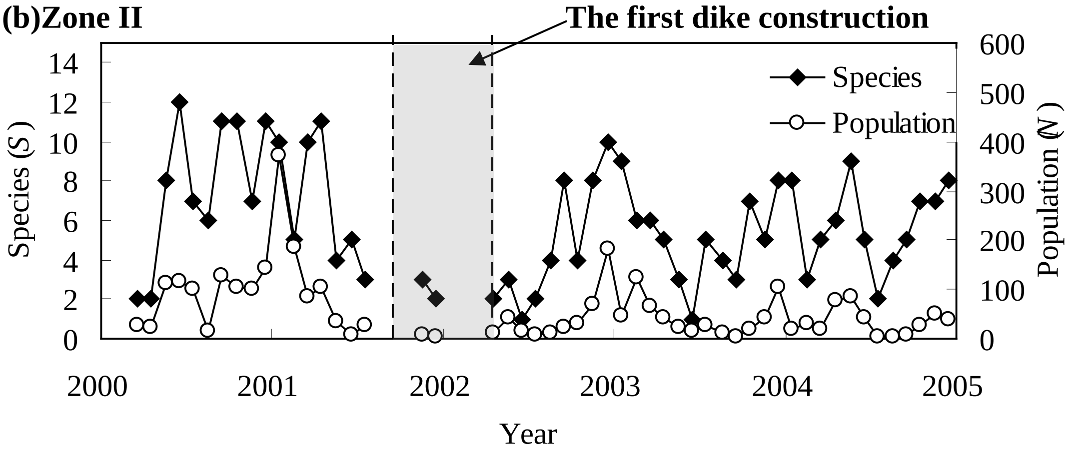


(c)Zone III

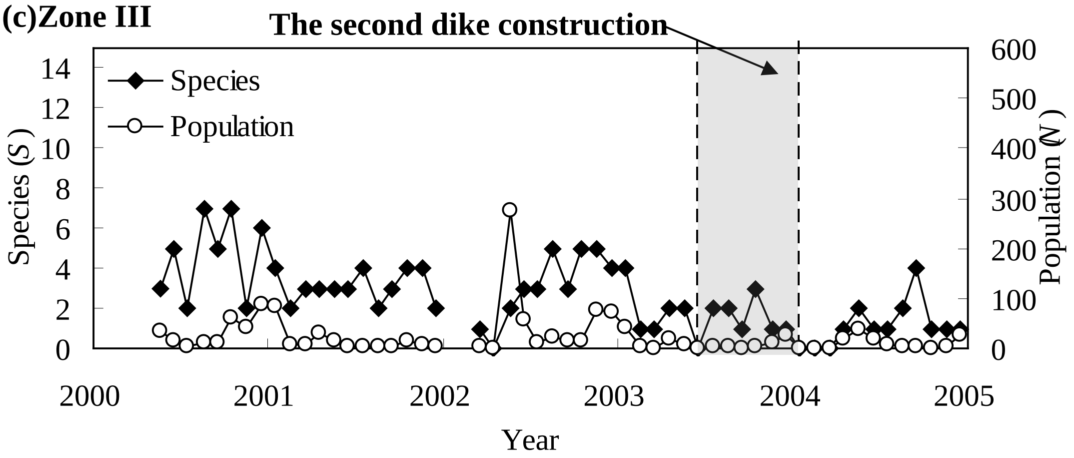
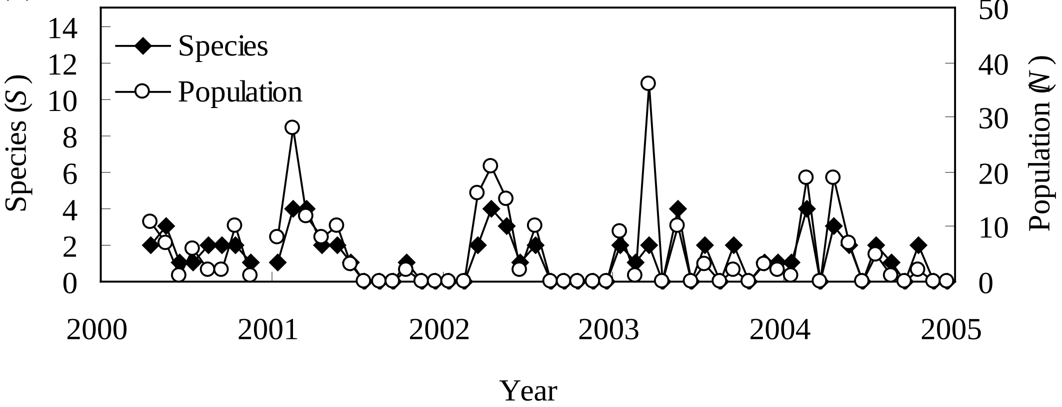
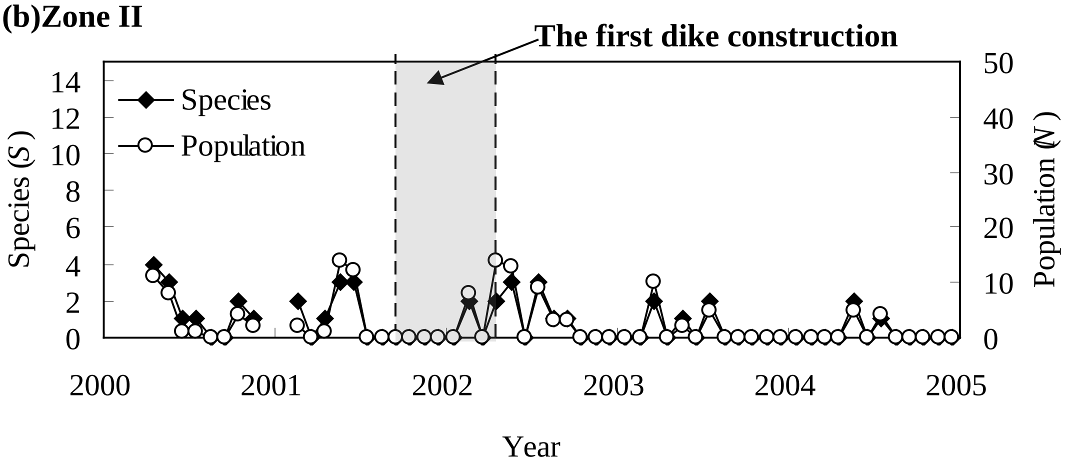


Figure 3. The time series of the species and population of fish

(a)Zone I



(b)Zone II



(c)Zone III

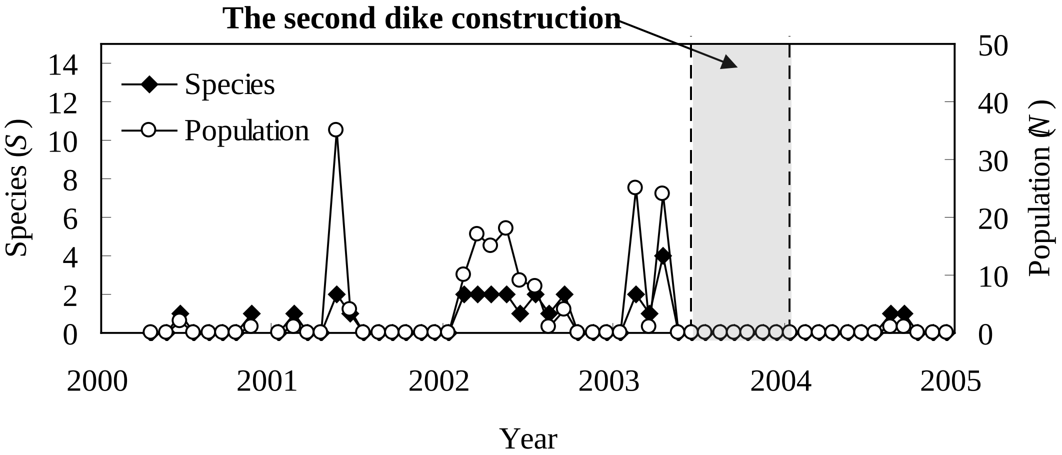
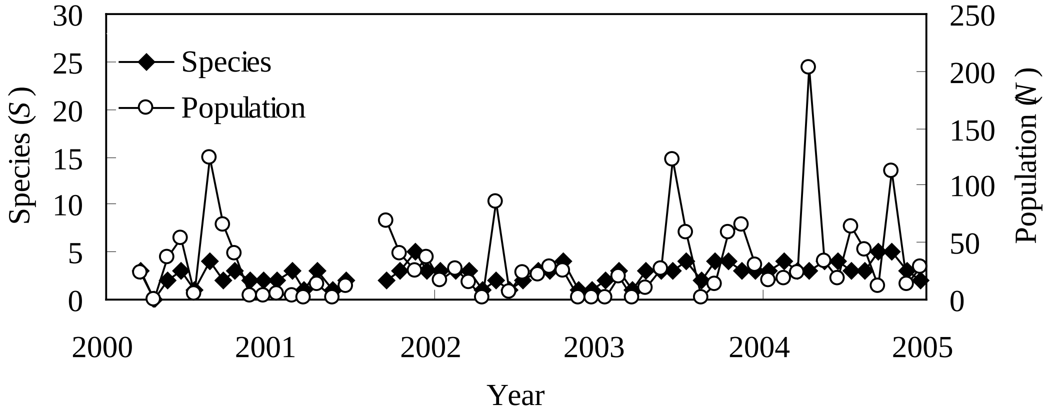
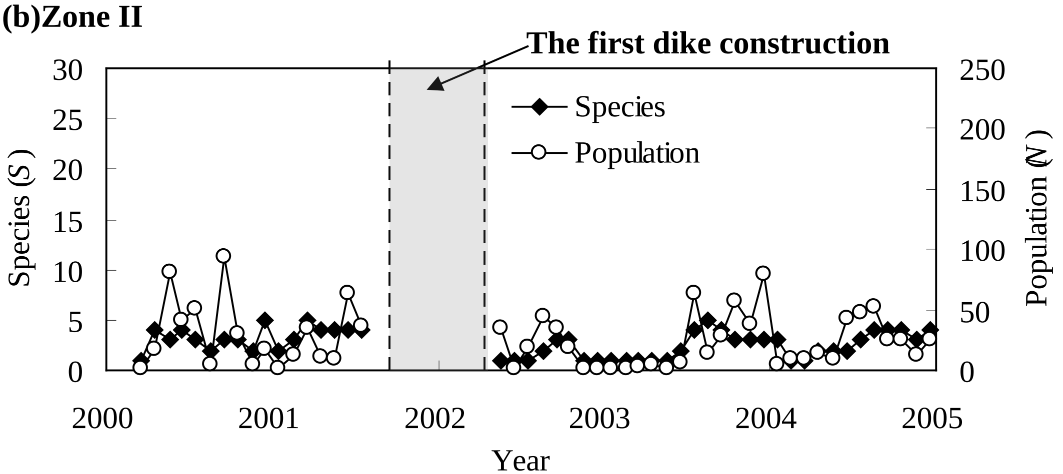


Figure 4. The time series of the species and population of amphibians

(a)Zone I



(b)Zone II



(c)Zone III

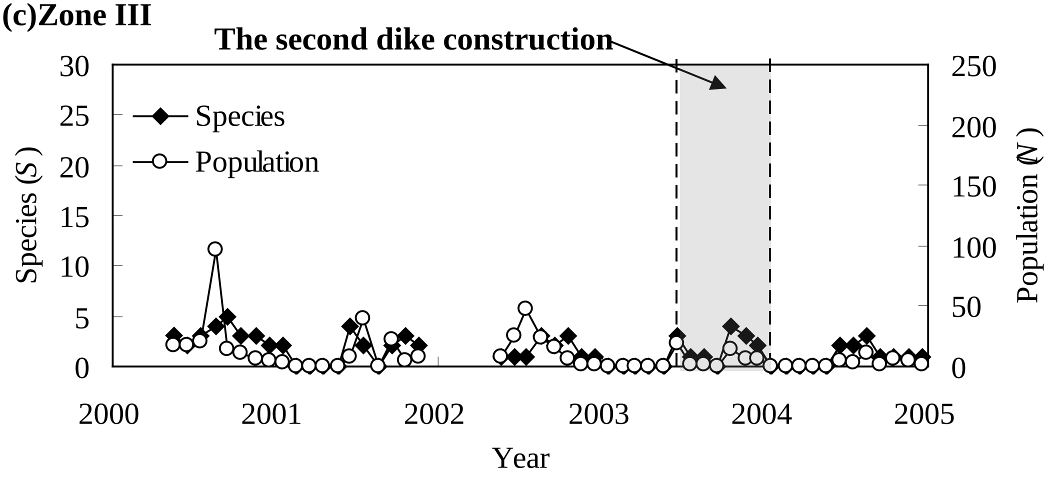
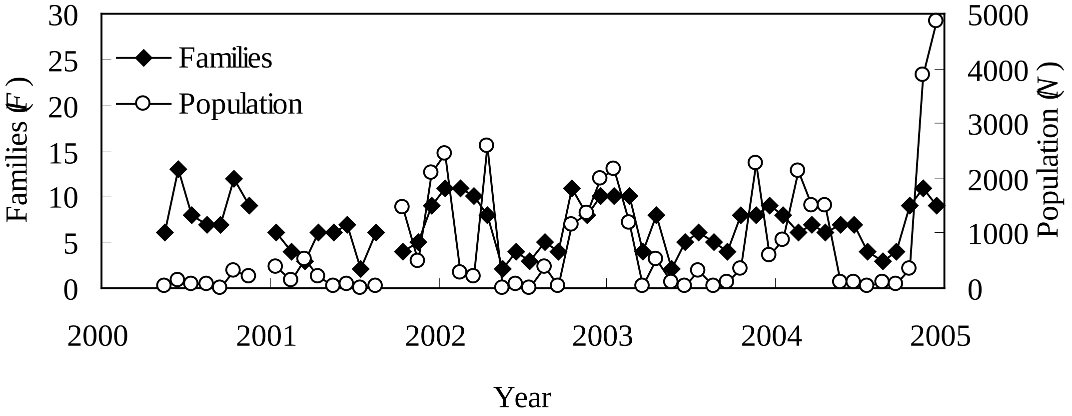
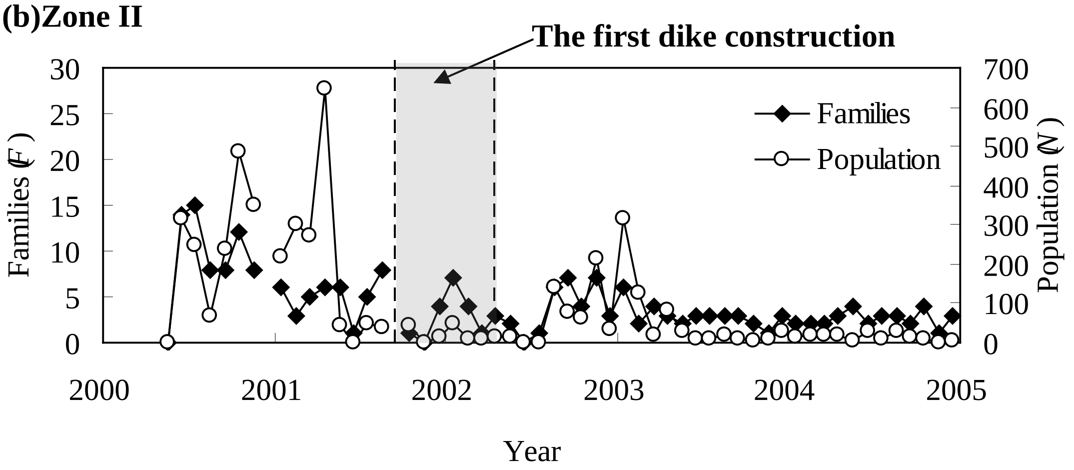


Figure 5. The time series of the species and population of crustaceans

(a)Zone I



(b)Zone II



(c)Zone III

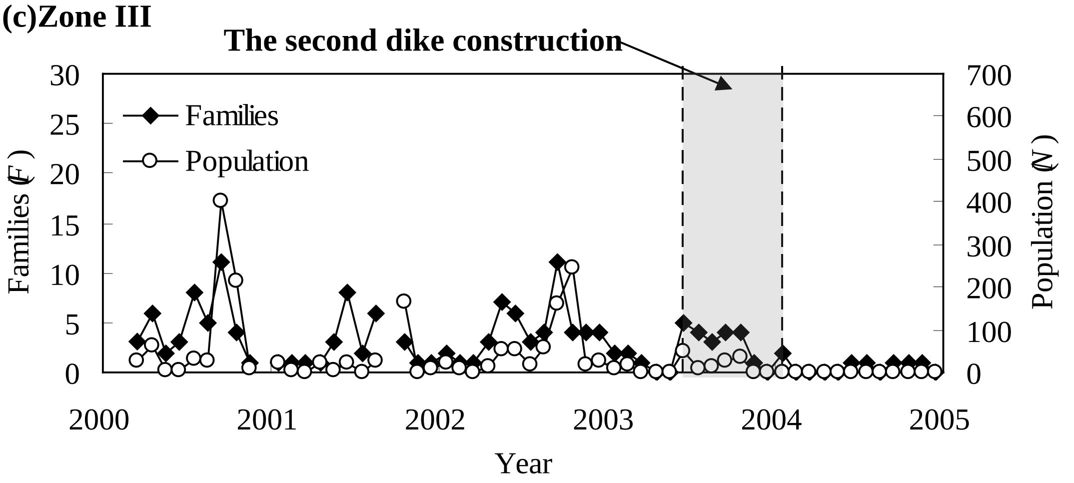


Figure 6. The time series of the families and population of aquatic insects

4. Crustaceans

In zone I, *S* increased significantly and *S* and *N* decreased significantly in zones III (Table 1 and Fig. 5).

The changes to diversity indices in zones I and II were insignificant. In zone III, *C* and *H'* indicated significant diversity degradation.

In zone II, during the first year after dike completion, *S* and *N* decreased slightly and recovered later (Fig. 5b). The biodiversity reduction in zone III was due to the impact of dike construction.

5. Aquatic insects

The number of *F* in zones II and III decreased significantly (Table 1 and Fig. 6). Notably, *N* increased significantly in zone I and decreased significantly in zones II and III.

In zone I, *SR* showed a significant trend of biodiversity degradation. In zones II and III, all three indices of diversity decreased significantly.

The biodiversity of aquatic insects was extremely susceptible to habitat alteration by dike construction. In zone II, the reduction in diversity continued until the end of the monitoring program.

Discussion

The degree of impact of flood control dikes on biodiversity differed for different species. Aquatic insects were most sensitive to dike construction, followed by fish, amphibians, and crustaceans. Birds were not sensitive significantly to dike construction. This experimental result was due to the different motilities of species and their dependence on the aquatic habitat. Most birds did not depend on aquatic habitats directly and the effects of dikes were limited due to their superior mobility; however, the same effects were extensive for other species, especially for aquatic insects.

Alterations to hydrology, siltation of substrates, and the riparian corridor by the dikes are factors that affect the biodiversity of freshwater habitats (Malmqvist & Rumdle, 2002). All of these factors had high significant adverse effects on fish, amphibians, crustaceans and aquatic insects, because these species and their aquatic habitats are inseparable. For example, aquatic insects assemblages are affected by the substrate (Ward, 1992). The surface characteristics of substrates and size of substrate particles influence the colonization patterns (Shieh & Yang, 1999); these characteristics were altered markedly by dike construction (WRPI, 2004). Thus, biodiversity of aquatic insects was markedly decreased where dikes were constructed. We suggest that aquatic insect is a useful ecological indicator for the Chihlan River.

The degrees of resilience to dike construction differed among fish, amphibians, crustaceans and aquatic insects. The ecological system recovered by itself after suffering an environmental impact; however, all did not recovered to their original situation at the end of monitoring period. In some cases, the biodiversity indices seemed to recover quickly after dike construction; however, the communities at the dike construction sites were altered significantly. For instance, the biodiversity of fish in zone II (Fig. 3b) recovered after construction of the first dike was complete.

This study further analyzed the investigated date, which indicates that 34% of the total population was exotic species in 2000. In 2004, exotic species account for 58% of the total population and markedly threatened the ecological niche of native species. This situation was not expressed completely by the biodiversity indices. Future work will further investigate the cause of this invasion of exotic species.

Conclusion

In conclusion, the impact on biodiversity by construction of dikes was significant. The construction caused the freshwater habitat degradation and resulted in the disappearance of species and a decline in biodiversity.

In 15 cases (five items at three sites), the trends of *C*, *H'*, and *SR* were very similar (Table 1). However, in comparison, the *p*-value of *SR* was smallest in 8 cases, indicating that *SR* was generally more sensitive to the impacts of constructions than *C* and *H'*, and can be applied in environmental monitoring in the Chihlan River.

The seasonal Kendall test can be applied effectively for trend analysis of time series data, and it can consider the seasonal characteristics of biological data. Moreover, the biological data are often missing, extreme or have zero values, and nonparametric methods can treat these data effectively.

Acknowledgments

Ted Knoy is appreciated for his editorial assistance.

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106 年 12 月 11 日收稿

107 年 01 月 04 日修改

107 年 01 月 16 日接受