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Effect of Dams on Fish Assemblages of the Tachia River, Taiwan

Ming-Hsiung Chang[1], Yao-Sung Lin[2] and Lin-Chung Chaung[2]

[1] Institute of Zoology, Academia Sinica, Taipei, Taiwan, ROC.

[2] Institute of Zoology, National Taiwan University, Taipei, Taiwan, ROC.

ABSTRACT

A total of 37 species was caught in the Tachia River from the Kukuan Dam to the river mouth between 1989 and 1992. Species richness increased from seven species upstream to 32 species downstream in the river. Shannon-Wiener's species diversity also increased from 1.24 in the upstream to 2.52 in the downstream section. The fish fauna of the Tachia River could be divided into three fish zones acccording to the fish fauna study of Tsao (1994), this study, and the positions of dams in the river. *Varicorhinus barbatulus* and *Crossostoma lacustre* were the dominant species in the upper segment between the Kukuan and Tienluen Dams. *Zacco* spp., *Acrossochelius paradoxus*, and *Hemimyzon formosanum* were the most abundant species in midstream between the Tienluen and Shikuan Dams. *Zacco* spp. *Tilapia* sp., and *Mugil cephalus* were the dominant species in the downstream segment below Shikuan Dam. Both fish richness and diversity indices were higher in the downstream than upstream sections. Among six widely distrubuted speices, *Zacco* spp. were not found upstream of Tienluen Dam, although it was dominant below Tienluen Dam. Except for the section below Shikuan Dam, the fish species richness and relative abundance showed no seasonal change. In the section below Shikuan Dam, more species and individuals were sampled in summer and autumn than in spring or winter. In flooding periods (e.g., summer and autumn), some species which predominated in upstream sections, including *V. barbatulus*, *Leiocassis adiposalis*, *H. formosanum*, and *C. lacustre*, could be collected frequently below Shikuan Dam. Species occurring near the river mouth could move further upstream during the flooding period. Native *Anguilla japonicus* and *Sicyopterus japonica* were caught near Shikuan Dam during the flooding period. The dams play a role in regulating downstream flow which may disrupt the river gradient and block upstream fish migration, and thus subsequently affect zonation of fish fauna in this river system.

Key words: Dam, Fish fauna, Species diversity, River zone.

INTRODUCTION

The phenomenon of fish faunas changing from headwaters to downstream reaches of streams is well documented. The number of fish species generally increases downstream (Beecher *et al.*, 1988; Pusey *et al.*, 1995; Reyes *et al.*, 1996) and/or zonation of taxocenes (Balon and Stewart, 1983; Moyle and Herbold, 1987; Williams *et al.*, 1996). The addition of species typically results from increases in habitat volume or diversity (Gorman and Karr, 1978; Martin, 1998), stability (Horwitz, 1978), and production (Lotrich, 1973). Fish communities in a river may differ markedly over short distances because of dramatic changes in physicochemistry and geomorphology (Balon and Stewart, 1983; Moyle and Herbold, 1987; Lyons, 1996; Maret *et al.*, 1997). In addition, human activities, such as impoundments, may

*Corresponding author: Ming-Hsiung Chang , Institute of Zoology, Academia Sinica, Taipei 115, Taiwan, ROC.

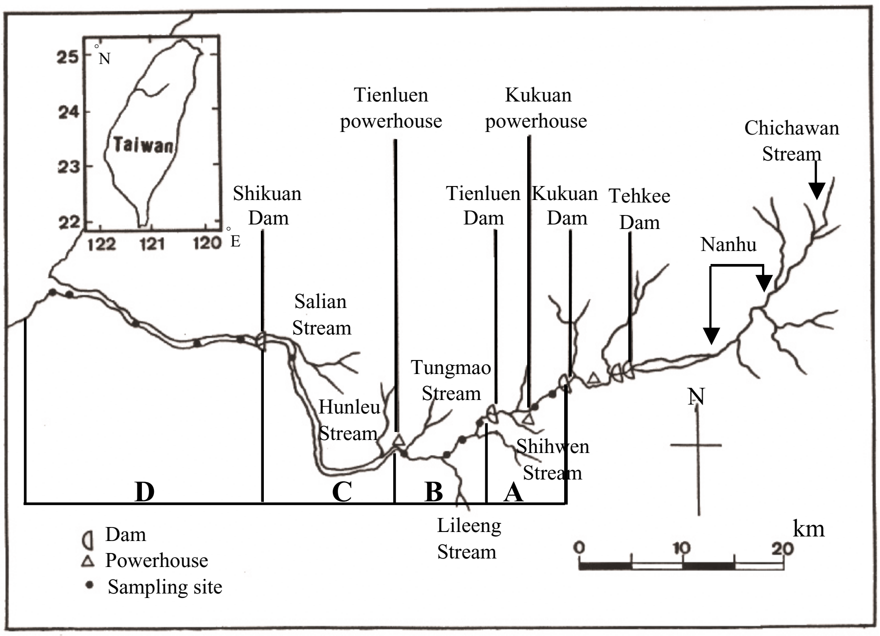

Figure 1. Locatioin of sampling sites in four sections of Tachia River.

also affect fish in streams. Dams can cause drastic changes in flow regimes, water temperatures, and water quality, subsequently influencing fish fauna in tailwaters (Edwards, 1978; Travnichek *et al.*, 1995; Wolf *et al.*, 1996). Blockage may influence fish movement and their escape from reservoirs (Cushman, 1985; Holmquist *et al.*, 1998). Upstream fauna may also be changed by the invasion of reservoir fishes (Jacobs and Swink, 1983; Rodriguez, 1998).

The influence of dams on stream fishes has received growing attention over the past ten years. However, few investigations of fish assemblages along a longitudinal stream and the effects of dams on stream fish fauna have been conducted in Taiwan. On the Tachia River, which already has the highest density of dams among streams in Taiwan, a sixth dam was recently completed. The dams, ranging in height from 25 to 180 m, were constructed to create storage reservoirs for water supply and electric power generation because of it contains the greatest water volume in Taiwan. No environmental impacts of these reservoirs upon the aquatic biota have been conducted before, during, or after construction of these dams. Conflicts between the dam's construction agency and the public concerning fish resources in the Tachia River have increased since the sixth dam was proposed for construction. To settle these disputes, it is necessary to examine the fish distribution in the Tachia River and to evaluate the effects of existing dams on fishes.

The present study investigated fish assemblages in the middle to lower reaches of the Tachia River. Objectives were to document changes in species composition in a downstream direction and to determine the effects of the dams on fish assemblages in the river. To evaluate the effects of impoundment on fish distribution, differences in fish faunas above and below dams were compared with those in two consecutive sections of the unimpounded river.

MATERIALS AND METHODS

Study area

The Tachai River, located in west-central Taiwan (Fig. 1), drains about 1236 km^2 making

Table 1. Habitat characteristics of stream reaches and reservoirs in four sections of the Tachia River, Taiwan. (Sections A, B, C, and D refer to Fig. 1)

Section	A ($n = 18$) Kukuan Dam to Tienluen Dam	B ($n = 32$) Tienluen Dam to Tienluen powerhouse	C ($n = 10$) Tienluen powerhouse to Shikuan Dam	D ($n = 30$) Shikuan Dam to the river mouth
Length (km)	8.3	12.5	28.6	23.8
Gradient (m km^{-1})	14.7	14.2	10.9	11.3
Mean water tempature (°C)	17.9 (3.9)	21.2 (4.5)	21.0 (2.6)	21 .0 (4.3)
Dissolved oxygen (ppm)	9.8 (1.8)	9.5 (2.2)	9.3 (1.4)	10.2 (2.0)
Mean width (m)	9.4 (4.2)	13.7 (6.3)	57.3 (5.7)	7.0 (3.4)
Mean depth (m)	0.4 (0.12)	0.3 (0.16)	0.5 (0.11)	0.4 (0.15)
Mean velocity (m s^{-1})	0.6 (0.33)	0.4 (0.21)	0.8 (0.34)	0.4 (0.23)
Dominant substrate	bedrock, large boulders	bouldesr, cobbles	boulders, cobbles	cobbles, gravel
Minimum discharge (m^3 s^{-1})	0.6	0.2	17.0	0.2
Turbidity	clear	partially clear	slightly turbidity	turbid
Land use	natural	farms, orchards	farms	farms, industry
Dam	Kukuan Dam	Tienluen Dam	No	Shikuan Dam
Dam height (m)	95.0	54.0	–	25.0
Surface area (ha)	62.0	–		6.5
Effective storage (Mm^3)	7.3	0.5	–	2.1
Drainage area (km^2)	686.3	780.2	–	1056.9
Designed discharge (m^3 s^{-1})	116.1	68.0	–	-
Water use	hydroelectric	hydroelectric	irrigation	hydroelectric, municipal, irrigation

it the third largest drainage in Taiwan. Along its 124-km length, 15 tributaries enter the river before it empties into the Taiwan Strait. Elevations in the headwaters exceed 2000 m. Annual rainfall in the watershed ranges from about 150 to 250 cm, concentrated in two periods: April to June and August to October. Typhoons in late summer and early autumn can bring intense precipitation and floods which may cause discharges exceeding 100 or more times the average base flow. The Tehkee Dam (180 m high) impounds a reservoir of 450 ha in surface area about 90 km from the river mouth. Because of its large capacity (158.9 million m^3 of effective storage) and high discharge (200 m^3 s^{-1} designed discharge), all downstream reservoirs and flows are regulated by Tehkee Dam.

The study area from the Kukuan Dam to the river mouth is about 75 km long (Fig. 1). This reach was divided into four sections, according to the location of the Kukuan Dam, Tienluen Dam, Tienluen powerhouse, and Shikuan Dam (Fig. 1), all of which cause significant changes in the fluvial system. Section A (most upstream) extends from Kukuan Dam to Tienluen Dam, section B from Tienluen Dam to the Tienluen powerhouse, section C from the Tienluen powerhouse to Shikaun Dam, and section D, from Shikuan Dam to the river mouth. The lengths of sections A, B, C, and D are 8.5, 12.5, 28.6, and 23.8 km, respectively (Table 1).

Kukuan Dam (95 m high) creates a reservoir surface area of 62 ha with effective storage of 7.3 million m^3. The reservoir's discharge (116.1 m^3 s^{-1} designed) is transported by tunnel to Kukuan powerhouse, about 4 km below the dam. Tienluen Dam (54 m high) is located 67 km from the river mouth. It creates a reservoir with an effective storage of 0.5 million m^3 of water. Water from the reservoir (68 m^3 s^{-1} designed discharge) is transported by tunnel to Tienluen powerhouse, 12.5 km below the dam.

Mean annual discharge recorded at the Tienluen gauging station, at kilometer 57 is about 8.86 $m^3 s^{-1}$. At this site, daily stream flows ranged from 0.89 to 658.2 $m^3 s^{-1}$ from 1988 to 1998. Mean annual discharge into the Tachai River from the outlet of the Tienluen powerhouse is about 66 $m^3 s^{-1}$. Daily stream flows in this reach ranged from 0.82 to 1080 $m^3 s^{-1}$ from 1980 to 1998. The Shikuan Dam (25 m high and 23.8 km from the river mouth) creates a reservoir surface area of 6.5 ha with an effective storage of 2.06 million m^3. Unfortunately, reaches between Kukuan Dam and Tienluen Dam and below Shikuan Dam are not gauged, and detailed discharge information is unavailable. Base flows of the reaches between Kukuan Dam and the outlet of Kukuan powerhouse and between Tienluen Dam and the outlet of Tienluen powerhouse come from three sources : dam leakage, groundwater and tributaries. Below Shikaun Dam, base flow comes from irrigation and wasterwater effluents. Water released from both floods and irregular operations of the powerhouses result in widely and frequently fluctuating flows in these reaches.

Physical characteristics of these four sections measured during periods of base flow are shown in table 1. Gradients of the four sections are almost the same, ranging from 10.9 to 14.7 m km^{-1}. Mean water temperatures in sections B, C, and D were similar (about 21 °C). Temperatures in Section A were slightly lower (near 18 °C). Dissolved oxygen in the four sections was always above 9.0 ppm. Flow volume and channel width of section C (17.0 $m^3 s^{-1}$ and 57.3 m) were greater than these of other sections (nearly 1.0 $m^3 s^{-1}$ and < 15 m). Mean depths (about 0.4 m) and velocities (about 0.6 m s^{-1}) were similar among the four sections. Substrates differed markedly among sections. Dominant substrates were large boulders in section A, boulders and cobbles in sections B and C, and cobbles and gravel in section D. From sections A to D, water quality gradually degraded from clear to turbid, primarily due to an increase in human activities. Although, one sampling site of section D was close to the estuary, the salinity remained near 0.3-0.8% for most of the year.

Methods

Fish were collected at 12 sites (Fig. 1) in the Tachia River from October 1989 to February 1992. Numbers of sampling site in sections A, B, C, and D were 2, 4, 1, and 5, respectively. Due to highly variable flow in section C, it was dangerous to sample in this section, so only one sampling site was established. Sampling sites in each section were selected to represent the range of habitat conditions throughout the section. Fish were also collected from three (Shihwen Stream, Lileeng Stream, and Tungmao Stream) and two (Hunleu Stream and Salian Stream) tributaries in sections B and C, respectively.

Fish were sampled seasonally by electrofishing for a total of ten samples per site. Fish were identified, measured for total length, and returned alive to the sampling site. *Zacco pachycephalus* and *Z. platypus* are difficult to distinguish in the field, so both were listed as *Zacco* spp. At each site, electrofishing was conducted from downstream to upstream by wading with a battery-powered, backpack-mounted electrofisher (100-200 V, 1 A pulsed DC). The same gear was used throughout the study reaches, and little variation in sampling efficiency was shown among sites. Because stream size varied greatly, we sampled fish for 30-40 min, so the length of sites covered varied between 100 and 200 m.

Fish were sampled during all seasons of the year. Because of the irregular flooding caused by waters released from dams, the sampling times and efforts were not identical among sampling sites. To prevent and diminish bias caused by floods, we pooled all fish collected at each site in each section to represent the fish assemblage of that section and these were used to compare fish assemblages among sections.

Data were subjected to both qualitative and quantitative analyses. The Shannon-Wiener species diversity index (Krebs, 1989), $H' = -\sum pi \ln pi$, of each section was calculated, where

Table 2. Phylogenetic list of fishes of Tachia River, Taiwan. Species found only at sites near the estuary are denoted with an asterisk (*).

Order	Family	Species
Anguilliformes	Anguillidae	*Anguilla japonicus*
Salmoniformes	Salmonidae	*Oncorhynchus masou formosanus*
	Plecoglossidae	*Plecoglossus altivelis*
Cypriniformes	Homalopteridae	*Crossostoma lacustre*
		Hemimyzon formosanum
		Sinogastromyzon puliensis
	Cyprindae	*Abbottina brevirostris*
		Acrossochelius paradoxus
		Carassius auratus
		Cyprinus carpio
		Paracheilognathus himantegus
		Pseudorasbora parva
		Varicorhinus barbatulus
		Zacco barbata
		Zacco spp.
	Cobitididae	*Cobitis taenia*
		Misgurnus anguillicaudatus
Siluriformes	Amblycipitidae	*Liobagrus formosanus*
	Bagridae	*Leiocassis adiposalis*
	Siluridae	*Parasilurus asotus*
Atheriniformes	Poeciliidae	*Gambusia affinis*
Perciformes	Gobiidae	* *Glossogobius aureus*
		* *Periophthalmus cantonesis*
		Rhinogobius brunneus
		Rhinogobius giurinus
		Sicyopterus japonicus
	Channidae	* *Channa maculata*
	Cichlidae	*Tilapia* sp.
	Teraponidae	* *Terapon jarbua*
	Mugilidae	* *Liza melinopterus*
		* *Mugil cephalus*
		* Mugilidae sp.
	Scatophagidae	* *Scatophagus argus*
	Eleotridae	* *Eleotris fusca*
	Serranidae	* *Ephinephelus* sp.
	Carangidae	* *Caranx sexfasciatus*

pi represents the proportion of individuals of i species to the total number of individuals present. Friedman test and Tukey multiple comparison (Zar, 1984) were used to compare the number of species over time among consecutive sections. The presence or absence of a species among sections was applied to calculate Sorensen's Similarity Index (Krebs 1989) between any two sections. In Sorensen's Index, $QS = 2c/(a + b)$, where c is the number of common species in both sections, and a and b are the number of species in the two sections. For relative abundance of species composition among sections, percent similarity index (PSI, Matthews *et al.*, 1988), $\mathrm{PSI} = 1 - 0.5\sum|p_{xi} - p_{yi}|$, for each pair of sections was determined. In this formula, Pxi and Pyi represent the proportion of the species i in sections x and y. These two indices of similarity range from 0 to 1, with 1 indicating complete assemblage similarity and 0 indicating no assemblage similarity.

RESULTS

Species richness

In the Tachia River and five of its tributaries, 35 fish species, representing 6 orders and

Table 3. Fish species from four sections of the Tachia River, Taiwan sampled seasonally, 1989-1992. Percentages of each species collected over years in each section were tabulated. values in parentheses are number of sampling sites in each section. Data of CC (Chichiawan Stream) and NH (Nanhu) are referred from Tsao (1994).

Section	**CC**	**NH**	**A (2)**	**B (4)**	**C (1)**	**D (5)**
Elevation range (m)	**above 1700**	**1300-1650**	**800-900**	**500-800**	**200-500**	**below 200**
Species			%	%	%	%
Oncorhynchus masou formosanus	D					
Plecoglossus altivelis			1.4	*	*	
Varicorhinus barbatulus	+	D	44.7	2.9	*	0.1
Crossostoma lacustre		D	36.8	16.7	3.4	0.2
Rhinogobius brunneus		+	11.9	18.6	21.5	19.9
Hemimyzon formosanum		+	2.6	15.3	18.3	4.3
Leiocassis adiposalis			1.5	2.7	2.6	0.9
Acrossochelius paradoxus		+	1.0	19.7	23.0	3.9
Zacco barbata				0.2	0.2	
Liobagrus formosanus				0.2	0.2	
Sinogastromyzon puliensis				0.1	0.2	
Zacco spp.				23.6	26.2	18.1
Abbottina brevirostris				0.1	1.7	3.8
Tilapia sp.				0.1	1.1	6.6
Misgurnus anguillicaudatus				0.1	0.2	0.7
Parasilurus asotus				0.1	*	0.5
Cobitis taenia					0.9	2.2
Carassius auratus					0.4	4.2
Anguilla japonicus					*	0.2
Pseudorasbora parva					*	0.2
Rhinogobius giurinus					*	0.1
Mugil cephalus						23.4
Liza melinopterus						3.9
Terapon jarbua						0.2
Scatophagus argus						2.4
Ephinephelus sp.						1.4
Eleotris fusca						0.7
Cyprinus carpio						0.1
Gambusia affinis					*	0.6
Glossogobius aureus						0.1
Periophthalmus cantonesis						1.4
Paracheilognathus himantegus					*	0.2
Channa maculata						0.2
Mugilidae sp.						0.5
Caranx sexfasciatus						0.1
Sicyopterus japonicus						0.1
Number of species	2	5	7	15	22	31
Total individual of fishes			2653	7496	1350	2100
Speices diversity			1.24	1.82	1.77	2.41

Note: + species present; D: dominant species; * species found in tributaries

18 families (Table 2), were recorded from November 1989 to February 1992. Of these fishes, *Anguilla japonica* and *Plecoglossus altivelis* became locally extirpated before 1990, and those specimens caught in sections B and C were believed to be from restocking since 1990. *Tilapia* sp., an exotic which has been introduced to Taiwan since 1944 for aquaculture, is now common in streams in Taiwan (Lin *et al.*, 1994). The total number of species caught in each section increased downstream, with 7, 15, 22, and 31 species caught in sections A, B, C, and D, respectively (Table 3). In section D, 11 species were found only in the site near the estuary, and if we excluded these 11 species from section D, then the number of species caught in section D would be close to that in section C.

The number of species caught below dams was always more than that above dams during the period of study. Wilcoxon paired-sample tests showed that valuse of species richness over time in sections B (mean = 7.9) and D (mean = 13.9) were significantly ($p < 0.01$) greater than in sections A (mean = 5.7) and C (mean = 7.4), but there was no significant difference in species richness between sections B and C, where no dam separated the sections.

Fish composition

Fish assemblages differed from the upper to the lower river sections (Table 3); the changes were greater between two consecutive sections separated by a dam. Fifteen species were found only in one section: *Mugil cephalus*, *Liza melinoterus*, *Terapon jarbus*, *Scatophagus argus*, *Ephinephelus* sp., *Eleotris fusca*, *Cyprinus carpio*, *Gambusia affinis*, *Glossogobius aureus*, *Periophthalmus cantonesis*, *Channa maculata*, *Paracheilognathus himantegus*, Mugillidae sp., *Caranx sexfasciatus*, and *Sicyopterus japonicus* were caught only in Section D (below Shikuan Dam). Ten species were found in two sections: *Sinogastromyzon puliensis*, *Zacco barbata*, and *Liobagrus formosanus* were collected only in sections B and C (below Tienluen Dam and above Shikuan Dam); and *A. japonicus*, *Carassius auratus*, *Pseudorasbora parva*, *Paracheilognathus himantegus*, *Cobitis taenia*, *Gambusia affinis*, and *Rhinogobius giurinus* were found in sections C and D (above and below Shikuan Dam). Six species were found in three sections: *Plecoglossus altivelis* was present in sections above Shikuan Dam; and *Abbotina brevirostris*, *Zacco* spp., *Misgurnus anguillicaudatus*, *Parasilurus asotus*, and *Tilapia* sp. were found in sections below Tienluen Dam. Six species occurred in all sections: *Acrossocheloius paradoxus*, *Crossostoma lacustre*, *Hemimyzon formosanum*, *Leiocassis adiposalis*, *Rhinogobius brunneus*, and *Varicorhinus barbatulus*. Differences in fish fauna composition between sections A and B (9 species) and those between sections C and D (16 species) were greater than between sections B and C (4 species). The index of Sorensen similarity between sections B and C was 0.86, which was greater then the 0.61 value between sections A and B and the 0.62 value between sections C and D (Table 4).

Table 4. Percent similarity index among sections (upper matrix) and index of Sorensen's similarity (lower matrix).

Section	A	B	C	D
A		0.27	0.21	0.17
B	0.57		0.84	0.37
C	0.48	0.86		0.42
D	0.31	0.26	0.48	

Differences in fish faunas between sections above and below dams also were evident from quantitative comparisons. Species diversity increased downstream from 1.24 in section A to 1.82 and 1.77 in sections B and C, then rose to 2.41 in section D. It is obvious that differences of species diversity between two consecutive sections above and below dams were greater than those without dam blockage.

The dominant species varied among sections (Table 3). *V. barbatulus* (44.7 %), *C. lacustre* (36.8 %) and *R. brunneus* (11.9 %) accounted for greater than 80% of the fish collected in section A. Five species, *Zacco* spp., *Acr. paradoxus*, *R. brunneus*, *C. lacustre*, and *H.*

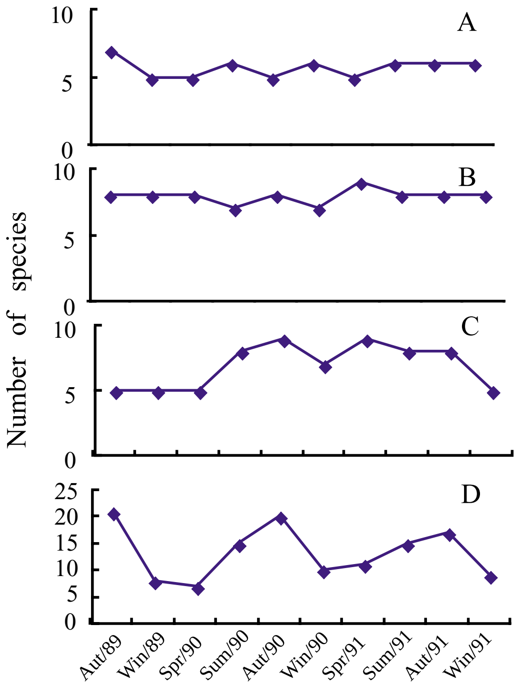

Figure 2. Seasonal changes in numbers of species caught in four sections of Tachia River from autumn 1989 to winter 1991.

formosanum, constituted greater than 90% of the total catch in both sections B and C. *M. cephalus*, *R. brunneus*, *Zacco* spp., *Tilapia* sp., *Car. auratus*, *Abb. brevirostris*, *Acr. paradoxus*, *L. melinopterus* and *Cob. taenia* were dominant species in Section D. PSI (Table 4) showed that similarity of percentage composition of fish fauna between sections B and C (0.84) was greater then the value between sections A and B (0.27) and that between sections C and D (0.42).

Seasonal changes

Except for section D, the number of species in the study area, showed no pattern of seasonal change (Fig. 2). Comparisons among ten catchments in section D suggested that fish were much more abundant in summer and autumn than in spring and winter (Table 5). The nine dominant species, except *L. melinopterus*, occurred in more than six catchments and accounted for 84.5% of the total fish taken. Most of the 16 species which were sampled in low numbers (< 15 individuals in less than 3 times), occurred in summer and/or autumn throughout the study period.

Seasonal differences of fish composition might have corresponded to the periodical fluctuations of water discharge from Shikuan Dam. According to the flow, the status of section D could be classified as flooding period (FP) or base flow period (BP). Most summer and autumn samples were collected in FP (except for two samples in summer 1991), while winter and spring samples were collected in BP. The percentage of dominant species changed little between different flow statuses. However, *V. barbatulus*, *C. lacustre*, *H. formosanum*, *P. parva*, and *Lei. adiposalis* which commonly inhabit sections B and C were sampled more frequently in FP than in BP. The occurrence of rare species in the Tachia River (*S. argus*, *G. aureus*, *Ephinephelus* sp., *Cha. maculata*, *E. fusca*, *Sic. japonicus*, *Cyp. carpio* and *A. japonicus*) were also more frequently found in FP than in BP.

Distribution pattern

There were four distribution patterns among six widely distribute and more abundant species. *Zacco* spp. was the dominant species in all sections below Tienluen Dam, but was never caught above this dam. *R. brunneus* consistently ranked second or third and accounted for about 10%-20% of fishes collected in all sections. *V. barbatulus* dominated collections in section A, ranked sixth in section B, and occurred only sporadically in sections C and D. *Acr. paradoxus* ranked seventh in sections A and D, but was the second most abundant species in both sections B and C. *C. lacustre,* second most abundant in Section A and fourth and fifth in sections B and C, was rarely caught in section D. The declining trend in percent composition of *C. lacustre* from sections A to C was clearer than in its rank among the other species. The ranking of *H. formosanum,* fourth or fifth from sections A to C, changed abruptly to ninth in section D, while

Table 5. Seasonal changes of fish composition in section D during autumn 1989 to winter 1991. The status of flow of section D during sampling is noted by 'FP' and 'BP', which represent flooding and base flow periods, respectively.

	1989		1990				1991						
	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum[a]	Aut	Win	Total		
	FP	BP	BP	FP	FP	BP	BP	B,F	FP	BP		FP (%)	BP (%)
Varicorhinus barbatulus					1						1	0.08	
Crossostoma lacustre	1			2	2						5	0.38	
Rhinogobius brunneus	84	22		22	61	23	60	36	81	31	420	19.09	27.98
Acrossochelius paradoxus	32				17	1		10	18	5	83	5.16	1.23
Zacco spp.	60	2		7	33	22	43	67	82	65	381	14.01	27.16
Leiocassis adiposalis	2			1	2	4			9		18	1.08	0.82
Hemimyzon formosanum				19	44	22		3	2		90	5.00	4.53
Abbottina brevirostris	9	5		2	3	3	6	7	37	9	81	3.93	4.73
Tilapia sp.	39		7	9	9	9	7	18	22	18	138	6.08	8.44
Carassius auratus	21	13	6	7	16		1	11	5	9	89	3.77	5.97
Cobitis taenia	10	5		3	5		4	2	5	12	46	1.77	4.32
Parasilurus asotus		2		1			6	1			10	0.08	1.65
Anguilla japonicus	2			1							3	0.23	
Pseudorasbora parva					1				2		3	0.23	
Paracheilognathus himantegus					1	2			2		5	0.23	0.41
Misgurnus anguillicaudatus	4	3					7				14	0.31	2.06
Cyprinus carpio	1				1						2	0.15	
Gambusia affinis			3	2		1	3			3	12	0.15	2.06
Rhinogobius giurinus	1		1								2	0.08	0.21
Sicyopterus japonicus				1	1						2	0.15	
Mugil cephalus	36		5	129	48		2	144	150	9	523	27.94	3.29
Liza melinopterus	7					7	10		50		74	4.39	3.50
Eleotris fusca	4	2			6				3		15	1.00	0.41
Channa maculata	2							1	1		4	0.23	
Glossogobius aureus	1										1	0.08	
Periophthalmus cantonesis	9		2	2	3			2			18	1.08	0.41
Ephinephelus sp.	20				5			1	4		30	2.23	
Scatophagus argus	6				4				4		14	1.08	
Terapon jarbua			4								4		0.82
Caranx sexfasciatus								1			1		
Mugilidae sp.								11			11		
Number of species	21	8	7	15	20	10	11	15	17	9	31	28	19
Number of individuals	351	54	28	208	263	94	149	315	477	161	2100	1299	486

[a] Data were excluded because two and three sites were sampled in BP and FP, respectively.

its percent composition among the other species in section A (2.6%) was obviously less than in section B (15.3%) or section C (18.3%).

DISCUSSION

Species richness

Fish assemblages of tributary headwaters of the Tachia River were studied by Tsao (1994) for protection and restoration of the endangered Formosan landlocked salmon (*Oncorhynchus masou formosanus*). In Tsao' study, fish species increased from one species (salmon) in upstream headwaters (Chichiawan Stream) to five species above Tekee Dam (Nanhu, Fig. 1). *V. barbatulus* and *C. lacustre* were dominant in reaches above Tekee Dam (Table 3), except in upstream reaches of Chicchiawan Stream which were solely inhabited by salmon. In this study, we collected fish in reaches below Kukuan Dam in Tachia River. Fish species richness in Tachia River increased from upstream to downstream reaches, which is similar to patterns in both tropical and temperate streams and rivers (Horwitz, 1978; Balon and Stewart, 1983; Moyle and Herbold, 1987; Beecher *et al.*, 1988; Angermier and Schlosser, 1989; Pusey *et al.*, 1995; Reyes *et al.*, 1996). These reports correlate longitudinal changes to increases in both drainage area and discharge; in turn, these factors are correlated with changes in both qualitative and quantative aspects of abiotic and biotic stream components. However, dams are the principal factor constraining the distribution of fish in Tachia River by the process of disrupting natural fluvial regimes (Edward, 1978; Poff and Allan, 1995; Kanehl *et al.*, 1997; Rodriguez, 1998).

Species composition below Shikuan Dam

The number of species increased from seven below Kukuan Dam (section A) to 21 above Shikuan Dam (Section C). However, if the permanent species existing in section D were considered as 'the real' species of section D, then there were less than 20 species inhabiting reaches below Shikuan Dam. This is counter to the trend of increasing species richness from upstream to downstream. One reason for this may be related to the highly fluctuating flows occurring in summer and autumn caused by hydropower generation and typhoons. Consequently, physical features varied frequently in response to discharge changes. For example, in Tachia River, stream width might abruptly change from 10 m to more than 50 m, and riffles might be transformed into rapidly flowing runs. Changes in fish assemblages below hydroelectric dams can result from an unstable environment caused by highly erratic and fluctuating flows (Bain *et al.*, 1988; Travnichek *et al.*, 1995; Wolf *et al.*, 1996). An unstable physical habitat may contribute to changes in fish assemblages by reducing food supplies, disrupting reproduction, or possibly eliminating some species from a river section.

Fish assemblages in section D were also believed to be influenced by wastewater effluents, especially from a paper mill near Shikuan Dam. During BP, it was common to find less than 20 average fish individuals per site in section D. Under such circumstances, less than 10 species of fish were found in section D (the 9 dominant species and a few rare species), which suggests that species richness did not increase downstream beyond Shikuan Dam. Except for permanent species, species composition in section D included 11 species known to occur near the estuary for spawning or nursing during summer and autumn; and it is believed that these species are minimally affected by upstream flow fluctuations and pollution. Most of these species could invade the fresh water of Tachia River, but were blocked by Shikuan Dam during FP when polluted water was diluted with water discharge from Shikuan Dam; but such invasions were restricted by highly polluted water during BP (e.g., *A. japonica* and *Sic. japonicus*). During FP, some upstream species, such as *V. barbatulus*, *C. lacustre*, *H. formosanum*, and *Lei. adiposalis* may have been flushed into section D. This may have temporally resulted in a higher fish assemblage diversity in section D. These fish will be unable to return upstream because of the Shikuan Dam barrier and will probably die during periods of polluted base flow. By excluding the species described above, species richness increased from one species in the most upstream headwaters to seven species below Kukuan Dam (section A) and 20 species in the reach above Shikuan Dam (section C), and then dropped to less than 20 species below Shikuan Dam (section D).

River zones based on fish fauna

Both the qualitative and quantitative similarity analyses (Table 4) indicate that the similarity of sections B and C assemblages was higher than between paired comparisons of the other sections. This dissimilarity among the other sections was especially evident between paired comparisons of sections above and below dams. There is no dam between sections B and C to block fish movement, and although discharge in section C is much higher, fish assemblages in sections B and C were virtually the same.

Based on species composition, longitudinal zonation of fish assemblages of the Tachia River could be readily divided into three zones, with certain species characteristic of each zone. Boundaries of fish zones were consistent with the location of dams. The mountain zone, above Tienluen Dam, was represented by *V. barbatulus* and *C. lacustre*. In the low hill zone, between Tienluen and Shikuan Dams, *Zacco* spp., *Acr. paradoxus*, and *H. formosanum* dominated. The lowland zone, below Shikuan Dam, provided habitat for both *Zacco* spp. (a primary freshwater fish) and *M. cephalus* (a peripherial freshwater fish). In undisturbed streams, fish zonation appears to correspond to habitat characteristics such as temperature (Matthews, 1986, Lyons, 1996) or gradient (Balon and Stewart, 1983; Moyle and Herbold, 1987; Paller, 1994; Maret *et al*., 1997). Sudden changes in habitat features often result in abrupt changes in community composition. Gradient changes little throughout that portion of the Tachia River encompassed by the study area; however, water temperatures in section A were lower than in other sections. We believe that two things explain the great difference between the fish faunas of sections A and B: a change in temperature and the presence of Tienluen Dam. Mean water temperature of Tunghou Stream, a stream situated in northern Taiwan, is the same as that in section A, yet its fish assemblage (Sheu, 1991) is more similar to that of section B than to section A, and is dominated by *V. barbatulus*, *C. lacustre*, *Zacco* spp., and *Acr. paradoxus*. From this we conclude that the zonation of fish assemblages found above Shikuan Dam can be attributed to the effects of Tienluen Dam rather than to temperature or gradient.

Anadromous and catadromous fishes may be eliminated if a dam obstructs migration (Holden, 1979; Cushman, 1985). Native *A. japonica*, a catadromous fish, and *Sic. japonicus*, a species common in streams, were not caught above Shikuan Dam, but they were present below the dam. *Zacco* spp. can be found in reaches at the same elevation (below 1000 m) in other rivers in Taiwan (Tzeng, 1986; Tsao, 1994). The sites we sampled ranged in elevation from 0 (section D) to 840 m (section A), so *Zacco* spp. Could possibly be distributed in all sections. However, it is presently only abundant below Tienluen Dam, which eliminates upstream movement. Because the biology of the fishes collected during this investigation remain little known and historical records of former fish assemblages in the study sections are lacking, we can only speculate as to which processes have had the greatest influence on the assemblages both above and below the dams on the Tachia River.

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水壩對大甲溪魚類相之影響

張明雄[1]、林曜松[2]、莊鈴川[2]

[1] 中央研究院動物研究所
[2] 國立台灣大學動物研究所

摘 要

一九八九年至一九九二年間，在谷關壩至出海口間的大甲溪流域四個河段，共捕獲魚類三十五種。種類數由上游河段的七種增加到至下游河段的三十一種，種類數有朝下游增加的趨勢。Shannon-Wiener歧異度指數也從上游的1.24增加到下游的2.41。依據上游源頭溪流魚類相（曹，1994）、本研究中之兩相鄰河段間魚類組成的差異性與水壩位置，大甲溪的魚類相可區分為上、中、下游三個魚類區。德基水庫之上與谷關壩與天輪壩之間的上游河段，鯝魚和纓口鰍是優勢種；天輪壩與石岡壩之間的中游河段，溪哥、石鱸和台灣間爬岩鰍是典型魚種；石岡壩以下的下游河段，則是以溪哥、吳郭魚和烏魚為代表性魚種。不論是魚種豐富度或是種歧異度，水壩下游都較上游為高。在六種廣泛分佈的魚類中，溪哥是天輪壩之下河段的優勢種，卻未曾在天輪壩之上的河段發現。除了石岡水壩以下河段的種類數與相對豐富度具有夏、秋兩季高於冬、春兩季外，石岡水壩以上河段的魚種組成都沒有季節性的變化。鯝魚、脂鮠、台灣間爬岩鰍與纓口鰍等上游河段的普遍種，在夏、秋兩季石岡水壩排水期間的出現率，遠高於冬春季的枯水期。此外，部份棲息於河口附近的魚類，亦可趁排水期朝上游淡水域上溯，野生白鰻和日本禿頭鯊即可在排水期近石岡壩處之河段捕獲。水壩不僅破壞自然河道落差，而且，阻隔魚類的上溯遷移；也控制下游河道的水量，造成棲地不穩定性和魚類被沖至下游，改變了溪流的魚類相。

關鍵字：水壩、魚類相、種歧異度、河流魚類區