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Feeding Habit of the Japanese Eel, *Anguilla japonica*, in the Streams of Northern Taiwan

Wann-Nian Tzeng[1], Juei-Jen Hsiao[1], Huei-Ping Shen[1], Yarng-Tzung Chern[1], Yu-Tzu Wang[1] and Jing-Yng Wu[†]

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ABSTRACT

Japanese eel, *Anguilla japonica* Temminck and Schlegel, was collected monthly with an electric shocker at the 4 stations of the Gong-Shy-Tyan stream and a Tanshui River tributary in northern Taiwan from September 1992 to January 1994. Physico-chemical environmental conditions, fish fauna, aquatic insects and terrestrial vegetation were also investigated. The sizes of the eel collected ranged from 6 cm to 76 cm dominated by one- and two-year old fish. The eel was an opportunistic omnivore, feeding mainly on invertebrates and vegetables available in the streams. The diet consisted mainly of tubifex worm (Oligochaeta), Hirudinea, Brachyura, aquatic insect (Ephemeroptera, Diptera), plant fragment and seed. The diet composition changed with eel size. The feeding activity was lower in the summer season probably due to stressed environmental condition. The relationships between feeding activity and prey availability and environmental condition are described.

Key words: Anguilla japonica, *Feeding habit, Relative importance of prey, Stream, Taiwan.*

INTRODUCTION

The Japanese eel, *Anguilla japonica* Temminck and Schlegel, distributes south from Philippines, through Taiwan, mainland China, Korea, and north to Japan (Tesch, 1977). It is a commercially important cultured species in these countries (Tzeng, 1985). The eel spawns in the middle Pacific Ocean in the west of Mariana Islands (14-16°N, 134-143°E) (Tsukamoto, 1992) in June and July (Tsukamoto, 1990; Tzeng, 1990). The eel metamorphoses from a leptocephalus to a glass eel in the continental shelf, and then becomes elver in the estuaries. Elvers are harvested in estuaries during their upstream migration for pond culture (Tzeng, 1985). Elvers migrate from the oceanic spawning grounds to the estuaries requires 4 to 5 months (Tzeng and Tsai, 1992, 1994). The eels live in rivers for 5 to 20 yr. During late autumn when eels become premature, they migrate downstream to the ocean to spawn (Tesch, 1977).

The knowledge on the early life history of the Japanese eel in the marine phase has considerably increased recently, including daily age and birth date (Tabeta et al.,

[1] Department of Zoology, National Taiwan University, Taipei, Taiwan 106.

1987; Tzeng, 1990; Umezawa and Tsukamoto, 1990), population structure (Tzeng and Tsai, 1992, 1994; Tzeng et al., 1994; Sang et al., 1994; Liu and Liao, 1995), timing of estuarine immigration in relation to environmental conditions (Tzeng, 1984a, 1985), fishing exploitation rates (Tzeng, 1984b) and otolith microchemistry and migratory history (Otake et al., 1994; Tzeng, 1994, 1995; Tzeng and Tsai, 1994; Cheng and Tzeng, 1996).

Due to environmental deterioration, electrofishing by local fishermen and the capture of elvers by many overlapping cross-river nets fixed at the river mouth, the eel population has significantly decreased in the rivers of Taiwan (Tzeng et al., 1994). It is now very rare to catch an eel larger than 40 cm in the inland waters. For the conservation of eel resources, the base line study of the habitat and feeding ecology of the eel is essential. The studies on the feeding habit of European eel *Anguilla anguilla* (L.) and American eel *A. rostrata* (Le Sueur) indicated that aquatic insects are the principal food, however, the diet varied with the availability of food organisms in the habitat (Opuszynski and Leszczynski, 1967; Sinha and Jones, 1967; Deelder, 1970; Biro, 1974; Ezzat and El-Seraffy, 1977; Rasmussen and Therkildsin, 1979; Hussein, 1981; Carpenter, 1983; Hartley, 1984; Nie, 1987; Aprahamian, 1988; Barak and Mason, 1992). The feeding habit of the Japanese eel in the rivers of Taiwan has never been studied.

This study intended to determine the dietary composition of the Japanese eel and their relation to the environmental conditions in the streams of northern Taiwan.

MATERIALS AND METHODS

I. Study area and sampling stations

The eel was collected from the 4 stations of the Gong-Shy-Tyan stream (GST) and a Tanshui river tributary in the northern Taiwan (Fig. 1). The GST stream originates from the Mt. Ta-Tun, flows through the Tanshui county, and meets the sea at Sha-Lung. It is approximately 10 km and the water level varies greatly with seasonal precipitation. It was moderately polluted by domestic sewage in the mid- and downstream portions. Three sampling stations were selected on the GST stream: Station S1, the area immediately above the estuary where the water depth was less than 1 m and scarcely affected by seawater, Station S2, the area downstream from a small dam, where was characterized by diverse topography with fast water movement during flood period, and Station S3, the area above the small dam with slow water movement. The shores of the 3 stations were rice fields with woody scrub and herbs.

The Tanshui River, the largest river in northern Taiwan, is approximately 165 km long. Because the river is too large for electrofishing, a tributary of the river at Chu-Wei (CW) was selected to collect the eel. The tributary was heavily polluted by both domestic sewage and thermal effluents.

II. Sampling design

The eel was collected monthly at the 4 stations of the GST stream and a Tanshui River tributary using electric shocker during daytime from September 1992 to January 1994. The duration of sampling was pre-set at 30 min for each station. In addition, to reduce the day-night effect of sampling, the eel was collected at 4 hr interval over a 24 hr period on 12-13 March, 23-24 July, 13-14 November 1993 and 23-24 January 1994,

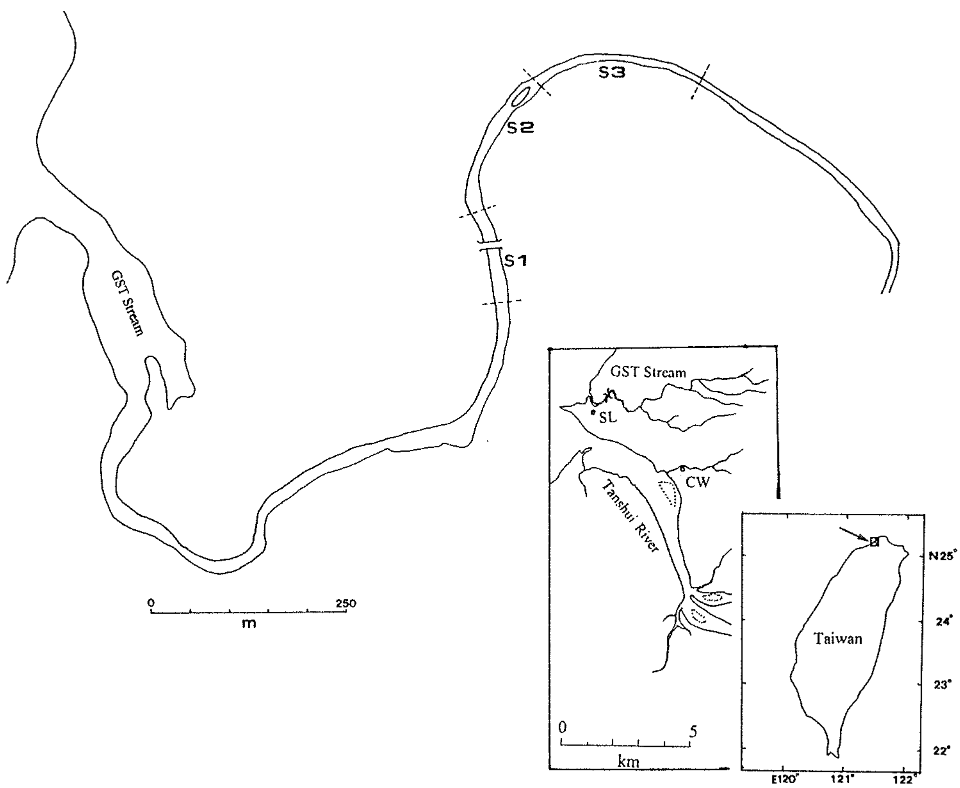

Fig. 1. Map showing sampling stations of the eel in the Gong-Shy-Tyan (GST) stream at Sha-Lung (SL) and a tributary of Tanshui River at Chu-Wei (CW).

respectively. The eels and other fishes collected were separated and preserved in ice or 95% alcohol in the field. A total of 1145 eels was collected. Of them 705 eels had stomach contents and were used for the stomach content analysis. The total length (TL) of the eel was measured to the nearest 0.1 mm. The TL shrinkage due to alcohol fixation was adjusted according to the formula, $Lf = 1.053\ La$, where Lf is TL of fresh eel and La is TL of the eel after alcohol fixation.

Also, vegetation along stream banks and aquatic insects in the stream were investigated. Aquatic insects were collected monthly at stations S1 and S3 from November 1992 to January 1994 using the Surber sampler (Bottom area 30 cm × 30 cm, net mesh 0.01 mm). Two samples were collected at each station. These were sorted to different size groups using 4, 1, 0.5 and 0.25 mm mesh-sized sieves, and fixed with 90% alcohol and counted.

During sampling, water depth was measured by a wood scale, current velocity by a flow meter, temperature by a mercury thermometer, salinity and conductivity by a salinometer (WTW microprocessor conductivity meter, LF196), dissolved oxygen (D.O.) by a microprocessor oximeter OXI196, and pH by a Coring M107 pH meter.

III. Stomach content analysis

The stomach contents of the eel were

examined after approximately two weeks fixation. Individual eel and its stomach contents were weighed. The condition factor (CF), feeding activity (FA) and stomach content weight index (SCWI) were calculated to evaluate the availability of the food and nutrition status of the fish. SCWI=(Stomach content weight) ÷ (Body weight) × 100%, CF=(Body weight) ÷ (Fish length)^3 × 10^n, and FA=(No. of eels with stomach contents) ÷ (Total No. of eels examined) × 100%. Food items were counted and identified to the lowest taxon as possible, and their percentage compositions were estimated.

Since no single method of stomach content analysis is satisfactory for describing the importance of any prey group; the prey importance was analyzed based on a combination of 3 indices to reduce a potential bias when a single index was used (Hynes, 1950; Windell and Bowen, 1978; Hyslop, 1980). The 3 indices are 1) the frequency of occurrence (*F*%): % of the total number of the fish whose stomachs containing a prey item in all of the fish examined, 2) the numerical abundance (*N*%): % of the total number of a prey item in the total number of all prey items in all of the fish examined, and 3) the gravimetric method (*W*%): % of the wet weight of a prey item in the total wet weight of all prey items. The index of relative importance (I.R.I.) of the prey was established from the 3 indices by the following equation (Pinkas et al., 1971):

$$\text{I.R.I.} = (N\% + W\%)\ (F\%) \quad \text{.. (1)}$$

The I.R.I. allows the prey items to be ranked and graphically represented by *N*%, *W*% and *F*% with an ordinate (Cailliet et al., 1986). Yet it also allows the importance of each separate food to be visualized. The significant difference and correlation in I.R.I. between habitats, seasons and the eel's size classes were tested with Kruskal-Wallis one-way analysis of variance by ranks and Spearman rank correlation (Siegel, 1956). Those with significant difference were further analyzed with Bray-Curtis dissimilarity measure and clustered with UPGMA (Unweighted pair-group using arithmetic averages) (Rohlf, 1989).

In trophic diversity of the eel was estimated by the Shannon-Wiener diversity index (*H*) (Wilson and Bossert, 1971), using the same data of prey items used in numerical abundance (*N*%) and gravimetric method (*W*%) by the following equation:

$$H = -\sum_{i=1}^{S} P_i \ln (P_i) \quad \text{........... (2)}$$

where P_i, is the proportion of each prey item contributing to the whole diet. Also, dietary diversity was measued as diet breadth (*B*) by the following equation (Cailliet et al., 1986):

$$B = \frac{1}{\Sigma (P_i)^2} \quad \text{..................... (3)}$$

The *B* value is more sensitive to abundant items and tends to emphasize relatively rare prey items. The diversity index is sensitive both to species richness and the evenness. Two indices are employed to deal with this problem. The evenness index (*e*) which measures how evenly the prey species are distributed in the diet (Cailliet et al., 1986) was calculated as follows:

$$e = \frac{H}{H_{max}} \quad \text{........................ (4)}$$

where H_{max} is ln *S*, the natural log of the number of food types. This value ranges from 0 to 1. Dominance index (*d*) which measures the extent to which one or a few species dominate the diet was estimated by the following equation:

$$d = \sum_{i=1}^{N} (P_i)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

RESULTS

I. Environmental factors and community structure

Table 1 shows the characteristics of the sampling sites, i.e. stream width and depth, current velocity, air and water temperature, D.O., salinity, pH and conductivity at the 3 stations (S1-3) of GST stream and one station in the Tanshui River tributary at CW. The stream was wider and deeper at S1 and S3 than at S2, but the current velocity was faster at S2 than at both S1 and S3. This was probably due to the dam located between S2 and S3. D.O. seemed to be correlated with current velocity; it was extreme low when the velocity was close to zero. Salinity was zero ppt indicating that the 3 stations are far from the influence of seawater. Mean pH was close to 7.0. Conductivity was similar between stations. Water temperature in the GST stream ranged between 31.7°C in June 1993 and 13.3°C in December 1993. Water temperature at CW was extraordinarily high at 32.1°C in April and 37.5°C in July. The high water temperature occurred almost all the year around, except November and December 1992, March and December 1993, and January 1994. These data indicated that the Tanshui River tributary at Chu-Wei was heavily polluted by thermal effluent. The low D.O. in both streams was due to slow water flow and sewage pollution.

The plant community along the banks at the 3 stations of the GST stream is shown in Table 2. A total of 13 species of plants were found at S1. *Broussonetia papyrifera* (L.) was most dominant, occupying approximately 80% of the community. It was followed by *Trema orientalis* (L.) (10%). At S2 the plant community structure was different from that at S1 and was more even. The dominant species was *B. papyrifera* (L.) which made up 40% of the community. The second dominant species were *Ficus septica* Burm. f., *Trema orientalis* (L.) and *Bambusa oldhamii* Munro. Each of them made up 10% of the community. At S3 the number of species decreased to 9 species, and *B. papyrifera* (L.) was the most dominant (50%).

A total of 28 species of fishes, 9 species of crustacean and 3 species of mollusca were found at the 3 stations (Table 3). *Anguilla japonica, Liza marolepis* and *Oreochromis* sp. were the most dominant species in the fish community, while *Eriocheir japonicus* and *Macrobrachium formosense* were the most dominant crustacea. The number of species and abundance of the fish decreased upstream, 35 and 32 species at S1 and S2, respectively, but only 16 species at S3, indicating the adverse effect of the dam. On the contrary, *Gambusia affinis, Channa gachua* and *Oreochromis* sp. were dominant in the upstream station. The occurrence and abundance of the fish also changed with seasons, e.g. *Eriocheir japonicus* was dominant at the downstream station (S1) in spring, *Liza macrolepis* was dominant in summer and autumn, and *L. affinis* in autumn and winter. *Anguilla japonica* was fairly constant in composition in all seasons and stations.

The species composition and abundance of aquatic insects and other in-

Table 1. Characteristics of the sampling sites. The sampling stations, S1-3 and CW are shown in Fig. 1.

	Station	Sample size	Mean ± S.D.	Range
Stream width (cm)	S1	15	93.6±15.13	76-143
	S2	15	69±8.52	52-84
	S3	15	128.93±9.99	108-142
	CW	1	27	27
Stream depth (cm)	S1	15	54.4±13.92	38-90
	S2	14	21.61±10.33	4-45
	S3	15	25.87±13.34	8-65
	CW	1	2	2
Velocity (m/min)	S1	14	4.2±8.38	0-25.2
	S2	15	38.84±15.14	9-67.2
	S3	15	7.92±7.13	0-20.4
	CW	14	29.44±13.44	7.2-54
Air temp. (°C)	S1	10	23.37±6.45	12.2-31.7
	S2	11	22.7±6.58	11.5-32.8
	S3	10	23.19±6.70	12.2-31.7
	CW	12	24.98±6.42	15.9-34
Water temp. (°C)	S1	15	22.01±5.04	13.5-30.5
	S2	15	22.22±5.17	13.3-30.9
	S3	15	22.47±5.49	13.3-31.7
	CW	15	26.9±6.90	15.7-37.5
D. O. (ppm)	S1	12	4.49±2.25	0.4-7.1
	S2	12	5.59±2.26	1.7-8.2
	S3	11	4.81±2.25	0.7-7
	CW	11	6.13±2.13	2.8-9.5
Salinity (‰)	S1	1	0.03±0.06	0-0.2
	S2	15	0.01±0.04	0-0.1
	S3	14	0.01±0.04	0-0.1
	CW	15	0.01±0.03	0-0.1
pH	S1	13	7.20±0.72	5.4-8.75
	S2	13	7.17±0.56	5.53-7.75
	S3	12	7.18±0.53	5.85-7.87
	CW	12	7.35±0.40	6.2-7.7
Conductivity (ms/cm)	S1	14	240.07±43.81	184-353
	S2	14	242.79±40.37	196-354
	S3	14	240.21±37.53	195-342
	CW	14	239.57±59.26	194-434

Table 2. Plant communities along the banks of the 3 stations of GST stream

Family & species	Station S1	S2	S3	Remark
I. Pteridophytes				
Athyriaceae				
Anisogonium esculentum (Retz.) Presl		+	+	H,†
Dennstaedtiaceae				
Microlepia strigosa (Thunb.) Presl		+		H,†
II. Dicotyledons				
Caprifoliaceae				
Sambucus formosana Nakai	+			S,†
Convolvulaceae				
Ipomoea cairica (L.) Sweet	+	+	+	V,†
Euphorbiaceae				
Macaranga tanarius (L.) Muell.-Arg.	+			T,†
Lauraceae				
Machilus thunbergii Sieb. & Zucc.		+		T,†
Leguminosae				
Pueraria lobata (Willd.) Ohwi	+	+		V,†
Moraceae				
Broussonetia papyrifera (L.) L'Herit. ex Vent.	+	+	+	T,†
Ficus microcarpa L. f.	+			T,*
Ficus septica Burm. f.	+	+	+	T,†
Ficus wightiana Wall. ex Benth.			+	T,†
Humulus scandens (Lour.) Merr.	+			H,†
Myrsinaceae				
Ardisia sieboldii Miq.		+		T,†
Ranunculaceae				
Clematis gouriana Roxb.		+		V,†
Ulmaceae				
Trema orientalis (L) Blume	+	+	+	T,†
Urticaceae				
Boehmeria frutescens Thunb.	+			H,†
Vitaceae				
Tetrastigma formosanun (Hemsl.) Gagnep.		+		V,†
III. Monocotyledons				
Araceae				
Alocasia macrorrhiza (L.) schott & Endl.			+	H,†
Gramineae				
Bambusa oldhamii Munro	+	+	+	T,*
Cyrtococcum patens (L.) A. Camus	+			H,†
Miscanthus floridulus (Labill.) Warb. ex Schum. & laut.	+			H,†
Pandanaceae				
Pandanus odoratissimus L. f. var. *sinensis* (Warb.) Kanehira		+		S,†
Smilacaceae				
Smilax china L.		+		V,†
Zingiberaceae				
Alpinia speciosa (Windl.) K. Schum.			+	H,†
Total no. of species	13	14	9	

Remark: T=Tree, S=Shrub, V=Vine, H=Herb, †=native (orginal), *=cultivated.

Table 3. Species composition in numerical percentage of teleost, crustacea and mollusca collected by electrofishing in the 3 stations of GST stream (S1 ~ 3) and a Tanshui River tributary at CW, February 1993 ~ January 1994

Family & Species	Season				Station				Total
	Spr	Sum	Aut	Win	S1	S2	S3	CW	
ANGUILLIDAE									
Anguilla japonica	30.98	15.69	21.52	26.18	18.98	13.76	20.00	36.29	21.08
Anguilla marmorata	2.55	0.88	0.32	5.82	1.81	0.18	0.00	4.43	1.79
CYPRINIDAE									
Carassius auratus	0.00	0.19	1.58	0.36	0.21	0.55	0.59	0.42	0.37
Hemiculter leucisculus	0.00	1.07	0.00	0.00	0.00	0.00	0.00	2.32	0.51
Pseudorasbora parva	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.42	0.09
Rhodeus ocellatus	0.00	0.68	0.00	0.00	0.00	1.28	0.00	0.00	0.32
PLECOGLOSSIDAE									
Plecoglossus altivelis	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.09
POECILIDAE									
Gambusia affinis	4.51	3.90	0.00	1.45	1.49	2.02	12.35	4.43	3.08
Poecilia reticulata	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.42	0.09
Xiphophorus sp.	0.00	0.00	0.00	0.36	0.00	0.18	0.00	0.00	0.05
SYNBRANCHIDAE									
Monopterus alba	0.20	0.19	0.00	0.36	0.11	0.18	0.00	0.42	0.18
PERICHTHYIDAE									
Lateolabrax japonicus	0.00	0.00	0.00	0.36	0.00	0.18	0.00	0.00	0.05
CENTROPOMIDAE									
Ambassis gymnocephalus	0.00	0.19	0.00	0.00	0.21	0.00	0.00	0.00	0.09
TERAPONIDAE									
Terapon jarbua	0.00	1.17	0.00	0.00	1.28	0.00	0.00	0.00	0.55
KUHLIIDAE									
Kuhlia marginata	0.98	0.19	0.32	0.73	0.43	0.73	0.59	0.21	0.46
CARANGIDAE									
Caranx sexfasciatus	0.00	0.10	0.00	0.00	0.11	0.00	0.00	0.00	0.05
LUTJANIDAE									
Lutjanus argentimaculatus	0.00	0.10	0.00	0.00	0.11	0.00	0.00	0.00	0.05
SPARIDAE									
Acanthopagrus latus	0.00	0.29	0.00	0.00	0.32	0.00	0.00	0.00	0.14
GERREIDAE									
Gerres filamentosus	0.00	1.36	0.32	0.00	1.49	0.18	0.00	0.00	0.69
CICHLIDAE									
Oreochromis sp.	7.06	0.88	6.96	20.73	1.92	12.84	15.29	2.11	5.70
MUGILIDAE									
Mugil cephalus	0.20	0.10	0.32	0.73	0.32	0.37	0.00	0.00	0.23
Liza affinis	0.20	2.44	14.56	8.73	5.12	8.81	0.00	0.00	4.41
Liza macrolepis	2.35	13.06	12.03	0.36	12.15	11.19	0.00	2.11	8.50

Table 3. (Continued)

Family & Species	Season				Station				Total
	Spr	Sum	Aut	Win	S1	S2	S3	CW	
ELEOTRIDAE									
Eleotris oxycephala	0.59	1.17	7.59	6.18	4.69	0.55	5.29	0.00	2.57
Eleotris fusca	0.00	0.00	0.32	0.00	0.11	0.00	0.00	0.00	0.05
GOBIIDAE									
Rhinogobius brunneus	0.59	0.58	0.32	0.00	0.32	0.92	0.00	0.42	0.46
Rhinogobius giurinus	0.20	0.10	0.00	0.00	0.11	0.18	0.00	0.00	0.09
Sicyopterus micrurus	0.39	0.10	0.00	0.00	0.32	0.00	0.00	0.00	0.14
Awaous melanocephaus	0.59	0.00	0.00	0.36	0.32	0.18	0.00	0.00	0.18
CHANNIDAE									
Channa gachua	0.20	0.88	5.70	0.73	0.96	1.10	3.53	1.90	1.38
Channa maculata	0.39	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.09
LORICARIIDAE									
Hypostomus plceostomus	0.00	0.00	0.32	0.00	0.11	0.00	0.00	0.00	0.05
GRAPSIDAE									
Eriocheir japonicus	18.43	5.65	5.06	3.27	11.94	8.99	2.94	2.32	8.13
CAMBARIDAE									
Procambarus clarki	0.59	0.29	0.32	1.09	0.43	0.37	1.76	0.21	0.46
PALAEMONIDAE									
Macrobrachium formosense	11.18	33.63	19.30	10.18	22.60	12.66	26.47	34.81	22.55
Macrobrachium japonicum	9.02	5.65	0.00	6.55	6.82	10.64	0.00	0.00	5.60
Macrobrachium nipponense	0.39	1.85	0.00	0.00	0.75	1.47	2.94	0.21	0.96
Macrobrachium lar	0.00	0.39	0.00	0.00	0.21	0.37	0.00	0.00	0.18
Macrobrachium latidactylus	0.39	0.00	0.32	0.00	0.11	0.18	0.59	0.00	0.14
ATYIDAE									
Neocaridina denticulata sinensis	5.69	4.48	0.32	2.55	1.49	7.16	2.94	5.27	3.81
Caridina japonica	0.78	.10	0.32	0.00	0.43	0.18	0.59	0.00	0.28
AMPULLARIDAE									
Ampullarius canaliculatus	0.00	1.07	0.00	0.00	0.00	1.65	1.18	0.00	0.51
PLEUROCERTIDAE									
Thiara tuberculata	0.20	0.10	0.00	1.09	0.00	0.18	0.00	0.84	0.23
NERITIDAE									
Neritina variegata	0.00	0.00	0.00	0.36	0.11	0.00	0.00	0.00	0.05
Unidentified	0.78	1.17	2.22	1.45	2.13	0.37	2.94	0.00	1.24
Total No. of species	28	36	21	23	35	32	16	20	45
Total No. of individuals	510	1026	316	275	938	545	170	474	2127

vertebrates at stations S1 and S3 is shown in Fig. 2. The number of species groups was greater at S1 than S3, indicating that the aquatic invertebrate community structure was more diverse at station S1. The abundance of aquatic invertebrates was greater in winter than the other seasons with the peak abundance in January at S1 and in February at S3. Of them, tubifex was the most dominant at S1 and S3 and was followed by Ephemeroptera and Chironomidae (larvae) at S1 and Hirudinea at S3.

II. Upstream migration and growth

Seasonal movement and growth of the eel in the stream were examined based on the length frequency distribution (Fig. 3). The eel at the sizes of 6-8 cm migrated into the downstream portion of the GST stream in winter, grew up to approximately 14 cm in spring, 16 cm in summer, 20 cm in autumn, 26 cm in winter and to 32 cm in the next year (Fig. 3A). The largest size of the eel found was 76 cm.

The eel in the tributary of the Tanshui

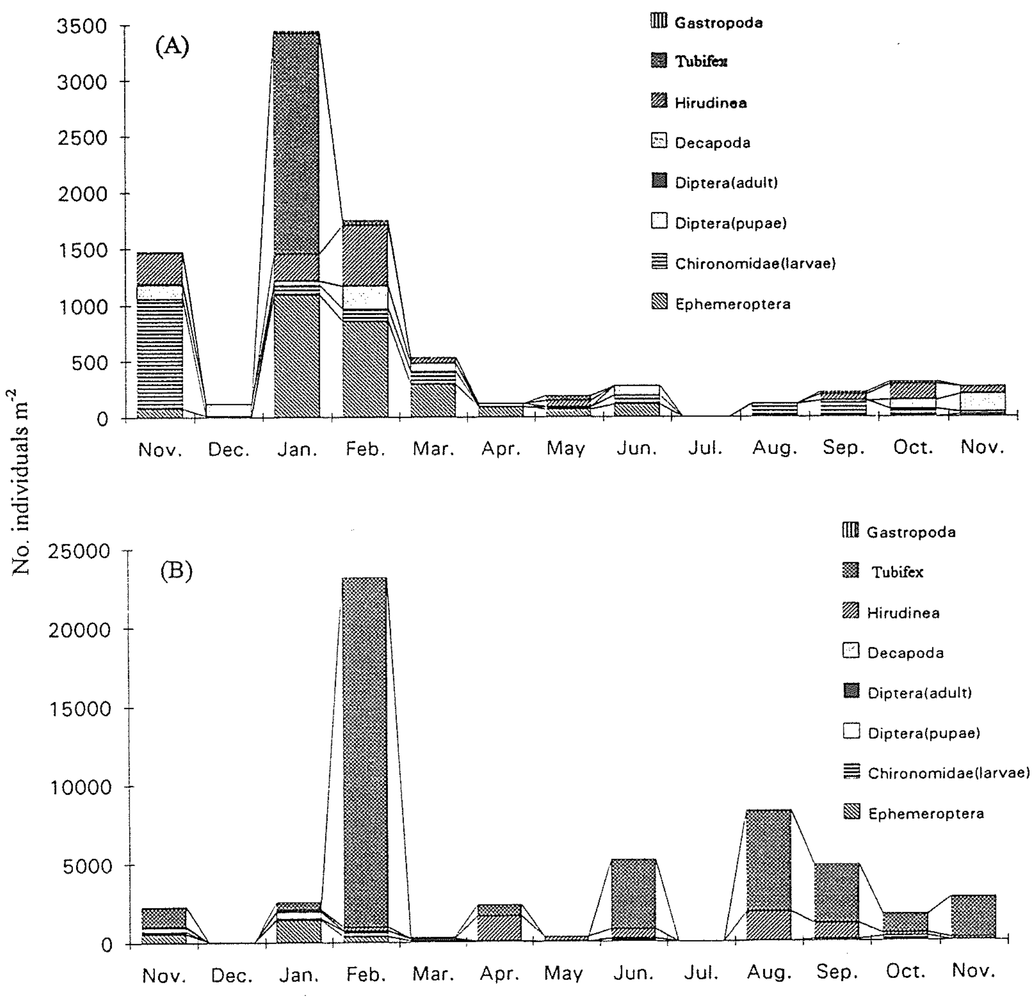

Fig. 2. Seasonal changes in species composition of the invertebrates at station S1 (A) and station S3(B) in Gong-Shy-Tyan stream during Nov. 1992 through Nov. 1993.

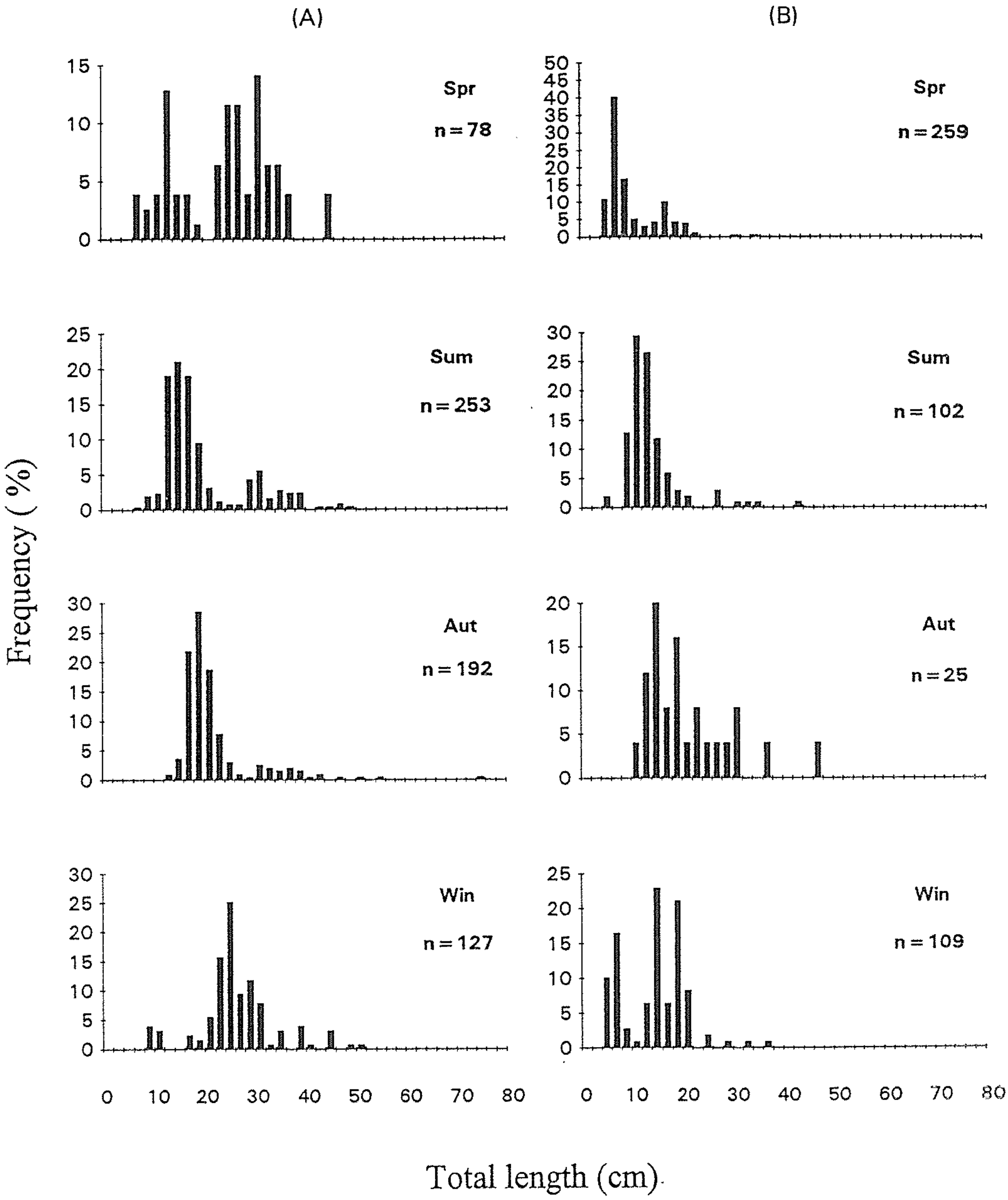

Fig. 3. Seasonal variation of length frequency distribution of the eels collected in GST stream (A) and a tributary of Tanshui River (B). n = sample size.

River at CW was relatively smaller as compared to these in the GST stream. The small eels migrated to the area were 8 cm, grew to 12 and 16 cm in autumn and winter, respectively. The shift of the modal lengths of the eels in the Tanshui River tributary, seemed less significant than that in the GST stream, and the eels larger than 30 cm were also fewer (Fig. 3B). The length frequency distribution indicated that the eels larger than one year old was very rare in the Tanshui River tributary.

The length frequency distribution of the eels was similar between stations S1 and S2, but significantly shifted to larger sizes at S3, modal length increased from 14-16 cm at S1 to 18-20 cm at S2, and then to 34-36 cm at S3. This indicated that the eels migrated upstream with growth (Fig. 4).

III. Dietary prey composition

The preys found in the stomach con-

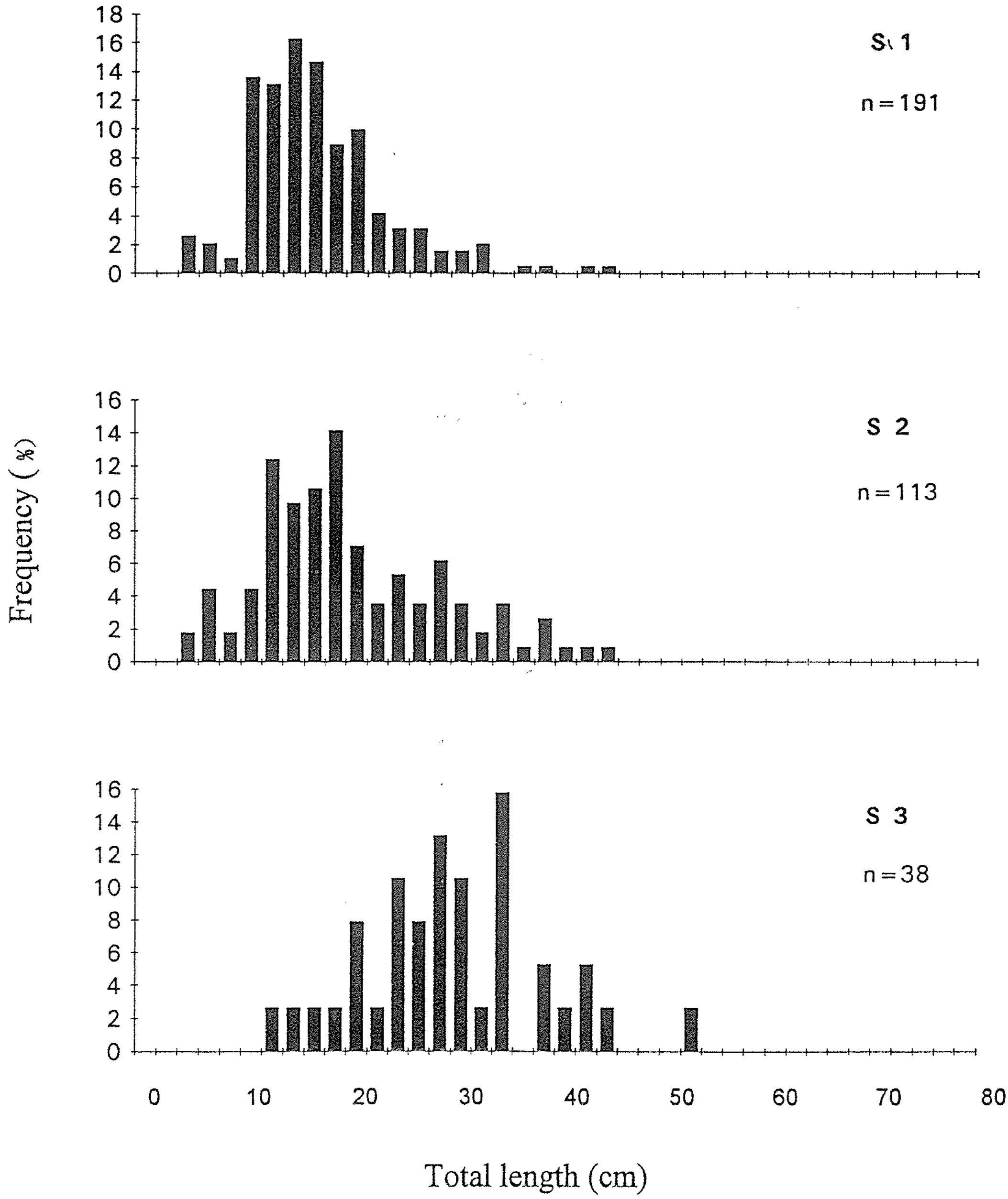

Fig. 4. Length frequency distribution of the eels in the 3 stations of GST stream. n = sample size

tents of the eels were classified into 26 categories. The indices of the relative importance of the preys (I.R.I.) are shown in Tables 4 and 5 by stations and seasons, respectively. The Kruskal-Wallis analysis indicated that there was no significant difference in the prey composition of the eels between stations ($H=3.679$, $p>0.1$) and between seasons ($H=1.962$, $p>0.1$). Spearman rank correlation analysis also indicated that there was a high positive correlation in the prey composition of the eels between stations ($r=0.49 \sim 0.91$, $p>0.01$) and between seasons ($r=0.68 \sim 0.83$, $p<0.001$).

Table 4. Index of relative importance of the prey (I.R.I.) for the eels collected from the 3 stations of GST stream (S1-3) and a Tanshui River tributary at CW

Food item	I.R.I.			
	S1	S2	S3	CW
1 Nematoda	25.47	6.39	205.26	0.00
2 Hirudinea	591.36	111.30	0.00	108.79
3 Tubifex	715.33	160.18	544.37	29.74
4 Gastropoda	0.10	3.46	0.00	1.98
5 Arachnida	0.00	0.00	0.00	0.08
6 Conchostraca	0.00	0.00	0.00	0.00
7 Isopoda	0.00	0.00	0.00	0.00
8 Macrura	0.11	78.30	0.00	8.13
9 Brachyura	158.24	730.60	173.66	255.77
Ephemeroptera				
10 *Baetis* sp. (N)*	18.21	356.99	285.94	2.86
11 Ephemeridae (N)	0.00	0.27	0.00	0.00
12 Odonata (N)	0.04	0.00	0.00	0.00
Diptera				
13 Chironomidae (L)*	314.37	220.98	0.00	28.90
14 Chironomidae (P)*	5.48	2.64	0.00	0.08
15 Other Diptera (L)	0.02	1.21	0.00	12.43
16 Other Diptera (P)	14.00	27.53	6.95	289.35
17 Other aquatic insects	0.70	5.09	0.00	8.41
18 Terrestrial insects	0.02	0.29	63.63	0.32
19 Eel	0.00	0.00	0.00	0.00
20 Fish scale	1.31	0.09	0.00	0.34
21 Spong	38.89	11.40	0.00	0.00
22 Plant fragment	1302.28	1684.56	3626.28	611.93
23 Seed	702.15	1315.28	8230.54	2.28
24 Plastic	17.34	27.90	3.473	290.60
25 Sand	3719.20	1248.79	3350.18	1466.15
26 Unidentified	7.13	11.29	0.87	1.34

*: N=Nymph, L=Larva, P=Pupa

Table 5. Seasonal variation of the index of relative importance of the prey (I.R.I.) for the eel collected from GST stream at Sha-Lung (a) and a Tanshui River tributary at Chu-Wei (b)

(a)

Foot item	I.R.I.			
	Spr	Sum	Aut	Win
1 Nematoda	97.95	0.31	40.14	17.28
2 Hirudinea	72.01	519.30	355.76	301.93
3 Tubifex	560.68	2914.96	162.09	316.91
4 Gastropoda	0.09	1.04	0.22	0.34
5 Arachnida	0.00	0.61	0.00	0.00
6 Conchostraca	0.09	0.00	0.00	0.09
7 Isopoda	0.00	0.00	7.64	0.00
8 Macrura	0.09	0.00	0.04	175.88
9 Brachyura	229.86	67.88	2016.32	378.95
10 *Baetis* sp. (N)*	412.14	0.62	0.00	313.78
11 Ephemeridae (N)	0.00	0.00	0.02	0.13
12 Odonata (N)	0.00	3.93	0.00	0.03
13 Chironomidae (L)*	17.12	104.36	325.46	455.06
14 Chironomidae (P)*	0.00	0.13	8.84	17.99
15 Other Diptera (L)	0.19	1.92	0.81	1.09
16 Other Diptera (P)	11.27	0.93	23.74	147.14
17 Other aquatic insects	0.56	0.00	0.09	4.78
18 Terrestrial insects	5.73	0.00	0.05	0.21
19 Eel	0.00	0.00	0.00	0.00
20 Fish scale	0.00	2.23	3.44	0.52
21 Spong	61.26	25.99	11.19	5.12
22 Plant fragment	1525.38	527.95	1016.81	1553.82
23 Seed	2533.53	251.13	473.84	2057.19
24 Plastic	74.20	37.21	10.28	10.27
25 Sand	2042.18	3464.17	3055.83	1378.44
26 Unidentified	41.32	1.52	14.62	129.21

(b)

Foot item	Spr	Sum	Aut	Win
1 Nematoda	0.00	0.00	0.00	0.00
2 Hirudinea	385.90	105.19	0.00	476.90
3 Tubifex	1140.69	1230.36	0.00	93.02
4 Gastropoda	2.61	0.00	0.00	7.09
5 Arachnida	0.05	0.00	0.00	0.00
6 Conchostraca	0.08	0.00	0.00	0.00
7 Isopoda	0.00	0.00	0.00	0.00
8 Macrura	0.00	0.00	590.44	0.00
9 Brachyura	4.02	818.52	145.29	18.30
10 *Baetis* sp. (N)*	8.89	0.00	0.00	8.44
11 Ephemeridae (N)	1.59	0.00	0.00	0.00
12 Odonata (N)	0.00	0.00	0.00	0.00
13 Chironomidae (L)*	7.55	11.02	6.78	93.34
14 Chironomidae (P)*	1.71	0.00	0.00	3.72
15 Other Diptera (L)	78.97	0.92	151.94	5.12
16 Other Diptera (P)	41.28	5.72	2406.72	35.36
17 Other aquatic insects	1.69	0.00	85.44	12.67
18 Terrestrial insects	0.00	0.89	3.29	0.00
19 Eel	1.47	0.00	0.00	0.00
20 Fish scale	0.03	1.76	3.67	3.42
21 Spong	0.00	1.76	0.00	0.00
22 Plant fragment	455.47	250.05	1300.01	1605.64
23 Seed	10.24	1.68	0.00	35.94
24 Plastic	868.92	134.42	200.50	265.91
25 Sand	1767.04	498.44	1201.38	3382.45
26 Unidentified	2.34	243.68	0.00	5.63

*: N=Nymph, L=Larva, P=Pupa

The top 10 prey items of the eels were expressed by the I.R.I. diagram with $N\%$, $F\%$ and $W\%$ by stations and seasons in Figs. 5 and 6, respectively. The ranking of prey importance was very similar between stations and between seasons. Plant fragment and seed were the two most dominant diets in the stomach contents of the eel at all 3 stations in the GST stream, but plant seed became less important in the Tanshui River tributary (CW). This corresponds to the terrestrial vegetation which was more abundant in the GST stream than CW. The next important prey items were Hirudinea, tubifex worm and Chironomid larvae at S1, but they

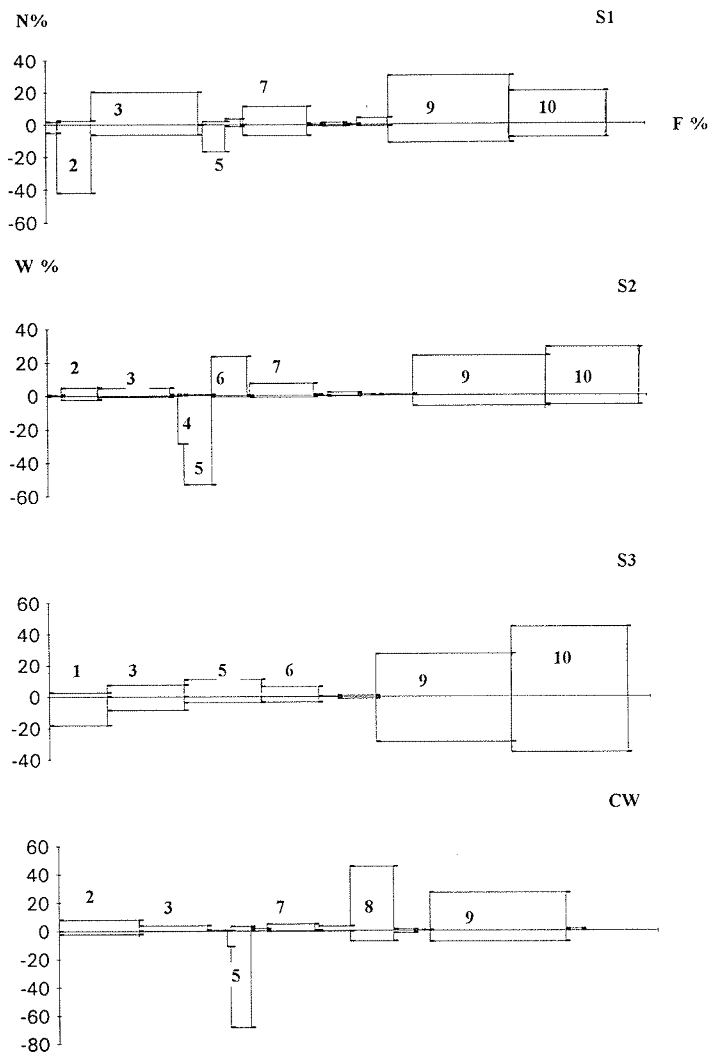

Fig. 5. Comparison of the index of relative importance of the prey (I.R.I.) for the eels collected from the 3 stations (S1, 2 & 3) of GST stream and a tributary of Tanshui River at CW. Figures in the diagram indicate the dominant food items: 1=Nematoda, 2=Hirudinea, 3=Tubifex, 4=Macrura, 5=Brachyura, 6=*Baetis* sp., 7=Chironomidae, 8=Other Diptera, 9=Plant fragment, and 10=Seed.

changed to Macrura, Brachyura and *Baetis* sp. nymph at S2, and to Nematoda, tubifex worm, Brachyura and *Baetis* sp. at S3. On the other hand, Brachyura and Diptera pupae became the secondary important prey in the Tanshui River tributary (Fig. 5).

In terms of season, plant fragment and seed were also two most dominant food items at the GST stream in spring and winter, tubifex worm in summer and Brachyura in autumn (Fig. 6). These phenomena indicated that the dominant preys of the eel slightly changed with seasons and locations.

Clustering analysis of the I.R.I. of prey items based on Bray-Curtis dissimilarity measure indicated that the prey composition of the eels obviously changed at 10 and 30 cm, respectively and could be classified into 3 different size groups, i.e. 5-10 cm , 10-30 cm and

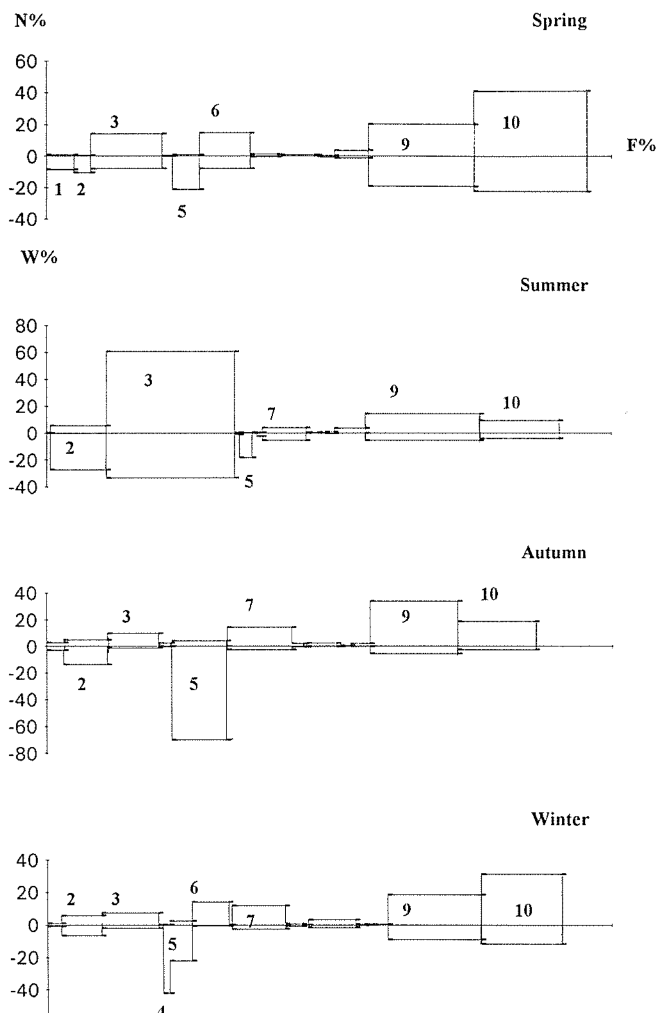

Fig. 6. Seasonal change of the index of relative importance of the prey (I.R.I.) for the eels collected in GST stream. Figures in the diagram indicate food items as Fig. 5.

30-40 cm (Fig. 7). Hirudinea, tubifex worm and Diptera were dominant in the small-size group, but shifted to plant fragment and Brachyura in the medium-size group and to almost Brachyura in the large-size group (Fig. 8).

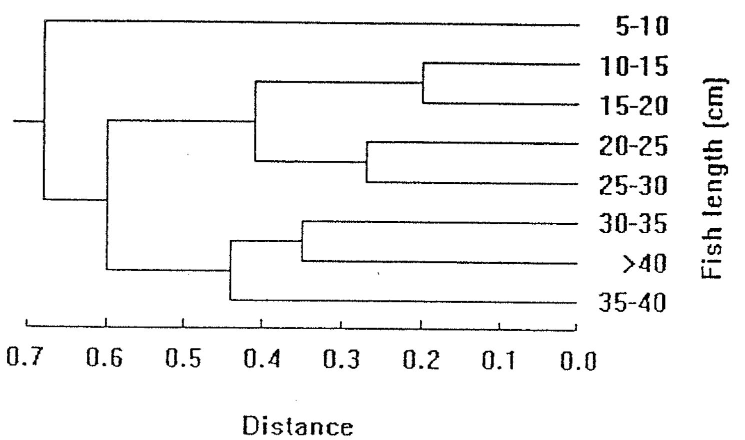

Fig. 7. Dendrogram of fish length clustered by the index of relative importance (I.R.I.) of food items using Bray-Curtis dissimilarity and UPGMA.

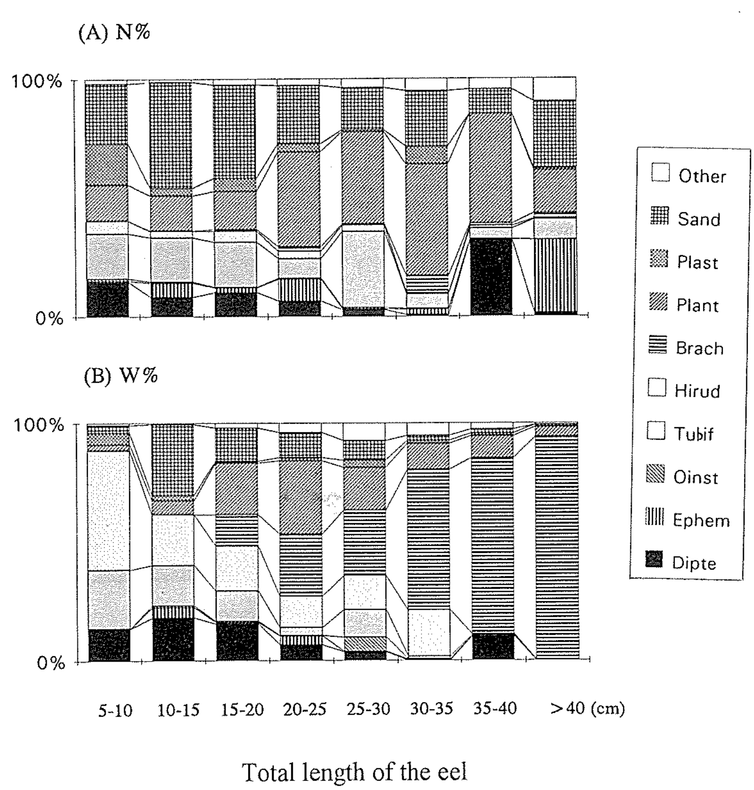

Fig. 8. Variation in numerical (A) and gravemetric (B) dietary composition with eel size.

IV. Seasonal changes in condition factor, feeding activity and SCWI

The monthly variations of condition factor, feeding activity and SCWI are shown in Fig. 9. The condition factor was higher in winter and declined to the lowest in August (summer), while the feeding activity and SCWI declined to the lowest in June and July. In other words, the condition factor became the lowest level about two months after the fish sufferred from poor feeding condition. The condition factor was considerably conservative, and seemed not to be affected immediately by the short-term variability of feeding activity and SCWI. Accordingly, the condition factor may represent the average nutrition status of eel and the food supply condition. The food availability of eel was lowest in the summer.

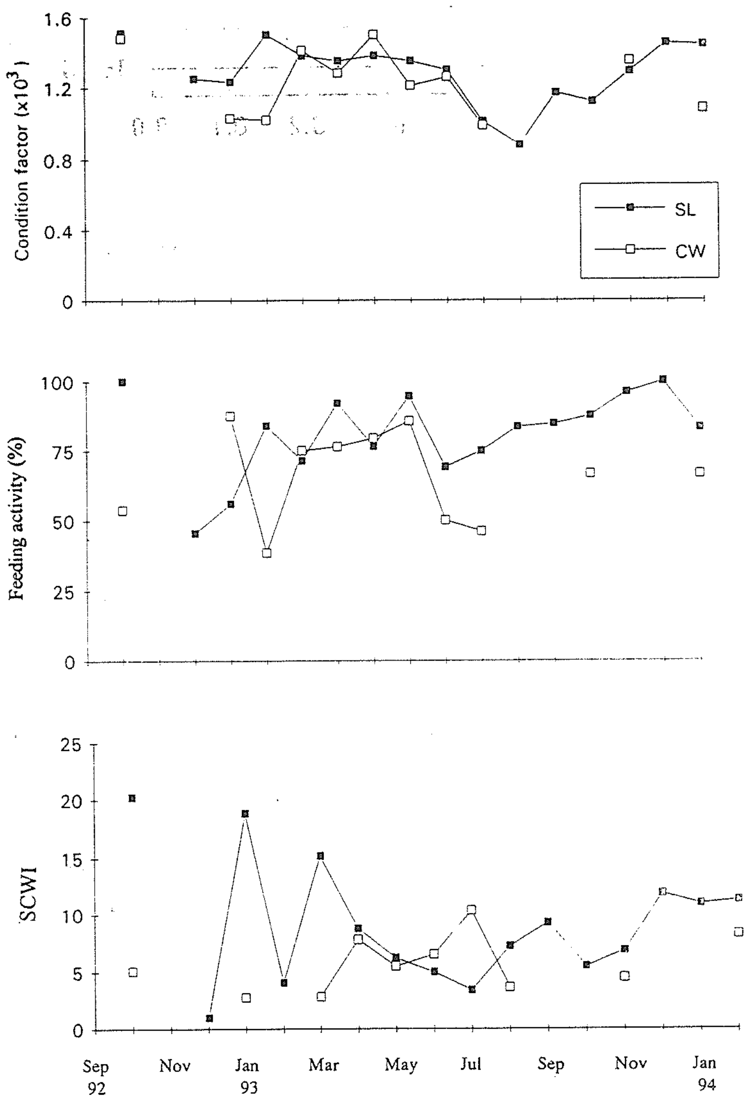

Fig. 9. Seasonal changes in condition factor, feeding activity and stomach content weight index (SCWI) of the eel collected from GST stream at SL and a tributary of Tanshui River at CW.

V. Prey diversity, evenness and dominance

Prey diversity and evenness indices of the eel were higher and dominance index was lower in the downstream (S1) than upstream site (S3), reflecting that the species diversity of the prey community in the environment is more complicated in downstream than upstream. Prey diversity and evenness indices were lower and dominance was higher in spring and summer than autumn and winter for numerical measure. However, it was opposite to the gravemetric measure. This may reflect that the species diversity of the prey in the environment was higher in spring and summer than in autumn and winter. The dietary prey diversity, evenness and dominance reflected the community structure of the organisms in the stream (Table 6).

Table 6. Spatio-temporal variation of prey diversity (*H*), evenness (*B*, *e*) and dominance (*d*) of the eels collected from the 3 stations of GST stream (S1, S2 and S3) during September 1992 through January 1994. *N*% and *W*% are numerical abundance and weight % of the prey

Diversity Index	Data source	Season				Station		
		Spr.	Sum	Aut	Win	S1	S2	S3
H	*N*%	1.65	1.37	2.03	2.00	1.94	1.88	1.48
	W%	2.03	0.30	1.26	1.39	1.81	1.32	1.55
B	*N*%	3.92	2.48	5.35	5.56	5.26	4.90	3.41
	W%	5.65	1.11	2.80	2.73	4.23	2.68	3.94
e	*N*%	0.53	0.44	0.65	0.64	0.62	0.60	0.47
	W%	0.65	0.09	0.40	0.44	0.58	0.42	0.49
d	*N*%	0.26	0.40	0.19	0.18	0.19	0.20	0.29
	W%	0.18	0.90	0.36	0.37	0.24	0.37	0.25

DISCUSSION AND CONCLUSION

The dietary composition of the Japanese eel was quite different from those of other anguillid eels in the other regions of the world. The diet of the Japanese eel in the streams of northern Taiwan was composed mainly of tubifex worm (Oligochaeta), Hirudinea, Crustaceans (*Eriocheir japonicus, Macrobrachium* spp.), aquatic insects (Ephemeropterans, Chironomids, Odonats), plant fragment and seed (Tables 4 and 5). In France, *Anguilla anguilla* fed mainly on Ephemeroptera, Gammaridae, Diptera and Tricoptera, which changed with season (Neveu, 1981; Lecomte-Finiger 1983). In southern Spain, *A. anguilla* fed on Annelid, Mollusca, Crustaceans, insects and fish (Arias and Drake, 1985; Lara, 1994). In Ireland, *A. anguilla* fed mainly on crayfish, nereid worms and plaice in the estuary (Moriarty, 1987). The European eel fed almost on zoobenthos (Burnett, 1952; Opuszynski and Leszczynski, 1967; Tesch, 1977; Ryan, 1984; Sloane, 1984). However, we found that plant fragments and seeds constituted a great proportion in the diets of the Japanese eel (Figs. 5 and 6). Accordingly, not only the benthic invertebrates, but also the falling leaves and seed of plants along the stream banks contributed to the nutrition resources of the Japanese eel (Table 2). Apparently, the eel was omnivorous and opportunistic feeder, eating not only aquatic invertebrates but also vegetables available in the habitats.

The diet composition of Japanese eels changed with fish size (Fig. 8). This phenomenon was also found in the European eel (Frost, 1946; Sinha and Jones, 1967; Ezzat and El-Seraffy, 1977; Mann and Blackburn, 1991; Barak and Mason, 1992).The European eel less than 40 cm in the southern England ate mainly on Ephemeroptera, Tricoptera, Chironomidae and Simuliidae larvae, Gammaridae and *Asellus* sp., while larger than 40 cm ate mostly on Diptera larvae, Gammaridae, *Asellus* sp. crayfish and fish. Piscivory was prevalent among the larger eels. For the American eel, aquatic invertebrates (including Ephemeroptera, Odonata, Plecoptera, Tricoptera, Lepidoptera larvae, Gastropoda, Oligochaeta, Amphipoda, Isopoda and Mysidacea) were dominant in the diets of small eel, but fish and crayfish were dominant in large eel (Loockabaugh and Angermeier, 1992). Jellyman (1989) indicated that 40 cm *A. australis* and 70 cm *A. dieffenbachii* tended to be piscivorous. This indicated that the feeding habit of the eel changed with growth.

Many studies indicated that the European and American eels in the temperate area stopped feeding in winter when temperature was lower than 8°C (Lecomte-Finiger, 1983; Kangur, 1989; Clarke et al., 1993). On the contrary, feeding activity of the Japanese eel in the tropical Taiwan was higher in winter but lower in summer as indicated from the seasonal changes in the feeding activity, SCWI and condition factor (Fig. 9). The reasons were probably due to the abundance of prey organism in the streams of Taiwan was small (Fig. 2) and water temperature was too high in the summer (Table 1).

The plant fragement and seed were predominate in the stomach content of the Japanese eel, irrespective of *N%*, *W%* or *F%* (Figs. 5 and 6). This indicated that the terrestrial vegetation on the stream banks contributed greatly to the feeding environment of the eel. Recently, the banks along the downstream of the GST stream have been transformed into the housing area of the Tanshui new city, and thus the terrestrial plants along the stream banks which supplied the primary food sources for the eel and the detritus for tubifex and other prey organisms have been clean up. These changes will affect the eel population in the stream.

It is conduded that the prey items of the Japanese eel were highly diverse including plant materials differed from those reported for other *Anguilla* spp. The Japanese eel was an opportunistic omnivore. The prey composition in their stomach contents reflected the ambient biotic environmental conditions.

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台灣北部溪流產日本鰻的攝食習性

曾萬年[1]．蕭瑞仁[1]．沈慧萍[1]．陳楊宗[1]．王友慈[1]．吳晶瑩[+]

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為了瞭解日本鰻的攝食生態，1992 年 9 月起至 1994 年 1 月止，按月於台灣北部河川下游地帶，以電魚方式採集魚類標本。同時，監測物理化學環境因子、魚類相、水棲昆蟲及植被等。鰻魚的體長從 6 公分至 7 6 公分不等，其中以 1 、 2 歲為主。鰻魚的主要食物種類包括顫蚓（貧毛綱）、水蛭、水棲昆蟲（蜉蝣目、雙翅目）及植物的碎屑和種子。食物種類組成隨著鰻魚體長而改變。鰻魚屬於逢機雜食性魚類，攝食棲地中易獲得的無脊椎動物及植物。可能是夏季的環境惡劣，鰻魚在該季節時攝食活動性低，這點在魚類的肥滿度上很明顯地表現出來。文中，並探討攝食活動與餌料生物豐富度、環境條件等之關係。

關鍵詞：日本鰻，食性，餌料生物種類，溪流，台灣。

[1] 國立台灣大學動物學系，台北，台灣 106 。