Ecological Studies on River Fishes in Central Thailand with a View to the Future

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Abstract: This report presents in abbreviated format some of the results of our ecological studies on river fishes in Thong Pha Phum and, in some cases, elsewhere in central Thailand. Important habitat or environmental characteristics were identified for fishes found in Thong Pha Phum and elsewhere in central Thailand along with species distribution and population estimates, the latter by the depletion method. Species richness and numerical abundance were dominated by cyprinids followed by silurids and balitorids. Important habitat factors for some other individual species of distributional or numberical importance are also discussed. The results of these studies are described more fully in Beamish et al., (2006; 2008), Beamish and Sa-ardrit (2006; 2007).

Key words: abundance, limnology, habitat, species richness, species associations, assemblage structure

Introduction

It is a common view that freshwater fish live not in random groupings but in structured communities held together by favorable abiotic and biotic mechanisms. In some cases a small number of environmental variables seem to exercise a strong influence on community structure while in others it is related to a wider range of factors (Robinson & Tonn, 1989; Edds, 1993).

The species rich and ecologically diverse Cyprinidae, the largest family of all freshwater fishes with more than 1500 species have evolved partially through highly adapted body forms and mouth structures so that they occupy virtually all habitats throughout their distribution (Howes, 1991). Indeed, in Thailand, they contribute the majority of the species in a waterbody (Smith, 1945). Catfishes, representing a number of families in the order Siluriformes are also well represented in Thailand (Vidthayanon *et al*., 1997). Fishes of the family Balitoridae, commonly called river, torrent or hillside loaches are native to Eurasia with their greatest diversity in Asia (Nelson, 1994). While there is almost no information on the ecology of balitorids (Dundgeon, 2000), they are commonly associated with life in fast flowing water for which they are well adapted. Additionally there are other fishes from species- impoverished families that contribute to community structures in Thai rivers such as snakeheads or Channidae, half beaks or Hemiramphidae and spiny eels or Mastacembelidae and about which relatively little is known of their habitat preferences.

The objective of this study was to provide quantitative measurements of fish abundance in small rivers and to identify the important habitat factors for species within families or orders. This information is important not only to understanding their environmental ecology but, where populations or species are declining, in assisting with conservation measures.

Methodology

Small rivers were sampled in central Thailand between latitudes of approximately 11° and 15° N and longitudes of approximately 97° 30' and 102° 60' E, representing an area of approximately 23,000 km². Fish were sampled from up to 159 sites at 84 stations on small rivers, ≤25 m in width (Figure 1; Table I). Sample stations were selected from locations ranging from heavily forested and sparsely inhabited to lightly settled areas where some subsistence to modest commercial agriculture occurred to more heavily farmed or urban areas. Stations were sampled throughout the year except when high discharges restricted visibility and personal safety. Prior to electro-fishing, conductivity was measured and used to set the voltage and electrical wave configuration to maximize fish capture efficiency and minimize harm to fish. Then, seine nets of about 3mm mesh were installed across the upper and lower limits of the site and their groundlines weighted with large rocks to reduce the probability of emigration from or immigration into the sampling reach.

A station was electro-fished by moving systematically from one retaining net to the other, beginning downstream or upstream based on visibility, water depth, velocity and turbidity. Usually four or five passes were made at a site. Relative capture efficiency between electrofishing in either an upstream or downstream direction was compared within several larger stations and not found to differ significantly (ANCOVA, $p<0.05$). Rates at which the logarithm of captured fish declined with number of passes did not change significantly among sites at each station. This implies also that the direction of electro-fishing did not affect the rate of capture. After each pass, fish were anaesthetized in a dilute solution of methaine tricaine sulfonate, then identified and enumerated. After fish recovered from the anesthetic, they were released upstream or downstream from the retaining nets. When unable to assign species status in the field a small sample of the unidentified species was killed by an overdose of anesthetic and preserved in 10% formalin for subsequent identification in the laboratory.

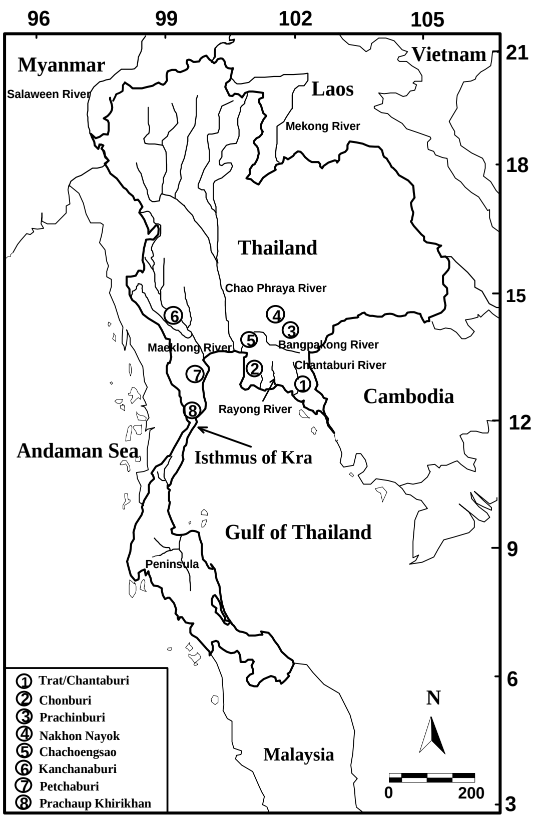

Figure 1. Rivers and provinces where samples where collected.

On each sampling occasion, width (± 0.1 m), depth (± 1 cm), and velocity (± 1 cm s^{-1}) of the stream reach were measured, each at least three times, and the means used to estimate discharge ($l \cdot s^{-1}$). Velocity was measured at the surface and adjusted to represent the vertical mean flow rate at each of three equally spaced locations across a station's width. Regularly calibrated meters were used to measure temperature (±0.1°C), conductivity (±5 $\mu S \cdot cm^{-1}$), turbidity (NTU), pH (± 0.1) and dissolved oxygen (± 0.1 $mg \cdot l^{-1}$). In addition, a water sample was collected for measures of ammonia, total iron, alkalinity and silica (APHA, 1992). Elevation was measured by GPS.

Substrate at each station was collected with a hand-held acrylic corer (5 cm inner diameter) to a depth of 10±3 cm. Particles on the substrate surface larger than the diameter of the corer were removed before a sample was taken and included in the analysis. Samples were air dried and sieved to determine particle size distribution by weight. Six size categories were adopted from the Wentworth scale, > 150 mm (boulder to large cobble), 150-60.1 mm (large cobble to large pebble), 60-5.1 mm (large pebble to coarse gravel), 5- 3.1 mm (medium to fine gravel), 3- 0.51 mm (fine gravel to coarse sand), <0.5 mm (medium sand to silt) and the mean particle size calculated. The substrate for each station was coded into six categories based on mean particle size with 1 being the smallest and 6, the largest. The substrate at a few stations was solid or almost solid bedrock and coded as 7. An average of three replicate substrate samples (range of 2-6) was collected at 40 stations. Variation was similar within each particle size category with an overall mean (±SD) of 26±12 %. One sample was collected at all other stations.

Linear and multiple linear regression analysis (MLR, SPSS11.5) were applied to examine the relationships between species numbers, abundance and each of the significant habitat variables. Canonical correspondence analysis (CCA, PC-ORD3.20) was employed to identify the importance of environmental characteristics to species within each of the groups studied (i.e. Cyprinidae, Siluriformes, Balitoridae, Others). In the canonical correspondence analysis, statistical significance of the relationship between a set of environmental factors and fish species was

Table I. Names of rivers sampled and location by province along with names of rivers and reservoirs downstream in the drainage. Water from all stations (n= 84) discharged directly or indirectly to the Gulf of Thailand except for two, identified by asterisks, that discharged to the South China Sea. When discharge was direct no other rivers are identified. When indirect, the final river downstream is identified. Number of stations sampled is given in parentheses. Eastern watershed includes Trat and Chantaburi, Chao Phraya includesChonburi, Prachinburi,Chachoengsao and Nakon Nayok; Peninsula includes Prachuap Khirikhan and Petchaburi; Maeklong includes Kanchanaburi Province (Vidthayanon et al. (1997)).

Province	Primary River	Rivers/Reservoirs Downstream
Trat	Khao Mapring (1)	
Trat	Nam Tok Khlong Kaeo (1)	
Trat/Chantaburi	Khlong Sato (2)	
Chantaburi	Khlong Pong Nam Ron (1)*	Mekong
Chantaburi	Khlong Klang (1)*	Mekong
Chonburi	Kongshi (1)	
Chonburi	Ban Than Trang (1)	
Chonburi	Chan Ta Than (1)	
Chonburi	Phan Sadet (1)	Rayong
Chonburi	unknown (1)	Rayong
Chonburi	Surasak (3)	Rayong
Chonburi	unknown (1)	
Chonburi	Khao Ha Yot (1)	Chantaburi
Chonburi	Paknam (1)	Chantaburi
Chonburi	unknown (1)	Bangpakong
Prachinburi	Prachangakham (1)	Bangpakong
Chachoengsao	unknown (1)	Bangpakong
Nakon Nayok	Nangrong (1)	Bangpakong
Prachuap Khirikhan	unknown (1)	
Prachuap Khirikhan	Klong Yang Khwang (1)	
Prachuap Khirikhan	Shikoo (1)	
Prachuap Khirikhan	Ban Hin Pit (1)	
Prachuap Khirikhan	Ban Chai Thale (1)	
Prachuap Khirikhan	unknown (1)	
Prachuap Khirikhan	Khlong Kariam (1)	
Petchaburi	Petchburi (1)	
Petchaburi	Pranburi (4)	
Kanchanaburi	Pat Kok (2)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Khayeng (16)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Pracham Mai (7)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Ban Rai (6)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Kapok (5)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Kratenjeng (2)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Lichia (3)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	unknown (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Kreng Kavia (1)	Kwae Noi, Maeklong
Kanchanaburi	Thi Khrong (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Satamid (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Pilok (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	E-pu (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Tawat (3)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Tuam (1)	Khao Laem, Kwae Noi, Maeklong
Kanchanaburi	Bang Ka Loo (1)	Khao Laem, Kwae Noi, Maeklong

taken using a Monte Carlo permutation test with 1000 permutations. Statistical significance of all tests was accepted at $P<0.05$.

Total abundance of fish within a station was calculated by the maximum likelihood technique (Carle & Strub, 1978). Numbers for many species were small and not amenable to this technique. Hence a conversion factor consisting of the total abundance estimate divided by total number of fish caught was applied to adjust the numbers of each species captured. Fish abundance was arithmetically adjusted to an area of 100 m^2.

Results

Water quality varied greatly among sites within and among river systems. At sites within Maeklong watershed, water was on average a few degrees cooler and higher in pH and alkalinity than in the other river systems (Table 2). Water at the Chao Phraya watershed sites was on average highest in ammonia, nitrate, total iron, color and turbidity. Physical habitat characteristics such as water depth and velocity, substrate composition and canopy while diverse within watersheds, were broadly similar among watersheds (Table 2). Substrate composition varied from sand to bedrock among sites but gravel was the average particle size within each watershed. Canopy ranged from full cover to total exposure but was mostly in the range of 15-30% cover. The two exceptions in similarity of physical characteristics among watersheds were river width and discharge that were, on average, least in the Chao Phraya watershed. Elevation was mostly between 100 and 300 m, with an overall mean of 180±2 m (n=119). Four sites had elevations above 700 m.

Abundance and habitat characteristics of Cyprinidae

Cyprinids dominated the fish populations at most of the sites, both in terms of species numbers and numerical abundance. Cyprinids were absent at only two of the 159 sites (84 stations) across all river systems with a maximum of 10 and 11 species occurring at each of seven and one site, respectively. Cyprinid richness varied among river systems from 11 to 32 species, with the largest number being found in Maeklong where the number of sample sites was also highest.

Species richness was influenced by several habitat characteristics across all watersheds and is described by the equation:

$$\log(S+1) = -0.180 - 0.141\log(W+1) + 0.813\log(O+1) + 0.139\log(A+1)$$

where S is number of cyprinid species·100m^{-2}, W, site width, m, O, dissolved oxygen, mg•l^{-1}, and A, alkalinity, mg•l^{-1}. Species richness at each site was adjusted to an area of 100 m^2 from the overall geometric mean of 97 m^2 (n=159) using a calculated slope of 0.168 and log (x+1) transformation of both variables. Habitat characteristics retained in the equation had significant t-values at $p<0.05$. The regression's F-value is 11.91 (3, 155 df, $p<0.05$) and correlation coefficient, 0.433 ($p<0.05$). The equation predicts species richness to vary inversely with habitat width. Species richness increased also with alkalinity and dissolved oxygen. Elevation was not included in the regression analysis, however, at the four highest sites, with elevations of approximately 700 to 850 m, cyprinid richness ranged only from 0 to 2 species.

Frequency of occurrence was high only for a few cyprinids in each of the river systems and only three species were captured in all systems, *Danio albolineatus, Rasbora paviana*, and *Puntius binotatus* (Table 3). Indeed, across all sites as well as within river systems, cyprinids accounted for almost 57% of all fish captured with a geometric mean (±SD) of 55±6 fish•100 m^{-2} for all sites. Numerical abundance of cyprinids was highest with a geometric mean of 71±3 fish 100 m^{-2} in Chao Phraya and lowest in Peninsula and Maeklong at 41±4 and 49±8 fish•100 m^{-2}, respectively. Only a few species were particularly abundant in each river system. In Chao Phraya, the three species that had high occurrences, *D. albolineatus*, *R. paviana* and *P. binotatus* were also abundant along with *Mystacoleucus marginatus*, which was, however, captured at fewer sites. Of the species captured most frequently in Maeklong, *Devario acrostomus* was most abundant. In Eastern rivers system, *Poropuntius deauratus, D. albolineatus* and N*eolissochilus stracheyi* were abundant when present but only *P. deauratus* was common to all sites. In Peninsular system, the most abundant species when present were *Puntius orphoides, P. binotatus* and *N. stracheyi* with only *P. binotatus* being present at most sites.

The only statistically significant habitat characteristics to cyprinid abundance were velocity and discharge, a relationship described by the equation:

Table 2. Chemical and physical characteristics as geometric means±SD and ranges for the sites in the river systems. Substrate particle sizes (asterisk) are for the coded values described in the text.

		Eastern			**Chao Phraya**	
	mean	SD	range	mean	SD	range
Elevation, m	133	1	112-156	90	2	92-112
Width, m	4.6	1.7	2.0- 10.0	3.2	0.6	1- 25.5
Depth, cm	29	2	17- 52	21	2	<5- 83
Velocity, cm s^{-1}	33	1	24- 60	20	2	0- 2777
Discharge, l s^{-1}	443	2	291- 1264	95	5	0- 2777
Canopy, %	18	4	0- 70	28	2	0- 100
Substrate*	3.3	1.7	0- 7	3.7	0.4	0- 7
Temperature, C	28.1	1.1	26.6- 32.6	27	0.1	22.3- 31.4
Conductivity, µScm^{-1}	52	1	39- 74	122	1	34- 671
Turbidity, NTU	3	2	1-6	13	2	1- 439
Color, CU	16	4	0- 53	78	1	12- 550
pH	7.3	0.6	6.8- 8.5	6.8	0.1	5.8- 7.9
Oxygen, mg l^{-1}	7.5	1.1	7.1- 8.5	6.4	0.2	2.3- 11.5
Ammonia, mg l^{-1}	0.01	<0.01	0- 0.02	0.08	0.13	0- 0.67
Nitrate, mg l^{-1}	1.6	0.6	0.2- 3.8	3.1	1.1	0- 33
Total iron, mg l^{-1}	0.4	0.2	0.04- 0.87	0.8	0.4	0.18- 5.70
Silica, mg l^{-1}	26.9	0.3	16.2- 36.2	21.0	1.0	<6- 40.0
Alkalinity, mg l^{-1}	32	1.0	22- 58	40	1	12- 380
		Peninsular			**Maeklong**	
Elevation, m				228	1	157-853
Width, m	5.5	0.8	1.7- 25	5.0	0.7	0.7- 18.7
Depth, cm	26	0.4	13- 38	23	1	<4- 74
Velocity, cm s^{-1}	36	1	15- 67	27	2	0-88
Discharge, l s^{-1}	500	2	81- 1165	260	3	<10- 5491
Canopy, %	16	3	0- 80	30	2	0- 95
Substrate*	3.9	0.8	0- 7	4.1	0.5	0- 7
Temperature, C	27.2	0.1	24.2- 30.3	24.3	0.1	17.3- 28.8
Conductivity, µS cm^{-1}	159	4	32- 6500	117	2	10- 1467
Turbidity, NTU	7	1	0- 24	6	2	0- 800
Color, CU	52	1	27- 104	13	3	0- 550
pH	6.9	0.1	6.1- 7.4	7.5	0.1	4.2- 8.7
Oxygen, mg l^{-1}	6.2	0.2	5.4- 8.2	7.3	0.2	4.5- 9.5
Ammonia, mg l^{-1}	0.03	0.05	0.01- 0.19	0.02	0.05	0- 1.00
Nitrate, mg l^{-1}	1.8	0.3	1.1- 4.7	1.1	0.9	0- 17.0
Total iron, mg l^{-1}	0.48	0.25	0.12- 1.44	0.28	0.30	0- 5.10
Silica, mg l^{-1}	17.8	0.3	13.8- 30.0	16.7	0.5	6.5- 41.6
Alkalinity, mg l^{-1}	51	2	15-137	74	2	5- 576

$$\log (N+1) = 2.168 + 0.510 \log (V+1) - 0.469 \log (D+1)$$

where N is abundance of cyprinids•100 m^2, V, water velocity, cm •s^{-1} and D, discharge, l•s^{-1}. The regression's F-value is 14.57 (3, 155 df, $p<0.05$) and the correlation coefficient, 0.40, significant at $p<0.05$. Thus, for a given discharge, cyprinid abundance increased with velocity and for a given velocity, abundance varied inversely with discharge.

In preparation for ordination analysis two sites were deleted due to the absence of cyprinids. All species were included in the analysis. The potential for useful information on habitat characteristics for rare or uncommon species was felt to be of greater ecological value than the negative impact of their limited occurrence on the analysis. Species and their abundance were significantly correlated with five habitat characteristics (p=0.012, 0.001 and 0.001 for axes 1, 2 and 3, Monte Carlo test with 1000 permutations). The first and second axes of the CCA were both significant explaining 55 and 48% of the variability, respectively, with

Table 3. Geometric mean abundance·100 m^2 ±SD, calculated on the basis of values at sites where species were present. Frequency of occurrence, %, is given in parentheses for each river system. Number of sites from the Eastern, Chao Phraya, Peninsula and Maeklong systems was 7, 50, 11 and 91, respectively. The identification number assigned each species is given in parentheses beside species name.

	Eastern	Chao Phraya	Peninsular	Maeklong
Amblyrhynchichthys truncatus (17)				1.1 (1)
Barbodes gonionotus (22)		1.3±1.2 (4)		1.1±1.3 (1)
Danio albolineatus (7)	100 (14)	16.4±7.2 (52)	3.5±4.0 (36)	23.9±3.9 (10)
Crossocheilus reticulates (36)	5.3±1.3 (29)			101 (1)
Cyclocheilichthys apogon (18)		2.6 (2)	5.3±2.4 (18)	2.3±4.5 (25)
Cyclocheilichthys armatus (19)		2±2.6 (6)		2.7±2.2 (8)
Cyclocheilichthys heteronema (20)		1.8 (2)		
Devario acrostomus (8)			4.3±8.1 (45)	20.3±6.5 (63)
Esomus metallicus (9)		8.5±3 (8)	1.4 (9)	
Garra cambodgiensis (37)	7.9±1.4 (29)	0.2 (2)		
Garra fuliginosa (38)	0.7 (14)			4.5±2.4 (22)
Garra sp.(39)				7.0±4.0 (21)
Poropuntius hampaloides (24)	1.3±2.4 (29)	1.7±5.2 (8)		2.1±2.4 (14)
Labiobarbus siamensis (31)				0.3 (1)
Labiobarbus leptocheilus (32)				2.5±9.3 (3)
Lobocheilus quadrilineatus (33)				0.4 (1)
Lobocheilus rhabdoura (123)				0.4 (1)
Mystacoleucus marginatus (21)	0.7 (14)	19.8±6.8 (32)		10.9±6.3 (56)
Neolissochilus blanci (15)		5.2±6.2 (10)		
Neolissochilus stracheyi (16)	16.3±10 (57)		15.5±1.4 (27)	4.6±4.6 (23)
Neolissochilus soroides (119)				15.7±2.6 (3)
Onychostoma gerlachi (114)			0.6 (9)	
Opsarius koratensis (4)				4.6±9.2 (11)
Barilius pulchellus (5)				5.1 (1)
Osteochilus hasselti (34)		4.0±1.0 (14)_	7.9±2.8 (27)	8.3±5.2 (51)
Osteochilus lini (35)		2.9±1.2 (14)		
Osteochilus waandersii (122)				3.7±5.4 (3)
Parachela maculicauda (6)		0.4 (2)		
Paralaubuca riveroi (3)				0.4 (1)
Poropuntius deauratus (23)	24.4±3.1(100)	10.9±6.2 (6)		8.8±2.0 (4)
Puntius brevis (25)				2.3±3.2 (7)
Puntius masyai (26)				1.6±2.2 (2)
Rasbora borapetensis (10)	42 (14)	1.2±5.9 (10)		3.2±2.3 (2)
Rasbora caudimaculata (11)				7.2±4.3 (57)
Rasbora myersi (12)		0.6 (2)		
Rasbora paviana (13)	9.1±4.6 (43)	16.6±4.1 (74)	12.4±5.4 (82)	4.3±1.5 (3)
Rasbora trilineata (14)		5.2 (2)	1.6 (9)	
Puntiuss binotatus (27)	7.3±6.6 (57)	16.1±3.5 (84)	16.5±4.8 (72)	8.0±4.0 (63)
Puntius lateristriga (28)			1 (9)	
Puntius orphoides (29)		4.2±2.8 (26)	22 (9)	6.1±4.9 (14)
Puntius partipentozona (30)		1.6±1.7 (14)		
Danio stolitezkae (117)				3.6±3.8 (12)
Systomus sp.(121)				0.6 (1)

the third axis explaining 38%. Undoubtedly the variability explained by each axis would have been higher had it not been for the large number of species absent from many of the sites. Each axis explains a statistically significant proportion of the species-environment relationship. The first axis illustrates a positive gradient of habitat width (r^2 = 0.26), discharge

(r^2= 0.34), dissolved oxygen (r^2= 0.23) and alkalinity (r^2= 0.23). Temperature (r^2= 0.57) loaded positively on the second axis. Habitat correlations were 0.88, 0.84 and 0.74 for axis 1, 2 and 3, respectively. The other habitat variables did not correlate significantly with cyprinid species and their abundance and were not included in the CCA analysis. Each of the five significant habitat characteristics increases along a vector in Figure 2 away from the origin with its length being a measure of the rate of change.

Cyprinids reacted to a wide range of the significant habitat characteristics. Most of the common species favored only modestly higher than the overall averages for habitat width (4.2±2.0 m), discharge (199±5 $l \cdot s^{-1}$), alkalinity (57±3 $mg \cdot l^{-1}$) and dissolved oxygen (6.9±1.2 $mg \cdot l^{-1}$). While there were differences in the position of the common species with respect to the significant habitat characteristics, they tended to be comparatively small. Only a few of the common species were found at the comparative extremes of one or more habitat characteristics. Thus, *D. albolineatus* was found at sites of narrow width, low discharge, alkalinity and oxygen but moderate temperature. In contrast, *D. acrostomus* were captured in water of low temperature while *Opsarius koratensis* were found where temperature was high. Among the species captured at fewer than 10 sites, extremes in low and high temperature were demonstrated by *Esomus metallicus* and *Neolissochilus blanci* and *Lobocheilus rhaboura, Paralaubuca riveroi* and *Systomus lateristriga,* repectively, although the latter three were captured at only a single site. Wider rivers and high discharge, alkalinity and dissolved oxygen characterized the sites where *Amblyrhynchichthys truncatus, Labiobarbus leptocheilus, Labiobarbus siamensis* and *Puntius brevis* were found, although, again site number was low.

Abundance and habitat characteristics of Siluriformes

Silurids represented 10.3±9.4 % of the fish species across all sites and were present in 67% of the 159 sites in all four river systems with a maximum of five species occurring at four sites. Silurid species richness varied among systems from 4 to 13 species with the largest number being found in Maeklong (Thong Pha Phum). The fewest species, four, were captured in Eastern and Peninsula systems.

Species richness was influenced by several habitat characteristics across all river systems and is described by the equation:

$$\log (S+1) = -1.195-0.233 \log (T +1)+0.841 \log (O+1) + 0.778 \log (I +1) + 0.115 P$$

where S is richness of silurid species$\cdot 100m^{-2}$, T,

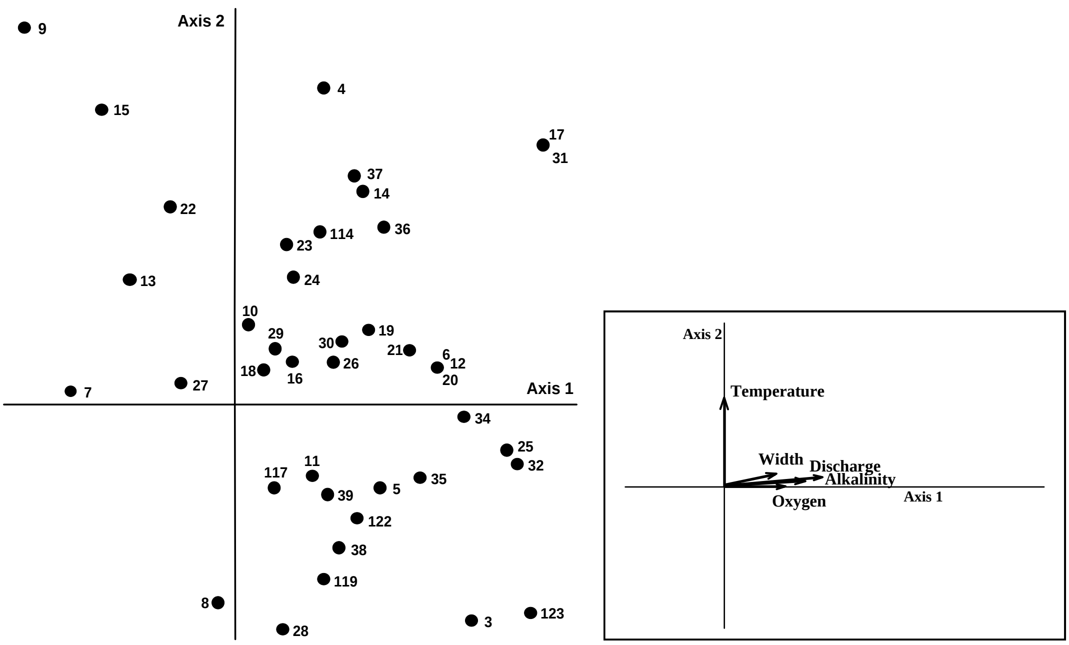

Figure 2. Distribution of cyprinid species with respect to significant habitat variables identified by canonical correspondence analysis for axis 1 and 2. Numbers represent species identified fully in Table 5.

Table 4. Abundance of silurids by species and river system based on all sampled sites. Means (SD) were calculated on log (x+1) transformed values. Numbers in parentheses identify species in Figure 3.

	Eastern	Chao Phraya	Peninsular	Maeklong
Pseudomystus siamensis (64)	1.4±2.2	2.6±1.7		0.2±2.2
Mystus gulio (65)				<0.1±1.1
Mystus havmolleri (66)				0.8±2.3
Mystus microcanthus (67)			0.1±1.2	<0.1±1.1
Mystus mysticetus (68)		0.1±1.8		
Mystus singaringan (118)				<0.1±1.1
Hemibagrus nemurus (69)	0.5±1.8	0.2±1.6		0.2±1.6
Ompok bimaculatus (70)		0.3±1.8		0.1±1.3
Pterocryptis cochinchinensis (71)		<0.1±1.1		0.1±1.4
Amblyceps maccronatum (72)		0.1±1.6		0.7±1.4
Amblyceps foratum (73)	2.2±2.3	0.4±1.8	0.3±1.7	
Glyptothorax laoensis (75)	0.4±2.5			<0.1±1.1
Glyptothorax platypgonoides (76)	6.4±4.0			<0.1±1.1
Glyptothorax species (120)				0.1±1.3
Clarias batrachus (77)		0.1±1.4	0.1±1.3	<0.1±1.0
Sillago maculate (124)			0.1±1.3	

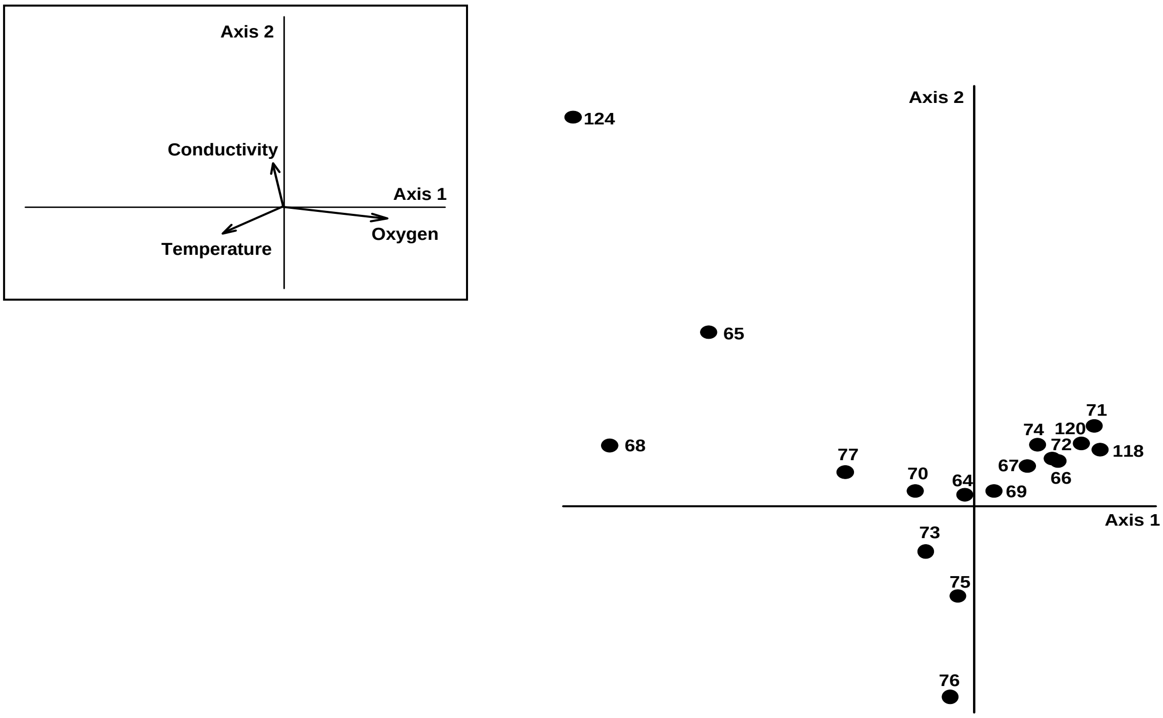

Figure 3. Distribution of siluridid species with respect to significant habitat variables Numbers represent species identified fully in Table 4.

turbidity, NTU, O, dissolved oxygen, mg·l^{-1}, I, total iron, mg·l^{-1}, and P, pH. Habitat characteristics retained in the equation had significant t-values at $p<0.05$. The regression's F-value is 10.94 (4, 154 df, $p<0.05$) and correlation coefficient, 0.47 ($p<0.05$). The equation predicts species richness to increase directly with ambient oxygen, iron and pH and inversely with turbidity. The highest elevation at which silurids were captured was 450 m with *Amblyceps mucronatum* and Glyptothorax sp. being present at the single site.

Numerical abundance of silurids was not high relative to the total numbers of fish captured. The GM for all species was 2.5±3.1 fish·100 m^{-2} across all 159 sites, representing only approximately 2 % of the total mean abundance for all fish (127±2.7 fish·100m^{-2}). Abundance was highest in Eastern at 10.9 fish·100 m^{-2} with means in the other river systems ranging from 0.6 to 3.8 fish·100m^{-2}. *G. platypgonoides* at 6.4 ± 4.0 fish/100m² was the most abundant species in the Eastern rivers system. In Peninsula and Maeklong all species except *P. siamensis* at 2.6±1.7 fish·100m^{-2} were represented by less than a single fish·100m^{-2}. In Chao Phraya, only *P. siamensis* exceded one fish·100m^{-2}.

The statistically significant habitat characteristics to silurid abundance were velocity, turbidity, oxygen, total iron and pH. This relationship is described by the equation:

$$\log(N+1) = -2.260 + 0.329\log(V+1) - 0.410\log(T+1) + 1.328\log(O+1) + 1.547\log(I+1) + 0.176P$$

where N is abundance of siluridids, 100·m^{-2}, V, water velocity, cm·s^{-1}, T, turbidity, NTU, O, dissolved oxygen, mg·l^{-1}, I, total iron, mg·l^{-1} and P, pH. The regression's F-value is 8.69 (5, 153 df, p<0.05) and the correlation coefficient, 0.47, significant at p<0.05.

In preparation for ordination analysis 52 sites were deleted due to the absence of silurids. All species were included in the analysis. In addition to the importance of velocity, turbidity, oxygen, iron and pH to species richness and abundance, individual species' abundance was significantly correlated with three habitat characteristics, temperature, conductivity and dissolved oxygen (p=0.004, 0.001 and 0.001 for axes 1, 2 and 3, Monte Carlo test with 1000 permutations). The first and second axes of the CCA were both highly significant explaining 80 and 67% of the variability, respectively, with the third axis explaining 38% (Figure 3). The first axis illustrates a positive gradient of dissolved oxygen (r^2 =0.81) and a negative gradient of temperature (r^2=0.19), and conductivity (r^2=0.09). Temperature (r^2= 0.1) and oxygen (r^2=0.17) loaded negatively on the second axis and conductivity, positively (r^2=0.29). Habitat correlations were 0.91, 0.89 and 0.80 for axis 1, 2 and 3, respectively.

Silurids reacted to a broad range of the significant habitat characteristics. Generally, the more abundant and commonly occurring species were comparatively conservative in their habitat preferences. Of the 17 species, 7 were captured at 20 or more sites across all systems. Most of the common species were clustered near the overall averages for habitat where silurids were captured, temperature (24.6±1.4 C), conductivity (121±2 µS·cm^{-1}) and dissolved oxygen (7.3±1.2 mg·l^{-1}). This was particularly the case for *P. siamensis, Hemibagrus nemurus, O. bimaculatus* and *A. foratum*. While there were differences in the position of the common species with respect to the significant habitat characteristics, they tended to be comparatively small. The habitat of both *O. bimaculatus* and *A. foratum* was characterized by slightly higher than average temperatures and lower oxygen. The remaining relatively common species, *Pterocryptis cochinchinensis, A. mucronatum* and *M. havmolleri* are predicted to prefer slightly higher than average oxygen and conductivity concentrations and lower temperatures. *Glyptothorax* sp. is positioned at lower than average temperature and above average oxygen. Two species, *Mystus mysticetus* and *Mystus gulio* occurred in water of low oxygen and high conductivity and temperature.

Abundance and habitat characteristics of Balitoridae

Balitorids were present in 74% of the stations with species numbers ranging to a maximum of seven at a single station and tending to be highest in the mountainous western region of Thong Pha Phum. Species number was related to several habitat characteristics and is described by the equation:

$$\log(S+1) = -1.161 + 0.446\log(E+1) + 0.401\log(S_u+1) + 0.262\log(S_i+1)$$

where S is number of species 100· m^{-2}, E, elevation, m, S_u, substrate coded value and S_i, silica concentration, mg·l^{-1}. Habitat characteristics retained in the equation had significant t-values at P<0.05. The regression's F-value is 19.01 (3, 80 df, P<0.05) and correlation coefficient, 0.65 (P<0.05). The equation predicts species numbers to increase directly with elevation, substrate particle size and ambient silica concentration.

Species number was also positively related to total balitorid abundance:

$$\log(S+1) = 0.109 + 0.326\log(A+1)$$
$$(n = 84, r = 0.82, P < 0.05)$$

where A represents total abundance of balatorids, adjusted to an area of 100 m^2.

Balitorid frequencies of occurrence and numerical abundances were high for only a few species. Highest frequencies were for *Homaloptera smithi, Acanthocobitis. zonalternans* and *Schistura* sp.1. Numerical abundance of all species of balitorids combined was not high with a GM (SD) of 4.9± 3.6 fish·100 m^{-2} representing 3.8 % of the total numbers of fish captured across all stations.

The significant habitat characteristics related to balitorid abundance were, again, elevation, substrate and silica. This relationship is described by the equation:

$$\log (N + 1) = -2.832 – 1.067 \log(E+1) + 0.792 \log (S_u+1) + 0.708 \log (S_i + !)$$

where N is relative abundance of balitorids·100 m^{-2}. Habitat characteristics retained in the equation had significant t-values at $P<0.05$. The regression's F-value is 15.14 (3, 80 df, $P<0.05$) and the correlation coefficient, 0.60, significant at $P<0.05$. Thus, the equation predicts balitorid abundance to increase directly with elevation, substrate particle size and ambient silica concentration.

Table 5. Geometric mean abundance±SD and range for the 84 stations along with the numbers (ID) used in Figure 4 to identify species. Abundance was multiplied in the table by 10 for convenience.

Species	ID	Abundance, 10(N·100m^{-2}) Mean	SD	Range
Acanthocobitis botia	40	1.1	15.3	0 - 10
Acanthocobitis zonalternans	41	8.7	29.4	0 - 178
Balitora sp.	42	2.7	21.6	0 - 243
Homaloptera bilineata	37	0.1	11.1	0 - 15
Homaloptera confuzona	43	0.1	18	0 - 577
Homaloptera smithi	44	12.4	31.5	0 - 803
Homaloptera sp.	39	0.5	15.7	0 - 625
Nemacheilus binotatus	45	0.1	10.8	0 - 10
Nemacheilus masyae	46	1.7	16.2	0 - 23
Nemacheilus platiceps	47	0.3	12.4	0 - 62
Schistura desmotes	48	6.3	28	0 - 575
Schistura kohchangensis	49	0.9	16.5	0 - 462
Schistura vinciguerrae	50	2.6	20.3	0 - 490
Schistura sp.1	51	0.9	3.1	0-46.6
Schistura sp.2		0.02	1.1	0-1.5
Schistura sp.3	53	0.09	1.5	0-16.3
Schistura sp.4		0.06	1.42	0-10.7
Tuberoschistura baenzigeri	54	0.1	1.5	0-10.7

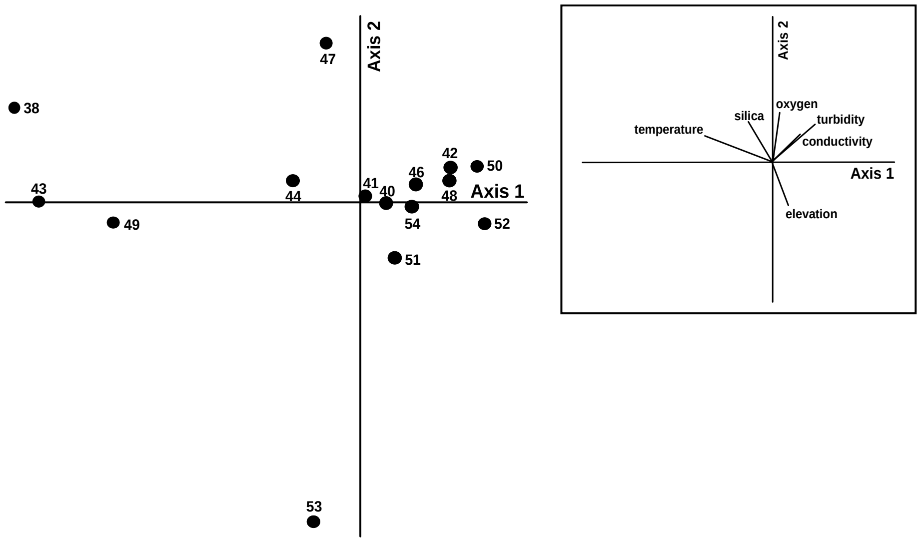

Figure 4. Distribution of Balitoridae species with respect to significant habitat variables identified by canonical correspondence analysis for axis 1 and 2. Numbers represent species identified in Table 5

Species with a high frequency of occurrence, indicating a wide distribution, were also numerically abundant (Table 5). This is expressed as a logarithmic linear regression;

$\log N_s = -0.910 + 1.128 \log O_s$

($n= 18$, $r= 0.91$, $P < 0.05$)

where N_s is relative abundance of a species, number of individuals·100 m^{-2} and O_s is the corresponding frequency of occurrence, %, across all stations

In preparation for ordination analysis 22 stations were deleted from the analysis due to the absence of balitorids along with three species whose frequencies of occurrence were <3%. In addition to the importance of elevation (geometric mean±SD,139±2m) substrate (3.7±1.7) and silica (16.5±1.6 mg·l^{-1}) to balitorid species numbers and total abundance, individual species were significantly correlated with six habitat characteristics, temperature (26.4±1.1 C), oxygen (7.5±0.8 mg·l^{-1}), conductivity (123±3µS·cm^{-1}), turbidity (7±2 NTU), silica and, again, elevation (P=0.035 and 0.006 for axes 1 and 2, Monte Carlo test with 1000 permutations). The first and second axes of the CCA were significant, explaining 49 and 42% of the variability, respectively (Figure 4). Habitat correlations were 0.88 and 0.88 for axis 1 and 2, respectively.

The analysis identified a broad range of responses to the significant habitat characteristics. Generally abundant species such as *Acanthocobitis zonalternans* and *Schistura* sp.1 tended to be associated with average levels of the significant environmental factors. A few species, particularly *Schistura* sp. 4, *Homaloptera confuzona, Schistura vinciguerrae* and *Homaloptera. smithi* were associated with relatively high temperatures. The analysis indicated an association with cooler temperatures for other species, including *Schistura* sp. 2 and *Schistura desmotes* . *Nemacheilus platiceps is* predicted to occur where dissolved oxygen and silica are relatively high in contrast to the low ambient oxygen and silica and high elevation that characterize the habitats of *Schistura* sp. 1 and 3. High oxygen, conductivity, and turbidity characterized important habitat features for *S. vinciguerrae* and *S. desmotes.*

Abundance and habitat characteristics of other species

Frequencies of occurrence varied among the other species captured in appreciable numbers, exclusive of those in the family Cobitidae, and river systems with only three species being present in all watersheds, *Monopterus albus, Macrognathus circumcinctus* and *Channa gachua* (Table 6). Numerical abundance was not high relative to the total numbers of fish captured. Over all sites the geometric mean (GM) for *C. gachua* was highest at 3.6± 3.7 fish·100m^{-2} followed by *species of Gobiidae* and *D. pusillus*.at 1.4± 3.8 and 0.8± 0.3 fish·100 m-^{2}, respectively. Gobiidae consisted mostly of *Glossogobius biocellatus, Glossogobius aureus, Butis butis, Pseudogobius* sp. and *Eugnathogobius oligactis*, howver, often identification was uncertain so species were grouped under family Gobiidae. Abundance in Eastern rivers system was highest for *M. armatus* and *M. circumcinctus* while in Chao Phraya it was for *C. gachua* and *D. pusillus*. In Peninsula and

Table 6. Mean frequencies of occurrence, %, for the other species captured in appreciable numbers at the various sites in the four watersheds, exclusive of the Cobitidae

	River System			
	Eastern	Chao Phraya	Peninsula	Maeklong
Dermogenys pusillus	0	64	45	1
Xenenthodon cancilla	57	12	0	41
Monopterus albus	14	44	14	21
Macrognathus circumcinctus	86	18	18	2
Mastacembelus armatus	86	14	0	53
Parambassis siamensis	0	28	0	4
Pristolepis fasciatus	0	4	0	29
Badis badis	0	0	0	10
Oxyeleotris marmorata	0	4	9	7
Channa gaucha	71	80	64	69
Channa striata	0	22	36	11

Maeklong the most abundant species were *C. gachua* and *D. pusillus* and *C. gachua* and *X. cancilla*, respectively.

Numerical abundance related significantly to specific habitat characteristics in MLR analyses for those eight species with comparatively high frequencies of occurrence. A significant relationship was not found for the more scarcely occurring *Parambassis siamensis, Badis badis, Oxyeleotris marmorata* and *Channa striata.* Among those species for which a significant relationship was found, the number of significant habitat variables varied from two for *M. albus* to five for *D. pusillus*. No variable was common to all species, the most frequent variable, stream width, being significant for five species. Of the variables measured only temperature was not found to be significant for any species. For *C. gachua* the equation predicts abundance to increase with ambient oygen concentration and decrease with width and depth. Gobiidae are expected to be most abundant in water of shallow depth, low cover and high dissolved oxygen. The MLR for *P. fasciatus* predicts abundance to be high at wide river sites in water of low silica and high alkalinity. *M. armatus* also is predicted to be most abundant at wide sites in clear water of high alkalinity and silica but low conductivity. The equation for *M. circumcintus* indicated abundance to be directly associated with sites of low cover with a substrate consisting of small particles and in clear well oxygenated water relatively high in nitrate and iron. *M.albus* is predicted to occur in greatest abundance at narrow sites in water of low pH with *X. cancilla* expected in greatest numbers where discharge is high but velocity low in water of low conductivity and high alkalinity. The MLR equation for *D. pusillus* predicts abundance to vary inversely with width and directly with clarity, color, ammonia and nitrate.

Discussion and Conclusions

In the present study, dissolved oxygen and alkalinity were important to cyprinid species richness, the former almost certainly reflecting the imposition of physiological constraints on metabolism and, the latter, its positive influence on plant productivity and, regulation of acid-base homeostasis in animals. Temperature has long been recognized to limit the range of species directly and indirectly. In central Thai rivers, water temperatures fluctuate little compared to changes in temperate regions. Nevertheless, it was a significant factor to species distribution in this study, although not to diversity or abundance.The majority of cyprinid species were clustered not far from the overall mean of 25.5±1ºC.

Some silurids are regarded as habitat generalists and exhibit great plasticity sometimes occurring in turbid standing water while at other times they appear to do equally well in the riffles of clear to heavily turbid streams and rivers. Other species have been associated with more specific habitat characteristics. Generally the catfishes in this study exhibited greatest species richness and abundance in clear, flowing water, high in dissolved oxygen, iron and pH. Additional characteristics such as a hard substrate of cobble or boulders not found to be significant in the present study have been identified as important in other studies (Tan and Ng, 2000). However, substrate composition is clearly correlated with water velocity and that was found to be significant in the present study.

Many, if not most silurids are nocturnally active and thought to rely more on the sensory function of cells located in their barbels than eyesight in locating food. However, silurid occurrence in water low in turbidity and high in both dissolved oxygen and total iron may not relate directly to their environmental preferences but to those of organisms high in their dietary agenda, algae and benthic invertebrates.

The diet of many silurids including species of Mystus, Glyptothorax and Amblyceps, includes a high proportion of plant material and insects (Rainboth, 1996) so that their occurrence at sites with average to above average dissolved oxygen and conductivity, with temperatures slightly below average may relate as much to the environmental preferences of their hosts as there own.

Habitat and abundance of Balitorids

The river loaches in this study exhibited greatest species diversity and abundance at high elevations where the substrate consisted mostly of large pebbles and the water was high in silica identifying these as important niche characteristics. No species was found at low flow locations. Curiously, in the present study, water velocity was not specifically identified as a significant variable on either of the first two CCA axes. On the third axis, velocity had the highest r^2 (0.28) of all variables, although the axis itself was not quite significant.

Individual species have been shown to vary in their substrate particle size associations or with logs and living and dead plants (Alfred, 1969). In the present study, plants did not occur at any of the stations where balitorids were captured and logs were uncommon, presumably a function of water speed. The general body shape of balitorids is consistent with their general habitat.

River loaches in this study differed among species in their responses to the significant environmental factors. Widely distributed and generally abundant species such as *A. zonalternans* and *Schistura* sp.1 tended to occur where the measured environmental factors approximated regional mean levels. In contrast, uncommon species tended to occur at relative extremes of one or more of these factors. Attribution of environmental preference without the benefit of physiological and behavioral support is difficult and is further complicated by limnological autocorrelations. Thus, high elevation streams tend to be close to their source where both ambient oxygen and temperature are likely to be low.

Ecological co-existance of balitorids within assemblages is undoubtedly complex. Studies on resource use in fishes have concluded that it is along the food resource axis that the greatest species segregation occurs. Partitioning of the food resource base by co-existing Thai river fishes, including *S. desmotes*, has been related partially to morphological features that enable a species to utilize resources less available to others thereby accommodating species diversity (Ward-Campbell et al., 2005).

Habitat and abundance of other species

The phylogenetically diverse species in this study displayed a wide range in abundance and habitat associations. For example, *M circumcinctus* was captured in all river systems although seldom abundant and was closely associated with soft substrates in keeping with Roberts' observation that at least some of the species of *Mastacembelus* are burrowers. The other mastacembelid in this study, *M. armatus* was more widely distributed than *M. circumcinctus* and was not associated with a soft substrate in accord with the observation that species in this genus are not burrowers (Roberts, 1986). The apparent preference of both species for water of low turbidity likely relates to prey capture efficiency assuming them to be visual predators. *M. albus* is a widely distributed species generally found burrowed in the mud of standing water bodies such as rice paddies. The habitat favored by *M. albus* in the small rivers of central Thailand included low pH and dissolved oxygen. The species' propensity for burrowing suggests that high ambient oxygen concentrations may not be a requirement and that cutaneous respiration across the scaleless body may be important. Habitat conditions associated with Gobiidae, high oxygen and discharge and shallow depth may relate equally or differentially with high metabolic rate and a dependency on drift organisms for their diet.

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