THE ECOLOGY OF FISH COMMUNITIES IN RIVERS IN EASTERN THAILAND: CO-EXISTENCE STRATEGIES

PROGRESS REPORT – 2

Submitted to:
BIODIVERSITY RESEARCH AND TRAINING PROGRAM,
C/O NATIONAL CENTER FOR GENETIC ENGINEERING AND BIODIVERSITY

Submitted by:
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Department of Biology,
Faculty of Science,
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1. Executive Summary

The proposed research has been partially delayed because of a longer than anticipated wet season and difficulties in acquiring a new electrofishing permit for one of the studies. This progress report consists of four parts, all related to understanding the spatial distribution and abundance of riverine fishes and their strategies for co-existence and is concentrating on a few relatively undisturbed smaller rivers mostly in southeastern Thailand. It is likely some rivers in south central Thailand will need to be included in one of our projects.

Diversity of freshwater fishes in Thailand is high, but information on their co-existence strategies in rivers is almost non-existent. A feeding study underway is investigating feeding strategies of fishes and relating these to their distribution and ecology. The study is taking place in headwater tributaries of Prasae, Chantaburi and Mekong rivers in eastern of Thailand. A early studied has concentrated on feeding periodicity among fishes. River sites were sampled at 6 hour intervals over 24-hour periods in February and November 2008 and February 2009 (n = 691). Species displayed distinctive temporal feeding patterns and differences among the major dietary items. A larger study now underway will describe the feeding dynamics of lotic fish in relation to food resources and how these relationships may change in relation to the availability and abundance of nutrients including that from allochthonous sources. Samples have been collected and processed in preparation for staple isotope analysis to assist in this objective. The ultimate trophic model will need to be dynamic to incorporate seasonal and distributional changes in food resources and fish community structures, composition and size.

Fish reproductive tactics and strategies including diversification in spawning time, multiple or batch spawning, intraspecific variation in fecundity and egg size and the extent to which these are influenced by habitat is under study in rivers in

Southeastern Thailand. Preliminary studies have included the examination of gonads from a few species (*Rasbora paviei, Macrognatus circumcintus and Glyptothorax sp.*) to determine when reproduction occurs, fish size at maturity and the development of a procedure to estimate fecundity or the number of eggs or oocytes raised to maturity. Fecundity was highest and egg diameter least in *Rasbora paviei.* Fecundity was least in *Glyptothorax sp.* which, interestingly, correlates with their relatively low abundance in rivers. Egg diameter was about the same for *Glyptothorax* sp. and *M. circumcintus*. In *M. circumcintus* spawns between December and February.

During the next reporting period the calendar date when species reproduce will be monitored along with the size (total length) at which species mature and their fecundity in a number of habitats in which abundances of individual species are expected to vary. Rates of maturity will be represented by the gonadosmatic index. Fecundity and egg size will be measured for mature fish and related to total length of fish. The overall objective is to understand the reproductive potential of fish species and how this may change with habitat quality as well as to describe species reproductive strategies that presumably have been sanctioned by natural selection allowing them to live together in relative harmony, at least at the population level.

An efficient procedure for determining biodiversity of fishes in entire watershed along with their spatial distribution patterns is providing promising although preliminary results. This procedure is expected to also provide an introduction to landscape effects on fish biodiversity. This is expected to provide for the first time in Thailand and almost worldwide, a technique to estimate the total number of species in an entire watershed within statistically acceptable limits such as ± 1 or 2 species Conservation concerns are pressing for freshwater fish and require the development of practical tools that can be used to determine the species composition of threatened habitats. This method is a potentially important conservation tool for Thai rivers at the present time and, in the future, to anticipated influences of Climate Changes in Southeast Asia

A fourth project reported here but one that does not require special BRT funding is well underway and is attempting to document ways employed by species to live in the habitats where they are found. Considerable information has been collected on body shapes, fin shapes, sizes and locations with the intent of interpreting how these morphologies assist fish in occupying their usual habitats. Specific gravities or densities have also been measured and are being examined in relation to species' habitats. The diet of fish is likely also be a consideration to fish habitat and this will be assisted by the research presently being conducted by one member of this group, P. Nithirojpakdee. Ultimately the intent is to synthesize a number of morphological, ecological, physiological and hydrodynamic characteristics of fish species and to match these with the physical and biological characteristics of their habitats in understanding how species are able to live where they are found.

2. Project Objectives

A. **Feeding Dynamics of Fish Communities in Eastern Thailand; Competition or Sharing?** How feeding relationships and diets of species-rich tropical fish communities respond to changes and differences in food resources during the wet and dry seasons; an effort will be made to unravel the importance of resource-sharing, competition and predation as well as to contribute to the understanding of how species richness and ecosystem stability are related, if at all. **(P. Nithirojpakdee, PhD candidate; Thai Research Fund Golden Jubilee Scholar)**

B. **Reproduction Tactics and Fecundity in Fishes**. Species differences and variation in timing and fecundity within species, among rivers and relationships to community compatibility. **(R. Plongsesthee, MSc Candidate; BRT Scholarship Recipient)**

C. **Quantitative Sampling to Determine Species Numbers and Distribution in River Systems.** Determination of a quantitative sampling method to estimate number of species and their longitudinal distributions in rivers within acceptable limits of precision. **(P. Chanintarapoomi, MSc. Candidate; BRT Scholarship Recipient)**

D. **Why Fish are Where You Find Them** - an integrative synthesis of morphological, physiological and hydrodynamic characteristics within communities of fishes the roles and the importance of biotic factors including competition, predation, morphology, diet and, importantly, abiotic factors in understanding how species are able to live in the habitats where they are found **(F.W.H. Beamish, Professor)**

and to make this information available through publications in International Journals of Science.

3. Introduction

The diversity of freshwater fishes in Thailand and other countries in Southeast Asia is among the greatest in the world on the basis of geographic area. Species richness is thought to be facilitated mainly by climatic and/or geological events when viewed over a large geographic area (Mahon, 1984; Moyle & Herbold, 1987). Large watersheds and high discharges are generally thought to support a large number of species (Hugueny, 1989; Oberdorff et al., 1995). On a more local scale, physical factors such as habitat size (Angermeier & Schlosser, 1989), habitat diversity (Gorman & Karr, 1978; Beamish et al. 2005; 2006; Beamish & Sa-ardrit 2006; 2007; Beamish et al. 2008; Tongnunui & Beamish 2009) and water currents (Hugueny, 1990) are among the variables thought to be important. Chemical characteristics also are known to manifest an influence through their interactive effects aptly described earlier by Fry (1971; Brett, 1979) within the concept, metabolic scope for activity.

This richness in species that occurs in Southeast Asian rivers is in contrast to what might be predicted from the view that competition and predation are the most important factors controlling both species and numbers of fish. The concept of competitive exclusion held by some (Ayala, 1969; Gilpin & Justice, 1972; McGehee & Armstrong, 1977), assumes communities exist at competitive equilibrium. This concept applies under conditions of habitat stability and uniformity and for species dependent on exactly the same resources. In contrast, physical and chemical conditions, predation and other factor are continually imposing their influence on population sizes and the nature of competitive interactions, making it likely that competitive equilibrium rarely occurs, if at all (Sale, 1977; Wiens, 1977; Huston, 1979). Even if competitive equilibrium is never achieved, the expected outcome of competition might be an eventual predominance of one competitor, with a decrease in the other. Recent theoretical evidence suggests this need not occur where life history strategies differ such that an advantage at one stage of the life cycle implies a disadvantage at another stage of the life cycle (McCann et al., 1998). Where life history strategies do not imply advantages, increasing intensity of competition should result in a decrease in species evenness and eventually species number. Intense competition should result in low diversity among competing species and high diversity might be expected where there is weak competition. This suggests that in Southeast Asia, species success may depend on the extent to which they have acquired strategies including feeding and reproductive tactics or strategies that allow them to share rather than compete for resources. A variety of strategies may be employed including those related to habitat, feeding and reproduction. Further, temporal or seasonal changes impose dynamic changes through effects on habitat and recruitment of aquatic organisms. The research in this proposal examines feeding and reproductive strategies that may account for the large species richness in Thai rivers as well as the suggestion that these serve to suppress competition in favor of sharing.

Thailand has not quantitatively surveyed a single watershed nor does it appear even to have a strategy in place to do so. Increasing concern for the knowledge and conservation of biological diversity requires the development of practical tools to determine species composition and their distribution in Thai rivers so that, at the very least, we know the species that are present. Reach-level surveys are not reliable for characterizing fishes of entire watersheds due to between site heterogeneities. Fish may move throughout the watershed to reach critical habitats. This is particularly important when evaluating the effects of habitat manipulations such as dams and removal of water for crop irrigation. No survey design can ensure detection of all species present in an area so determining an appropriate trade-off between the risk of failing to detect species and excessive and costly sampling is required. Species accumulation curves have been used to guide landscape-level species inventories and to develop sampling guidelines for a number of taxa including plants (Gimaret-Carpentier et al., 1998), birds (Neave et al., 1997) and insects (Dobyns, 1997). Species accumulation curves provide a quantitative method for assessing the completeness of faunal inventories, estimating total species richness and developing guidelines for the minimum sampling effort needed to reach a target level of inventory completeness (Moreno & Halffter, 2001). The shape of a species-accumulation curve depends on the relative abundance and distribution of species so the best mathematical model will depend on taxa, environment and scale (Colwell & Coddington, 1994). Several models have been suggested but only one inter-comparison has been conducted on fish and that in a temperate region (Smith & Jones, 2005).

Species vary also in their feeding relationships with evidence of a species-related divergence in diet as well as in the particle size of ingested food (Ward-Campbell, et al., 2005). Evidence in hand, while scant for most Thai species, clearly indicates diet to be related to species morphology, in particular mouth position, shape and size (Ward-Campbell et al., 2005; Ward-Campbell & Beamish, 2005). Body shape is also intimately associated with diet as well as habitat. Body shape, fin size, shape and location to a significant extent determine where in the water column fish can live. Density and fish buoyancy is also important in facilitating a benthic or pelagic lifestyle. Thus, variations in these characteristics among species not only direct species to occupy different habitats but also to different food resources thereby favoring multi species coexistence through a reduction in competition pressures.

In earlier studies this laboratory has determined significant physical and chemical habitat characteristics associated with habitat preference for many Thai fish species (Beamish et al., 2005, 2006, 2008; Beamish & Sa-Ardrit, 2006, 2007 ; Tongnunui & Beamish, 2009). We are measuring other body proportions including fin shape, area and location along with their angle of insertion, all relative to total and standard length and weight, and all of which are considered important to swimming performance as well as to maintaining a benthic lifestyle in fast flowing water. We also note eye location and size, mouth location and gape height and width, the latter as indicators of the size of food that can be ingested. These measurements will be collated with observations on where species actually are found within a river to provide for an understanding and guidance for the conservation of river ecosystems, particularly those in the headwaters of Thailand's important river systems.

Progress during this second budgetary period has focused on feeding, fecundity and morphometric measurements along with sampling tactics to estimate total number of species within rivers (Figure 1). This latter study on quantitative sampling method has been slowed by a prolonged and excessive rainy season as well as a difficulty in obtaining a broader-based electrofishing license from the Department of Fisheries that will allow us to sample a greater diversity of rivers. We expect to be able to satisfy the Department of Fisheries within the next few weeks.

Collectively these projects are expected to yield information useful to understanding high species diversity and why species are where they occur in Thai rivers. Progress on specific subprojects is given below. Photographs of some study sites, sampling methods and fishes are presented in Figures 1. We continue to attract international scientists in addition to those that we reported in our first report, Dr. L. Page, Professor of Ichthyology, Museum of Ichthyology, University of Florida, Gainesville, Florida; Dr. R. Mayden, Professor, Department of Integrative Biology, St. Louis University, St. Louis, Missouri and Dr. S. Compton, Professor of Forestry, Leeds University, Leeds, England in regards a study on seed dispersal by fish. During the second report period we were visited by D.V. Gillman, Director of Research for Central Canada, Canada Department of Fisheries and Oceans and Dr D.L.G. Noakes, Professor and Senior Scientists, Department of Fisheries and Wildlife, Oregon Hatchery Research Center, Oregon State University.

Figure 1. Sample sites and activities. A. Collecting benthic macroinvertebrates, B. Sample site on headwater tributary of Chantaburi River., C. Electrofishing at site on Prasae River, D., E., F. Sites on Prasae River and identification of fishes after electrofishing

A. Feeding Dynamics of Lotic Fish Communities in Eastern Thailand

Patchara Nithirojpakdee, PhD candidate,

Thai Research Fund Golden Jubilee Scholar

Progress Report for the Period July, 2008 to February, 2009

Introduction:

Fish feeding dynamics represents an important component in the comprehension of co-existence strategies and community structure. Critical to this is the understanding of when species feed or, feeding periodicity, how much they consume and their respective dietary constituents relative to available resources. Debate continues on the relative importance of resource sharing and competition within fish communities, especially those in which species richness is high as in the rivers of Thailand. One strategy in resource sharing within communities that is already evident from the current study is species-specific variation in temporal feeding schedules. Ontogeny is also important as diet typically changes with development, in part due to changes in mouth size and other morphologies. A second current study is examining potential food resources within a habitat including the macrobenthos, periphyton and stream drift. The analyses of these collections which are in progress are expected to provide guidance for further investigation including seasonal variations in food resources and the importance of autochthonous and allochthonous nutrients to resource productivity. This information is seen as being of fundamental conservation importance in understanding interactions among trophic or feeding levels within lotic fish communities.

Early food web studies derived their diet information mostly from the contents of digestive tracts, more specifically, stomach contents (Xu, et al., 2007; Rybczynski et al., 2007). While this can yield direct diet information it needs to be applied with care. Stomach contents represent only the food consumed over a short time period and possibly within small areas. Secondly, stomach contents provide no information on digestibility or assimilation efficiency of the contents. The proportions of prey found in stomachs may be biased by differential evacuation rates among the ingested foodstuffs (Tarvainen et al., 2008). This method also has difficulties as not all ingested material is assimilated and some ingested animals are digested much more quickly than others and often not visible in the analysis. Recently, the ratios of the natural stable isotopes of carbon (C^{13}, C^{12}) and nitrogen (N^{15}, N^{14}) have been used as an alternative method in exploring trophic relationships. The stable isotope composition of fish tissues reflects spatio-temporal integration of the assimilated diets during a longer period (Tarvainen et al., 2008). These two methods should preferably be used together to complement and not to replace each other.

The current phase of this study (July, 2008 to February, 2009) investigated feeding periodicity, diet and appetite of lotic fishes at several sites on the Chantaburi, Prasae and Mekong rivers, Eastern Thailand. These studies are being conducted within the framework of the food resources available to the fishes. Species from several families have been collected but to date analyses have focused entirely on species within the Family Balitoridae.

Objectives:

1. To measure feeding periodicity, diet and amounts of food consumed in relation to species and fish size during the wet and dry seasons.
2. To examine species' diets within habitats relative to potential food resources including macrobenthos, periphyton and stream drift.
3. To evaluate interaction dynamics of feeding strategies relative to food resources within fish habitats.

Methods:

My study area includes several headwater tributaries of three rivers in eastern Thailand, Prasae, Chantaburi and Mekong rivers. Fishes are collected at three-month intervals or less within a specific lotic habitat by electro fishing (Plafkin et al.,1986). For the feeding periodicity studies, fish are collected at six hour intervals. Potential food resources that are being evaluated include macrobenthos, periphyton, plankton and drift organisms. Macrobenthos are collected with a D-net (also called a kick net) (Lind, 1974.), drift nets are set in each habitat to collect those organisms that have lost contact with the substrate and are refferred to as drift organisms. Drift nets are emptied every 6 hours as drift organisms display temporal variation in occurrence (Meritt, Resh & Cummins, 1996). Samples are being collected in random sequence.

Periphyton is scraped from hard surfaces such as rocks or submerged wood from an area of approximately $1 cm^2$.

Captured fish are killed with an overdose of MS-222 (methane tricaine sulfonate) and preserved in 10% formalin for subsequent examination in the laboratory. Fish are identified from a number of sources including; Smith (1945), Banarescu (1971), Dekkers (1975), Kottelat (1984, 1988, 1989, 1990, 1998, 2000), Nelson (1994), Dawson (1981), Roberts (1986,1994), Burridge (1992), Lee & Ng (1994) and Rainboth (1996), Musikasinthorn (2003) and others. In addition, Dr. Prachya Musikasinthorn and his graduate students provided technical training in fish identification at Kasetsart University in January, 2009.

Digestive systems, between the esophagus and anus, are removed from preserved fishes. Generally, only in the stomach is an attempt made to identify taxa of contents. In other regions of the digestive tract only the weight of contents is measured. After removing excessive water, stomach or intestinal contents are weighed and, in the case of stomach contents, identified to lowest practicable taxonomic category.

Muscle tissue of fishes, macrobenthos and organism is being collected and processed for stable isotope analysis. Tissue is dried to constant weight at 60°C, ground to a fine powder with a mortar and pestle, and stored in a desiccator. Stable isotope ratios will be expressed relative to a standard reference (Xu, et al., 2007; Rybczynski et al., 2007). Arrangements were made to conduct the stable isotope analysis at Thailand Institute of Nuclear Technology (TINT). However, operational problems with the equipment have delayed analyses and prompted me to look for alternative equipment sources. Potential sources include Professor R. Cunjak, Rivers Institute, University of New Brunswick, Canada and Professor D.L.G. Noakes, Department of Fisheries and Wildlife, Oregon State University, Oregon, U.S.A. However, these sources if available will likely be more costly. Certainly a closer source would be more convenient.

Macrobenthos and drift organism are preserved in 70% ethanol for subsequent identification (Morse et al., 1984; Merritt & Cummins, 1996; Wiggins, 1977; Yule & Sen, 2004; Dudgeon, 1999 and McCafferty, 1981). Periphyton and plankton is being collected and preserved in glutaldehyde or Lugol's solution for identification (Hartley et al., 1996; Prescott, 1970; Mizuno, 1979; Pennak, 1989; Fitzpatrick, 1983). My insect identification skills were improved through technical guidance from Professor Pornthip Chantaramongkon and her graduate students through a taxonomic training period (June-July 2008) at Chang Mai University.

Results:

Four sites were selected on headwater tributaries of three rivers, Prasae and Chantaburi and Mekong rivers. All sites were in areas that appeared to be relatively free form urban and intensive agricultural influences. The four sites differed considerably in chemical characteristics but not in their physical features (Table 1).

Table 1. Locations, sampling dates and physiochemical characteristics (geometric means) of each sample site.

	Prasae	Chantaburi River		Mekong River		
	River	Site 1(KY)	Site 2(KP)			
Date	29-Feb-08	23-Nov-08	1-Feb-09	1-Mar-08	22-Nov-08	7-Feb-09
Latitude	12° 57' 97" N	12°52' 29.3" N	12°53'02.4" N	12°54'35.6" N		
Longitude	101° 42' 63" E	102°06' 0.08 " E	102°06'53.6" E	102°24'35.1" E		
Depth (cm)	40	45	30	50	70	50
Width (m)	4	8	6	5	5	5
Conductivity (µS/cm)	44.16	30	30.4	66.94	10	100
pH	7.08	7	6.99	7.47	8.23	7.36
Temperature (°C)	24.08	27.7	26.36	26.16	24.4	25.66
Oxygen (mg/l)	6.98	7.1	7.9	4.88	7.7	7.67
Velocity(cm/sec)	12.46	-	30.85	79.77	-	96.76
Alkalinity (mg/l)	17	-	-	-	-	-
Substrate (cm)	22.5	25	115	35	45	35

Composition of Fish Community

Preliminary data on number of species at the four lotic sites identified more than 30 species. Still to be identified are four species of Cyprinidae and two silurids (Catfish). Fish species structure differed among the sites. Some species were found only at some sites. *N. platiceps* was captured only at the sites on the Prasae River. *Nemacheilus masyae* occurred only on sand substrate where the current was slow. *Homaloptera confuzona* was found only in Chantaburi River (site 2). *Balitora* sp. were captured only where water current and dissolved oxygen were high. In contrast, *Homaloptera smithi*, *Channa gachua*, *Mastacembelus* sp., *Amblyceps* sp. and *Rasbora paviei* were found at every site but differed in abundance (Table 2). For example, *Homaloptera smithi* was relatively common at some sites and uncommon at others.

Balitora sp. was quite abundant on a tributary of the Mekong River but absent at the other tributaries (Table 2.).

Table 2. Species of fish captured at the tributary sites. Abundances were adjusted arithmetically to an area of 100 m^2

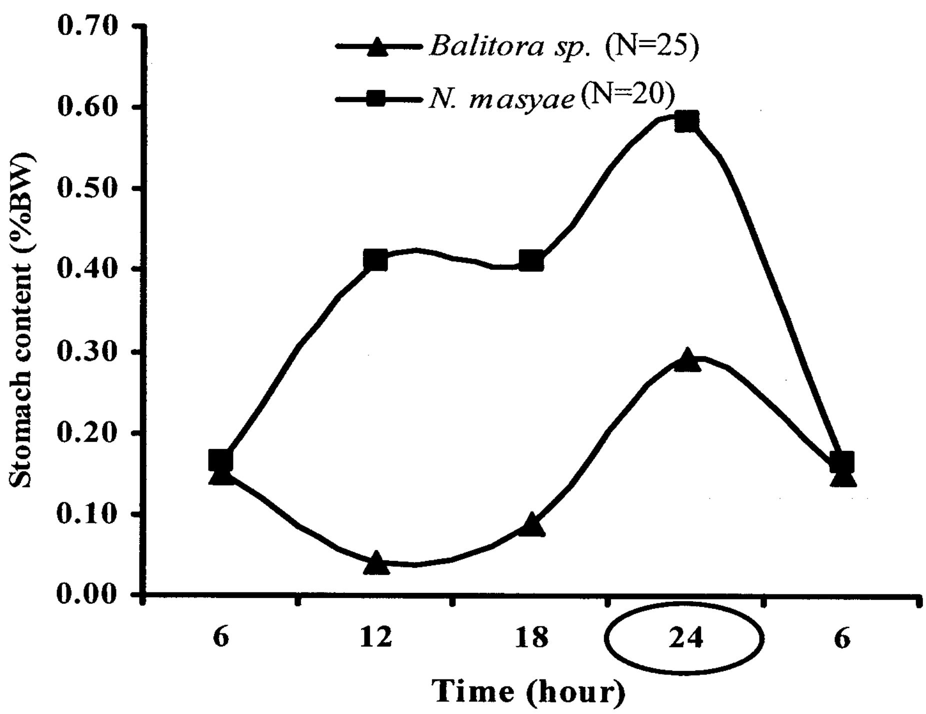
Species	Abundance(number/ 100m^2)			
	Prasae River	Chantaburi River		Mekong River
		Site 1(KY)	Site 2(KP)	
Amblyceps sp.	8.0	10.1	6.9	19.1
Balitora sp.	0.	0	0	17.1
Betta sp.	7.5	1.0	1.2	0
Channa gachua	9.5	2.3	5.2	9.4
Clarias sp.	0	0.3	0.2	0
Esomus metallicu	15.0	0	0.2	0
Glyptothorax laoensis	0	0	0	2.9
Glyptothorax major	0	3.8	9.5	0
Gobiidae	0	3.1	1.2	0
Homaloptera confuzona	0	0	0.5	0
Homaloptera smithi	4.5	2.5	11.9	11.4
Lepiocephalichthys sp.	0	0.1	0	0
M. circumcinctus	0	2.9	0	0
M. armatus	4.5	9.5	9.8	21.7
Monopterus sp.	0	0.3	0.2	0.3
Mystacoleucus marginatus	0	2.5	7.1	1.4
Mystus sp.	0	7.5	7.1	0
Nemacheilus masyae	0	3.8	7.1	0
Nemacheilus platiceps	16.0	0	0	0
Ompok sp.	0	0.3	0.2	0
Osteochilus hasseli	0	0.6	0.5	0.6
Pangio sp.	0	0.1	0	0
Parambassis sp.	5.0	0	0	0
Pristolepis sp.	0	0.3	0.5	0
Psedomystus siamensis	0	8.8	20.0	2.9
Rasbora paviei	15.0	1.3	2.4	1.4
Schistura kohchangensis	0	8.8	16.7	20.0
Tetradon sp.	0	0	0	0.3
Xenentodon cancila	0	0.3	0.5	0.6
Total species (n)	170	560	459	382

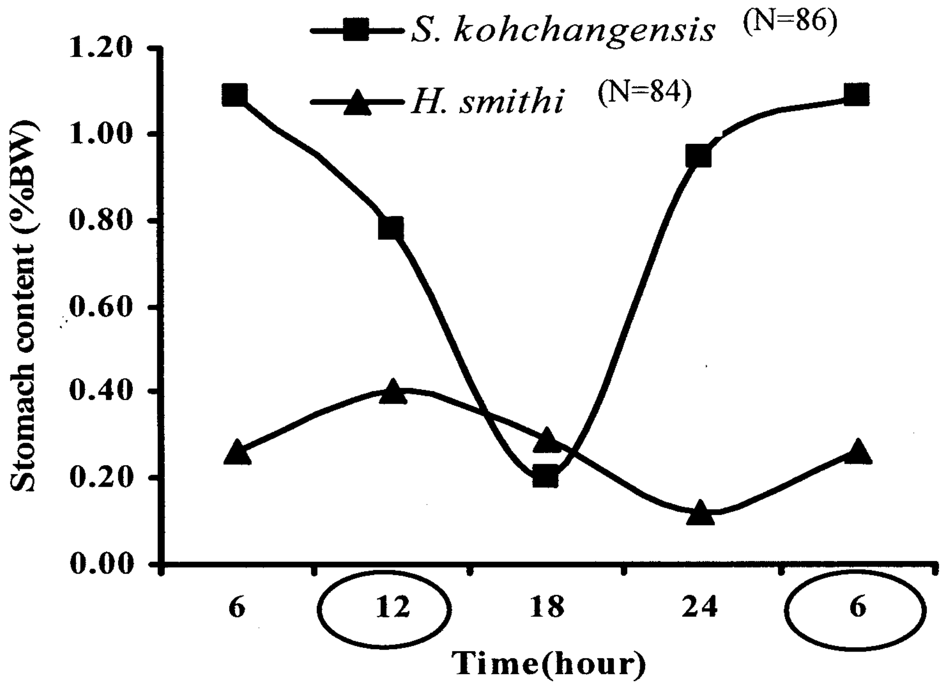
- Species were considered to be common when their abundance was >10 fish / 100m^2

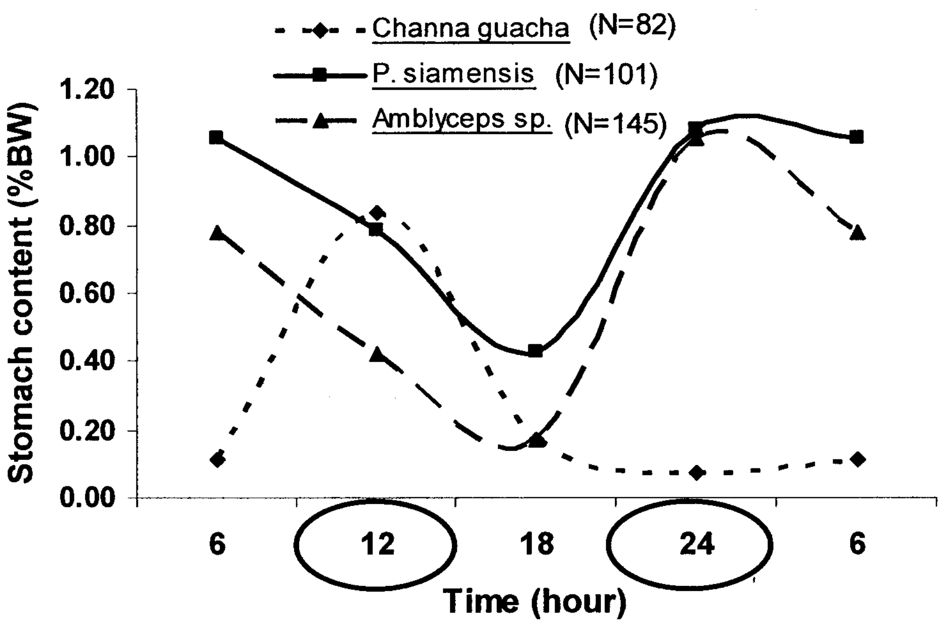
- Species were considered to be moderately common when their abundance was 2 to 9 fish/ $100m^2$
- Species were considered uncommon when their abundance was <2 fish/ $100m^2$

Feeding periodicity

Lotic species demonstrated different feeding patterns suggestive of a resource-sharing tactic. Feeding activities of *Balitora* sp., *N. masyae*, *Pseudomystus siamensis* and *Amblyceps* sp. based on weight of stomach contents, indicated them to be nocturnal with maximum food consumption at midnight (24 hours; Figure 1). On the other hand, in *S. kohchangensis,* maximum food consumption occurred at 06 hours and at noon (12 hours) for *C. guacha*, *Mastacembelus* sp. and *Macrongathus* sp.




S. kohchangensis (N=86)
H. smithi (N=84)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Stomach content (%BW)
6
12
18
24
6
Time(hour)


Channa guacha (N=82)
P. siamensis (N=101)
Amblyceps sp. (N=145)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Stomach content (%BW)
6
12
18
24
6
Time (hour)

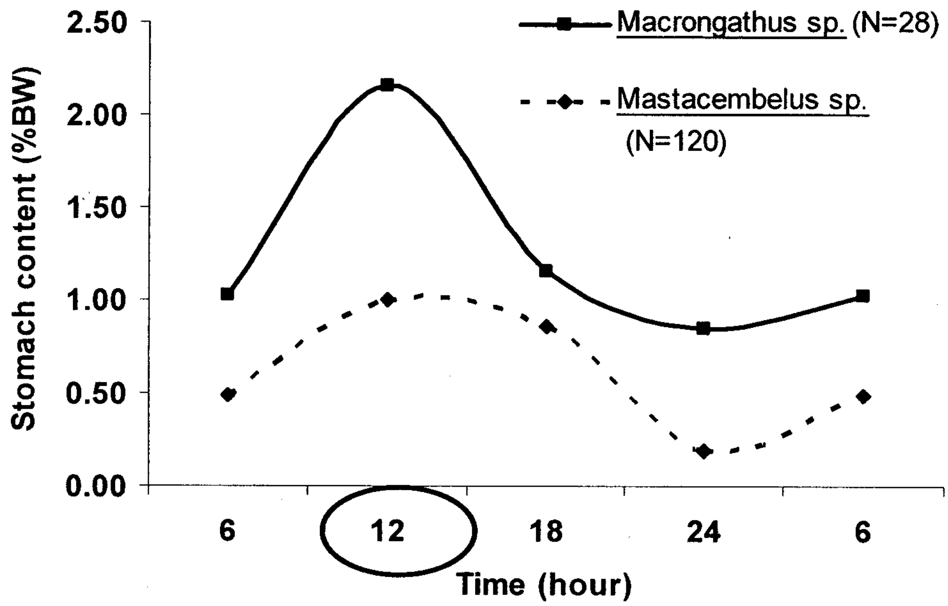


Figure 1. Stomach contents as % body weight (%BW) of several benthic fishes at 6-hour intervals in February, November 20008 and February 2009.

Diet of the Family Balitoridae

The diet of Balitoridae consisted of benthic invertebrates, phytoplankton, macrophyte and zooplankton (Table 2, Figure 2). Results are suggestive of intraspecific differences among the major dietary items although not always with statistical support. I found significant differences in the dietary contributions of Trichoptera, Ephemeroptera, insect fragments, Plecoptera and Terrestrial insects in the stomachs of benthic species. Plecoptera and terrestrial insects were significantly more abundant in the stomachs of *Nemachilus sp.* (26.6 and 0.2%) than other species. *Balitora* sp. *and Nemachilus* sp. fed mostly on Ephemeroptera (61.7 and 66.5% by weight) whereas the major dietary item for *Schistura kohchangensis* and *Homaloptera smithi* was Ephemeroptera (66.3 and % by weight) and insect fragments, respectively. (Table 2).

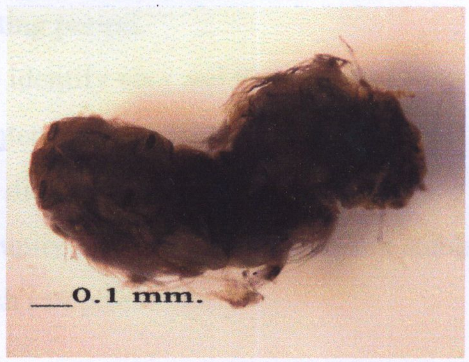
Table 2. Diet when food consumption was at a maximum among species in the Family Balitoridae in November, 2008 expressed by the point method and expressed as a percentage of food consumed (Hynes, 1950).

Diet/Fish	*S. kohchangensis* (06.00 h)	*Nemachilus* sp. (24.00 h)	*H. smithi* (12.00 h)	*Balitora* sp. (24.00 h)
Coleoptera	0.0	0.0	6.8	0.0
Crustacea	0.2	0.0	0.0	0.0
Diptera	5.9	4.8	3.2	1.0
Ephemeroptera	14.5	61.7	10.3	66.5
Insect egg	0.0	0.0	0.6	0.0
Insect fragments	7.3	0.0	63.9	31.5
Lepidoptera	2.0	0.0	0.0	0.0
Macrophyte	3.6	0.0	0.0	0.0
Phytoplankton	0.1	0.0	0.0	0.1
Plecoptera	0.0	26.7	0.0	0.0
Terrestrial insect	0.0	0.2	0.0	0.0
Trichoptera	66.3	6.6	15.7	0.5
Number of fish	10	3	14	10

Order Coleoptera

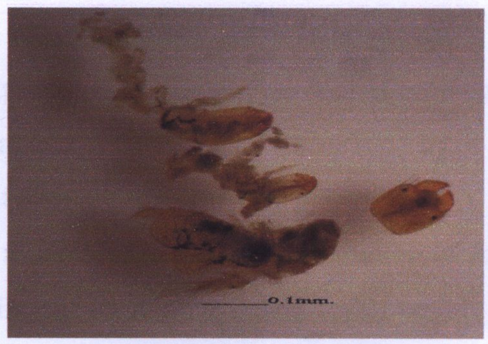
Order Diptera

Order Ephemeroptera

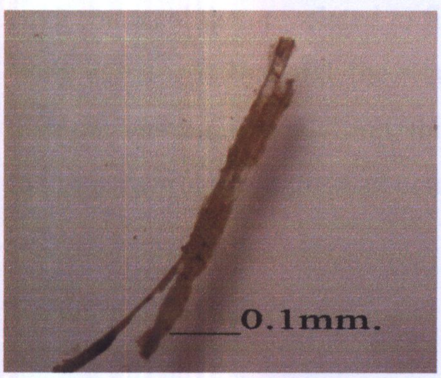


Order Lepidoptera

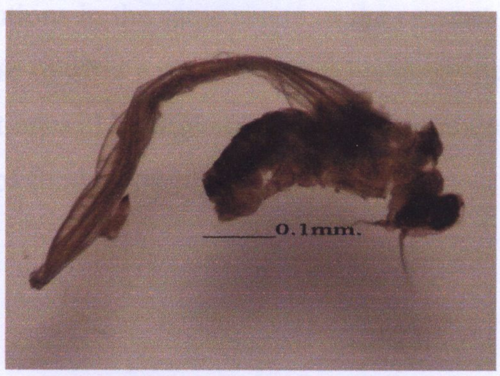
Order Ephemeroptera



Order Trichoptera



Macrophyte



Terrestrial insect

Figure 3. Photographs of taxa recovered from stomachs of individuals in the Family Balitoridae

Plan for the next reporting period:

1. Currently I am preparing a poster of my research to be displayed at a conference sponsored by the Thai Research Fund and to be held in Pattaya, April 3-5, 2009.
2. Also I am preparing a manuscript for publication on feeding periodicity for submission to an international journal such as Journal of Freshwater Ecology or Journal of Fish Biology. I expect to submit this manuscript towards the end of the next reporting period.
3. My present research priority is to identify taxa and their relative proportions from the stomach contents of fish to determine the relationship between feeding and diet during wet and dry season.
4. A priority if and when the opportunity arises will be to measure stable isotope levels in the processed fish samples.

Expected Outcomes:

Conservation of the diverse and often uncommon species of fishes in the headwater tributaries of Thai rivers requires quantitative knowledge of their ecology, particularly that related to feeding dynamics and how this may be influenced by ambient environmental conditions. Important also are the seasonal dynamic interactions among trophic levels within fish assemblages and the distribution of food resources leading ultimately to an understanding of food webs in tropical lotic habitats. When combined with our earlier quantitative studies on the significant environmental factors related to fish distributions in the same rivers as the present study in Eastern Thailand, the results promise to offer a particularly valuable guide to their conservation. In addition, this information will be important in the assignment of food interaction strengths and construction of food webs.

B. Reproduction and Fecundity of Thai Fishes and the Influence of Habitat

R. Plongsesthee, MSc, Candidate;

BRT Scholarship Supported

Progress Report for the Period December, 2008 to February, 2009

Introduction:

Fish reproduce in different ways and at different times but each strategy must allow for the adequate survival of enough juveniles or recruits and, ultimately, adults to assure species sustainability. Some species produce a large number of small eggs but provide no post spawning care. Other species produce fewer but larger eggs, favoring the additional investment of energy to egg size and the provision of larger larvae at hatch and a reduction of early predatory mortality. Still others allocate portions of their reproductive energies to the care and protection of their eggs and young. Temporal variations in reproduction may more efficiently allocate reproductive habitat and food resources for newly hatched fish.

This research began in January, 2009, and will focus on fish reproductive tactics and strategies including diversification in spawning time, multiple or batch spawning, intraspecific variation in fecundity and egg size and the extent to which these are influenced by habitat. Comparative attention will be given to highly and only moderately successful species, the criteria of success being relative abundance.

Preliminary studies have included the examination of gonads from a few species (*Rasbora paviei, Macrognatus circumcintus and Glyptothorax sp.*) to determine when reproduction occurs, fish size at maturity and the development of a procedure to estimate fecundity or the number of eggs or oocytes raised to maturity. Attention will be paid to obvious occurrences of atresia or the absorption of eggs.

Objectives:

1. Gonads from one or more species of each of the major families in several rivers of southeastern Thailand will be captured once bimonthly or as appropriate. Rates of maturity will be represented by the gonadosmatic

index (de Vlaming et al., 1982) with suitable adjustments for fish total length and weight (Erickson et al., 1985).

2. Within each species, the relation between fecundity and total length will be measured, to compare rates of change with size and among species.
3. Some species will be selected that are known to occur over a wide range of habitats. This is expected to provide information on the influence of habitat on fish health, if any, as well as on the rate of maturation and fecundity. Health will be represented by the coefficient of condition. Background information on habitats and fish occurrences and abundance has been taken from Beamish et al. (2006); Beamish & Sa-ardrit (2006); Beamish et al. (2008); Tongnunui & Beamish (2009).
4. Fecundity and maximum egg diameter will be measured at maturity for each species to be studied. Time of spawning will be observed or derived from gonadosomatic index values.

Methods:

Preliminary studies were conducted on fish preserved from previous studies including ; *Rasbora. paviei* (January, 2001), *Macrognathus ciruimcintus* (December, 2008 and February, 2009) and *Glyptothorax* sp. (December, 2008). Gonads (ovary or testes) were removed, blotted to remove excess fluid and weighed (± 1 mg). Gonadosomatic index, (GSI) was calculated as gonad weight/total body weight (Rheman et al., 2002; Brewer et al., 2008). Fecundity was estimated for mature ovaries by counting all eggs when estimated to be fewer than 1000 or, when higher, fecundity was estimated from subsamples based on weight rather than volume (Bagenol & Braum, 1968). Maximum egg diameter was measured under microscopy.

Results:

There was marked variation in fecundity among the cyprinid, *Rasbora paviei*, spiny eel, *M. circumcintus* and the catfish, *Glyptothorax* sp. Fecundity was highest and egg diameter least in *Rasbora paviei.* Fecundity was least in *Glyptothorax sp.* which, interestingly, correlates with their relatively low abundance in rivers. Egg diameter was about the same for *Glyptothorax* sp. and *M. circumcintus*.

Of the species examined to the present only *R. paviei* produced more than 1000 eggs. For this species approximately 20% of the eggs by weight were counted and fecundity arithmetically adjusted to the total ovary weight. For one individual, fecundity was compared from subsamples representing approximately 6, 15, 20, 22, 28 and 31% of the total weight. For a subsample equal to 20% or more of the total ovary, estimates of fecundity were comparable to the total count. However, when subsamples were less than 20%, the estimate of fecundity was higher than the total count. In the *R. paviei* that were examined, fecundity increased directly with total length. However, egg diameter did not appear to differ with fish size.

The preliminary study suggests that *M. circumcintus* spawns between December and February as eggs were present in December and, at that time, easily separated from the ovarian membrane. As well, the gonadosomatic index was high. Further, in February no eggs were found in large and presumably mature females. However, it is possible, perhaps even probable that maturity in this species may occur also at other times in other rivers. This will be pursued in subsequent studies.

Table 1. Measurements on gonads of several fish species including fecundity and maximum egg diameter and in relation to river.

Date	Klong	Species	Fish number	Total length of fish (mm.)	Body Weight (mg.)	Ovary Weight (mg.)	GSI Index, %	Egg Number	Egg Diameter (mm)
Jan 18/ 01	Surasuk	*R. paviei*	1	63	2261	26	1.14	135	0.09
			2	71	3605	131	3.63	625	0.10
			3	73	3691	232	6.28	906	0.11
			4	81	5504	191	3.48	845	0.10
			5	81	4981	325	6.52	1852	0.11
Dec 26/ 08	Satornoi	*M. circumcintus*	1	135	11460	391	3.41	318	0.18
			2	90	3420	149	4.37	334	0.14
Feb 20/ 09	Tagad	*M. circumcintus*	1	128	11290	6	0.05	0	-
			2	130	12553	13	0.10	0	-
			3	132	13550	31	0.23	0	-
			4	140	14621	18	0.13	0	-
Dec 26/ 08	Satornoi	*Glyptothorax* sp.	1	50	2460	109	4.41	86	0.18
			2	51	2440	132	5.42	108	0.20
			3	51	2940	136	4.62	84	0.20
			4	52	2960	73	2.48	40	0.16

Plan for the next reporting period:

The methods used in the preliminary analyses to estimate fecundity and egg diameter will be applied to more fish to further improve precision after which the most accurate and precise methods will be applied to the fish that will collected.

During the next reporting period the size (age) at which species mature will be investigated for a number of the sites proposed in this progress report. For those species that show evidence of maturing, gonad weight will be measured from which gonadosomatic indices will be calculated. Fecundity and egg size will be measured for mature fish and related to total length of fish.

Selected species will be sampled from sites that differ appreciably in their habitat characteristics characteristics. It is expected that abundance of individual species will vary with habitat characteristics. Thus, the objective is to select diverse habitats for studies relating to the influence of biotic and abiotic characteristics on species fecundity, frequency of spawning and other pertinent information. Candidate species are listed in Table 2. Once sites are selected they will

Table 2. Candidate species for fecundity studies that are known to occur in diverse habitats and abundances in southeastern rivers in Thailand.

Families	Species
Cyprinidae	1. *Rasbora paviei* 2. *Puntius binotatus*
Balitoridae	1. *Homaloptera smithi* 2. *Nemachoilus masyae*
Bagridae	1. *Psuedomystus siamensis*
Amblycipitidae	1. *Amblyceps sp.*
Sisoridae	1. *Glyptothorax sp.*
Mastacembelidae	1. *Macrognathus circumcinctus* 2. *Mastacembelus armatus*
Channidae	1.*Channa gaucha*

be examined at least bimonthly and, at times, more often. For example, the sample site on Khlong Plu (Table 3 and 4) has high abundances of *R. paviei, P. binotatus* and *C. guacha* along with high concentrations of ammonia and low oxygen. In contrast, at Klong krua wai and Klong Pai poon sites, ammonia was present in comparatively low concentrations and oxygen was moderately high relatively and abundances of *R. paviei, P. binotatus* and *C. guacha* were low.

Table 3. Some of the chemical and physical, characteristics of sites sampled for fish (see Table 4) at sites on rivers in southeastern Thailand.

River Data	Stations					
	Pa Yub Nai	Khlong Ta Kard	Sa La Nam Luk	Khlong Chum Sang I	Khlong Sa Pan	Khlong Chum Sang II
Stream order	1	1	1	2	1	2
Latitude-Longitude	± 7m	± 2m	± 7m	± 5m	± 5m	± 5m
	N 13°00'56.6"	N 12°58'57.7"	N 12°55'07.8"	N 12°57'19.7"	N 12°58'07.5"	N 12°56'57.0"
	E 101°28'46.8"	E 101°31'13.6"	E 101°28'42.5"	E 101°32'29.2"	E 101°31'42.1"	E 101°31'49.9"
Elevation (m)	30	28	40	17	20	20
Oxygen (mg/l)	8.6	7.9	7.6	7.6	10.8	7
Conductivity (μS/cm)	217	194	82	78	180	91
Alkalinity (mg/l)	64	25	60	25	69	24
pH	7.63	734	7.06	7.17	7.7	7.06
Temperature (°C)	24.8	24.9	26.4	24.3	27.7	23.2
Ammonia (mg/l)	0.0011	0.12	0.13	0.08	0.09	0.11
Depth (m)	0.2	0.6	0.2	0.6	0.3	0.3
Width (m)	4	4.5	3	3	3.5	4
Substratum	Sand	Sand-Clay	Sand	Sand	Sand	Sand

Table 3. (Continue)

River Data	Stations						
	Khlong Plu	Khlong Krua wai	Khlong Pai poon	Surasak (site 1)	Surasak (site 2)	Klong Mue sai2	Huai Map pu
Stream order	1	-	-	-	-	-	-
Latitude-Longitude	± 6m	± 3m	± 6m	-	-	-	-
	N 13°07'25.3"	N 12°54'35.6"	N 12°53'02.6"	N 13°04'88"	N 13°09'14"	-	-
	E 101°24'46.2"	E 102°24'35.1"	E 102°06'49.2"	E 101°09'87"	E 101°05'66"	-	-
Elevation (m)	30	179	110	-	-	-	-
Oxygen (mg/l)	3.1	6.45	7.6	3.7	6.2	3	9.1
Conductivity (µS)	1221	162	47	112	77	784	117
Alkalinity (mg/l)	518	89	40	26	22	360	30
pH	7.89	7.54	7.52	6.5	6.6	7.7	7.0
Temperature (°C)	22.3	29.2	27.0	25.3	25	25.3	24
Ammonia (mg/l)	1.1	0.03	0.01	0.08	0.06	600	2.04
Depth (m)	0.3	0.3	0.4	0.4	0.2	0.3	0.1
Width (m)	2	4	5	4	1.2	2.4	2.9
Substratum	Sand	Sand-Rock Small rock	Rock-Sand Big rock	-	-	-	-

Table 4 Species of fish and the number caught at sites located on rivers in southeast Thailand. Numbers of fish have been arithmetically adjusted to a common area of 100 m^2.

Station	Species									
	R. paviei	*P. binotatus*	*H. smithi*	*N. masyae*	*P. siamensis*	*Amblycep sp.*	*Glyptothorax sp.*	*M. circumcinctus*	*M. armatus*	*C. gaucha*
Pa Yub Nai	30	15	11	6	6	0	0	0	2	7
Khlong Ta Kard	25	6	30	39	10	0	0	6	5	30
Sa La Nam Luk	122	127	0	0	3	0	0	9	13	67
Khlong Chum Sang I	9	5	22	10	10	0	0	5	1	1
Khlong Sa Pan	37	1	20	12	0	0	0	1	4	7
Khlong Chum Sang II	36	5	1	0	1	0	0	8	2	4
Khlong Plu	162	43	0	0	0	0	0	0	0	2
Khlong Krua wai	0	0	2	0	4	17	5	17	15	18
Khlong Pai poon	0	0	29	14	12	0	15	6	0	4
Surasak (site 1)	19	15	0	0	0	0	0	0	0	2
Surasak (site 2)	229	146	0	0	0	0	0	0	0	88
Klong mue sai2	9	37	0	0	0	0	0	0	0	0
Huai map pu	3	3	0	0	0	0	0	0	0	5

Plan for the next period (February, 2009 to December 2011)

Plan	2009-2010		2010-2011	
	2 - 6	7 - 12	1 - 6	7 - 12
1. survey and select sites	↔			
2. Collect samples	↔	↔	↔	
3. Lab. (fecundity).		↔	↔	↔
4. Write thesis and paper for publication			↔	↔
5. BRT conference			↔	↔

Expected Outcomes:

1. Description of reproductive tactics and strategies of fishes including diversification in spawning time, multiple or batch spawning, intraspecific variation in fecundity and egg size and the extent to which these are influenced by habitat
2. The study is expected to contribute to understanding the pathways of reproduction sanctioned by natural selection in fishes
3. The information on the effect of habitat on reproductive potential is expected to be of conservation value
4. Prepare and defend an MSc thesis and, concurrently, to submit a paper for publication in an international science journal

C. A Sampling Strategy to Estimate Species Richness, Distribution, and Habitat Associations within Watersheds in Thailand

Peangchai Chanintarapoomi, MSc Candidate

BRT Scholarship Supported

Progress Report for the Period July, 2008 to February, 2009

Introduction:

Tropical communities of both plants and animals are characteristically diverse, with large number of species and complex interrelationships compared with those in temperate communities (Lowe-McConnell, 1987). Freshwater fishes in tropical regions are extremely diverse. There are more than 1,300 species each in the Amazon and Congo River basin as compared to 250 species in the Mississippi River and 190 species in all of Europe (Zakaria-Ismail and Sabariah, 1994).

Southeast Asia has been a focus of great biogeographical interest (Rainboth, 1966) again with a rich ichthyofauna that characterizes tropical freshwaters elsewhere. Indeed, Zakaria-Ismail (1994) has suggested the estimated number of 1,000 species in Southeast Asian as an underestimate. Not surprisingly, Thailand supports an extremely diverse aquatic fauna and flora within her six major river systems, Northern (Salween River System), Central (Chaophraya River System), Western, Peninsular, Eastern (Mekong River System) and Southeastern (rivers of Southeast Thailand) (Smith, 1945; Vidthayanon, Karnasuta and Nabhitabhata, 1997). The Southeastern rivers system cover a smaller area that of the other systems but within its confines, habitat is diverse varying from mountainous to forested plain and extensive tidal areas covered with marsh grass and mangrove swamps (Smith, 1945). The extremely dendritic three rivers in this region (Chanthaburi, Prasae and Trat rivers) each drain to the Gulf of Thailand via relatively short main channels. Surveys of the fishes of this area are few and not recent. Sidthi (1981, in Vidthayanon, et al., 1997) reported 120 freshwater species from the Chantaburi River with four species being exclusive to the area.

Information on the spatial distribution patterns of fish species and species richness at sampling sites is important to the conservation and management of fishes

(Patton, et al., 2000). Conservation concerns are pressing for freshwater fish and require the development of practical tools that can be used to determine the species composition of threatened habitat (Smith and Jones, 2005). Fisheries biologist and managers often need to estimate fish species richness in a segment of stream (Lyon, 1992). An important and complimentary concern and the objective of the present study is a need to develop an efficient sampling strategy for entire watersheds that will allow for the estimation of the total number of species present including uncommon and even rare species along with fish distributions and habitat associations.

Objectives:

1. To develop an efficient randomized stratified sampling strategy and sound mathematical model to accurately predict the number of species in the wadeable portions of entire watersheds including uncommon species.
2. To examine spatial distributions of the more common species within watersheds.
3. To relate species richness with watershed area and other potentially important physical factors.

Methods:

This study is focusing on small to medium-sized rivers located in Thailand, specifically, Chonburi, Rayong, Chanthaburi and Trat provinces in Southeastern Thailand but is also including rivers in Kanchanaburi, Petchaburi and Prachubkirikhan provinces. Some rivers have been partially sampled while sampling has not yet begun on others. The plan is using 1:50,000 scales maps, with information for 1999, from the Royal Thai Survey Department to distinguish stream order (Strahler, 1966, in Mackie, 2004) and road crossings. Sequence of study sites is being randomly selected within river orders from topographical maps. An effort is be made to select rivers or at least portions of rivers from diverse landscapes. To qualify, water depth must allow for backpack electrofishing, generally not much above one meter. All sites must be understood to have a permanent water supply.

Sampling is by backpack electrofishing (Smith-Root Model 15-D) in the wadeable portions of major rivers and several smaller rivers from among several provinces. Before starting to electrofish, water conductivity is measured to adjust voltage and waveform to maximize capture efficiency and minimize injury to fish. Block nets, 3 mm mesh size, are installed across the upstream and downstream limits of a site to prevent fish escapement. Length of stream at each site is approximately 35 times the mean stream width (Lyons, 1992). Sampling consists of 3 passes over a site. This is expected to assure a capture efficiency in excess of 90% of the fish present (Patton et al., 2000). Those fish that can not be identified in the field are killed by an overdose of methane tricaine sulfunate (MS 222) and preserved in 10% formalin for identification in the laboratory. After initial preservation in formalin, specimens are later permanently preserved in 80% ethanol.

Specimens are indentified from a number of taxonomic keys including: Smith (1945); Brittan (1954); Sontitrat (1976); Dawson (1981); Robert (1986, 1992, 1994); Kottelat (1990, 1994, 1998); Ng and Lim (1990); Karnasuta (1993); Kottelat and Lim (1993); Robert and Kottelat (1993); Rainboth (1996); Fang (1997); Musikasinthorn (1998); Fang and Kottelat (1999); and Ng and Kottelat (2000).

The total number of species within a river system is predicted from a polynomial regression fitted to the cumulative number of new species captured within a river and the total area sampled. This is illustrated in Figure 1.

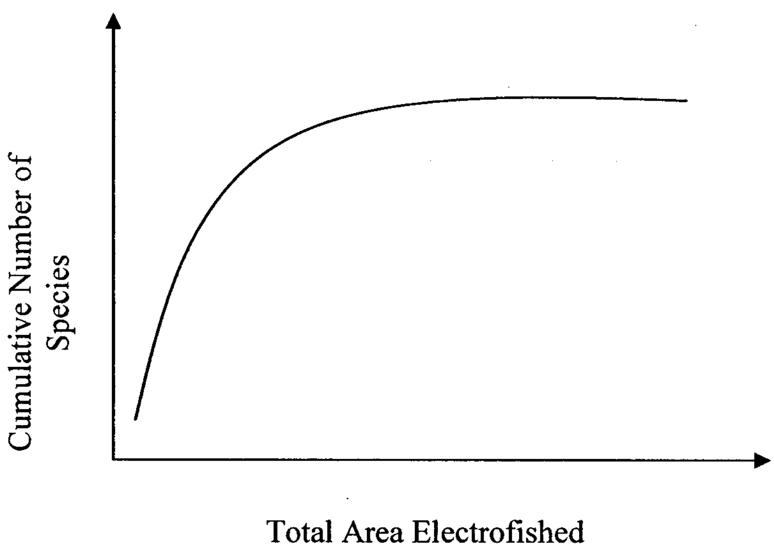


Figure 1. Example of the expected relationship between the cumulative number of new species and the sampled area of a river.

Results:

Initial sampling began on the Prasae River, however, progress was slowed by a prolonged and heavy wet season that caused conditions to be unsafe for electrofishing. However a few sites have been sampled (Table 1) and more sites will need to be sampled. Despite the need for more samples a regression was computed based on the sites sampled and is shown in Figure 2. The figure clearly indicates the capability of the method in predicting total number of species present within a river system. In this example the regression accounts for 96% of the variability among the values of the cumulative number of new species and sampled river area. Extrapolation of the regression to an asymptote suggests a total species number of about 50 in Prasae River and that this can be estimated from a sampled area of about 3000 m^2, or less than 0.1% of the river's total area.

Table 1. Sampled sites on Prasae River indicating river order, mean site width and total area, total number of species found at each site as well as the cumulative number of new species.

Site	Stream order	Area (m^2)	Width (m)	No. of species	No. of new species
1	1	560	4	21	21
2	1	675	4.5	32	11
3	1	300	3	34	3
4	2	300	3	17	2
5	1	420	3.5	29	1
6	2	520	4	22	1
7	1	140	2	11	0

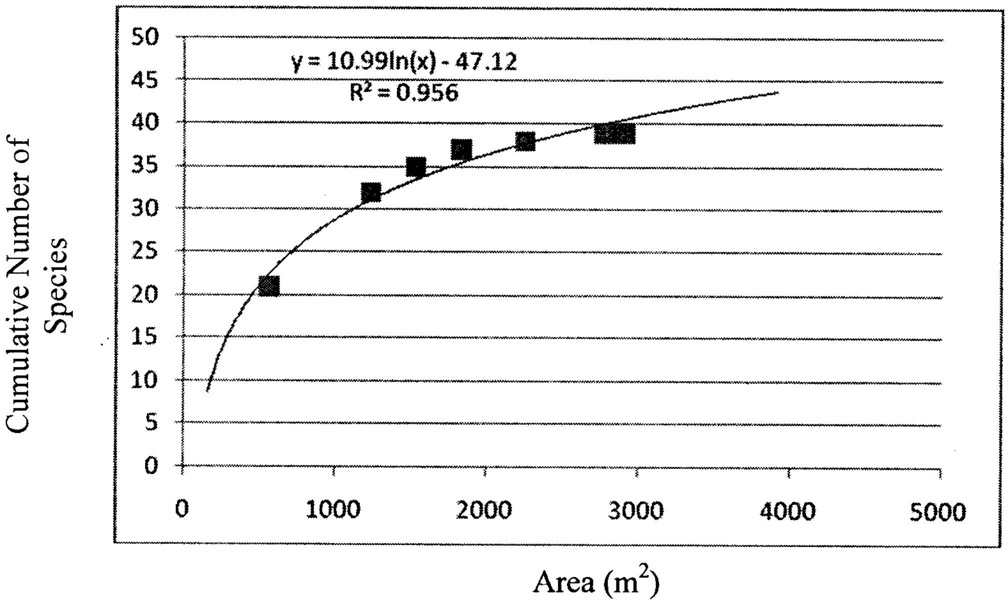


Figure 2. Relationship between cumulative number of new species and electrofished area of Prasae River. In the regression equation, y indicates number of species and x, sample area.

A similar pattern is emerging for other partially completed rivers including Huay Khayeng, Huay Prachan Mai and Huay Ban Rai in Kanchanaburi province (Tables 2, 3 and 4 and Figures 3, 4 and 5) .

Table 2. Sampled sites on Huay Khayeng in Kanchanaburi Province indicating river order, mean site width and total area, total number of species found at each site as well as the cumulative number of new species.

Site	Stream order	Area (m^2)	Width (m)	No. of species	No. of new species
1	3	435.6	9.9	14	14
2	4	283.8	6.6	16	7
3	1	16.06	0.73	6	2
4	3	1721.59	50.8	23	7
5	4	1591.81	54.6	43	17
6	1	14.98	1.07	9	0
7	2	70.11	4.1	14	0
8	3	96.6	4.6	8	0
9	1	19	0.95	7	0
10	3	258.88	19.4	19	1
11	1	30	1	8	0
12	1	388.5	12.6	30	3
13	4	295.67	23	24	3
14	1	83.82	2.2	19	2

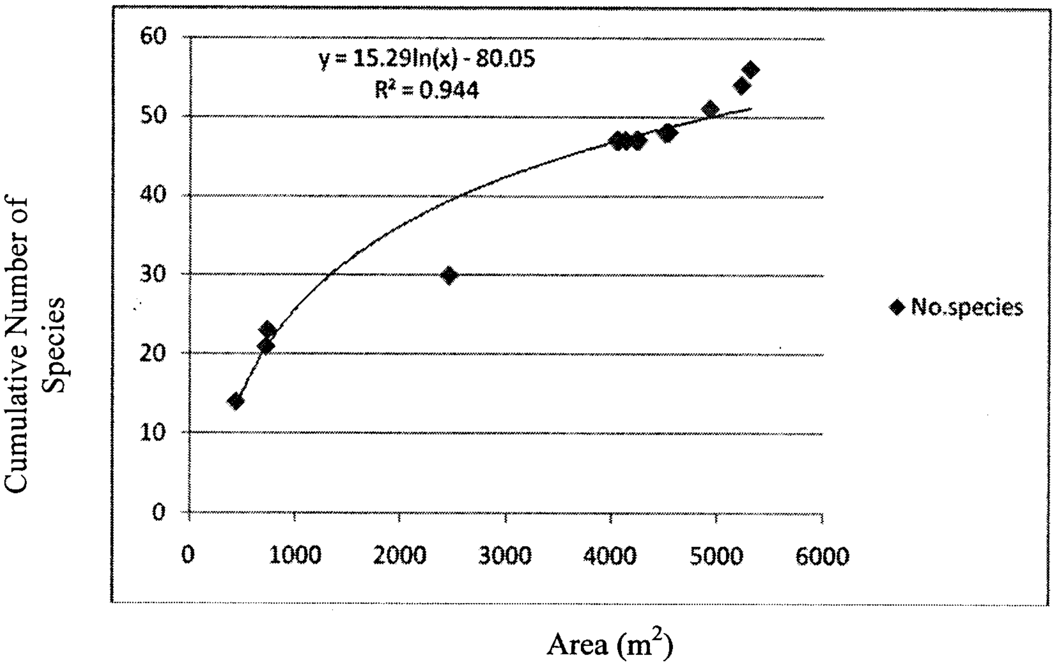


Figure 3. Relationship between cumulative number of new species and area of Huay Khayeng in Kanchanaburi Province electrofished. In the regression, y indicates number of species and x, sample area.

Table 3 Sampled sites on Huay Ban Rai in Kanchanaburi Province indicating river order, mean site width and total area, total number of species found at each site as well as the cumulative number of new species .

Site	Stream order	Area (m^2)	Width (m)	No. of species	No. of new species
1	3	133	3.5	13	13
2	3	176.8	5.2	10	5
3	3	116.25	4.65	17	9
4	3	305	12.2	13	3
5	3	123	4.1	21	4
6	2	224.1	8.3	17	3

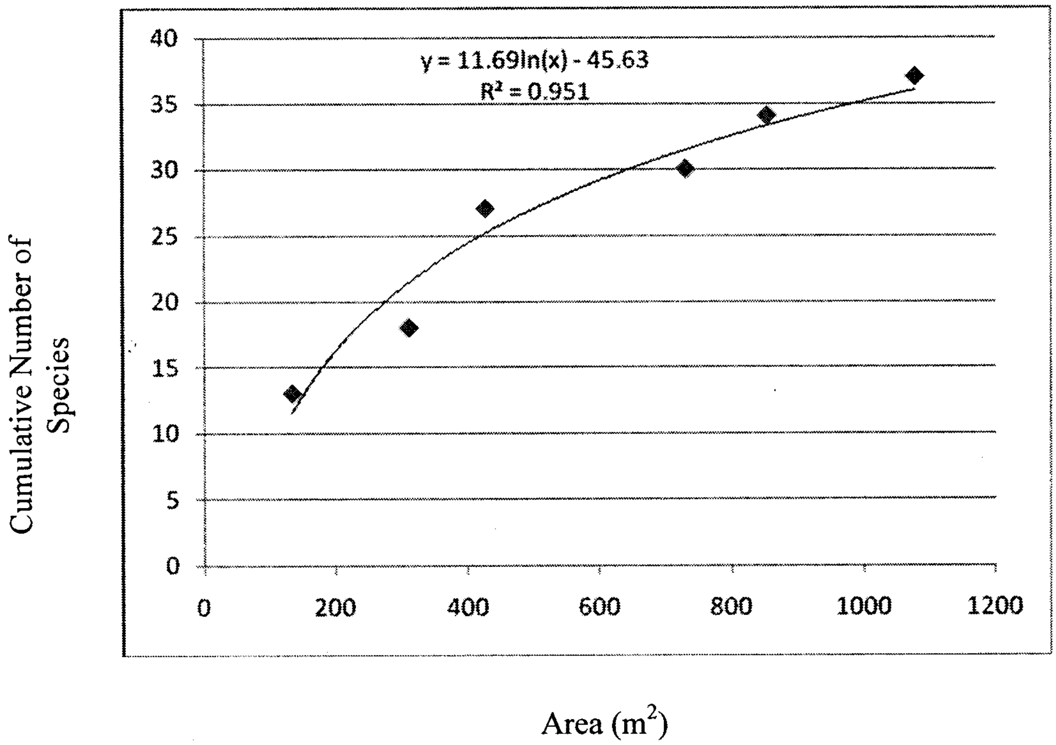


Figure 4. Relationship between cumulative number of new species and area of Huay Ban Rai in Kanchanaburi Province electrofished. In the regression, y indicates number of species and x, sample area.

Table 4 Sampled sites on Huay Prachan Mai in Kanchanaburi Province indicating river order, mean site width and total area, total number of species found at each site as well as the cumulative number of new species .

Site	Stream order	Area (m^2)	Width (m)	No. of species	No. of new species
1	2	102.18	2.6	17	17
2	1	79.5	2.65	19	3
3	1	117.5	9.7	19	2
4	3	436.8	9.1	24	8

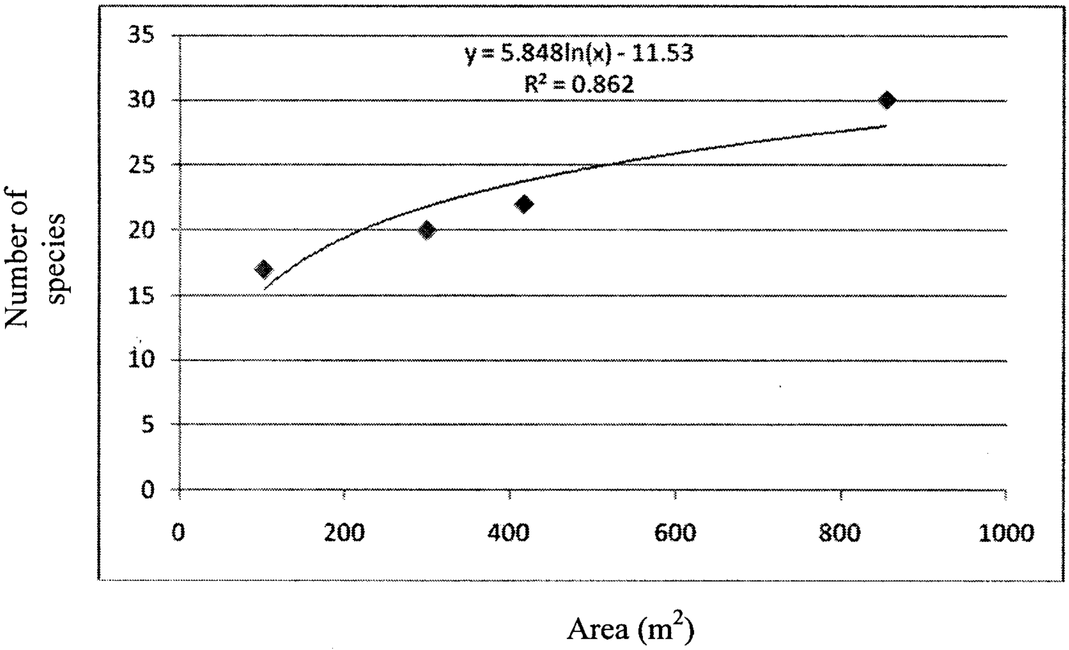


Figure 5. Relationship between cumulative number of new species and area of Huay Prachan Mai in Kanchanaburi Province electrofished. In the regression, y indicates number of species and x, sample area.

Each of the rivers in Kanchanaburi demonstrated a similar pattern in the relationship between number of species and area electrofished, and provided an estimate of the total number of species on the basis of a small fraction of the river's total area.

This study has much still to do but clearly appears an efficient method for estimating the number of species within a watershed on the basis of samples representing only a very small percentage of the total area.

Plan for next reporting period

1. Continue to sample sites from rivers located in several provinces including Chonburi, Rayong, Chanthaburi, Trat Kanchanaburi, Petchaburi and Prachubkirikhan provinces.
2. Begin to calculate polynomial regression equations to predict number of species in each of the completed rivers.
3. Begin to examine species distribution and abundances within watersheds.

Plan for the next period (February, 2009 to December 2011)

Plan	2009-2010		2010-2011	
	2 - 6	7 - 12	1 - 6	7 - 12
1. survey and select sites	←——	——→		
2. Collect samples	←——	——→		
3. Lab. (Identified species)	←——	——→		
4. Write thesis and paper for publication			←——	——→
5. BRT conference			←——	——→

Expected Outcomes:

1. Provide for the first time in Thailand and almost worldwide, an efficient method to estimate the total number of species in an entire watershed within statistically acceptable limits such as ±1 or 2 species.
2. This will allow for comparisons of biodiversity or species numbers within and among landscapes with the potential to identify the important factors in determining fish biodiversity
3. This is a potentially important conservation tool for Thai rivers at the present time and, in the future, to anticipated influences of Climate Changes in Southeast Asia
4. Prepare and defend an MSc thesis and, concurrently, to submit a paper for publication in an international science journal.

D. Why Fish are Where You Find Them

F.W. H. Beamish, Professor

Progress Report for the Period July, 2008 to February, 2009

Introduction

Physical factors such as water velocity, cover and channel size while restrictive to some species pose no barrier to others. Similarly, the physiologies of species have evolved to function over a range of chemical concentrations. Thus while some species require high ambient oxygen concentrations to meet their metabolic needs, others are able to function equally well in much lower concentrations (Beamish, 1964a). Similar patterns have been described for other chemical variables such as carbon dioxide (Beamish, 1964b) and ammonia (Fry, 1971). Unfortunately comparable studies are largely unavailable for species indigenous to Southeast Asia.

Species vary also in their trophic relationships with evidence of a species-related divergence in diet as well as in the particle size of ingested food (Ward-Campbell, 2005). Evidence in hand, while scant for most Thai species, clearly indicates diet to be related to species morphology, in particular mouth position, shape and size (Ward-Campbell et al., 2005). Body shape is also intimately associated with diet as well as habitat. Body shape, fin size, shape and location to a significant extent determine where in the water column fish can live. Density and fish buoyancy is also important in facilitating a benthic or pelagic lifestyle. Thus, variations in these characteristics among species not only direct species to occupy different habitats but also to different food resources thereby favoring multi species coexistence through a reduction in competition pressures.

The objective of the current study represents a synthesis of several completed projects previously supported by BRT as well as a current project for which little to no money is required with the objective of determining why fish species are where they are found in rivers. The synthesis will include the importance of habitat, including chemical and physical characteristics along with fish morphology, in relation to diet and their physical location within rivers. It is recognized that the chemical environment also exercises influence on fish distribution but the physiological studies required to demonstrate these relationships is beyond the capacity of this study. However, inferences will be drawn for earlier studies on temperate fishes. Other studies include the density of fish (fish mass relative to that of water), as well as morphological measurements to determine habitat or dietary adaptations such as for living in fast flowing water, such as holding their position in fast flowing water with a comparatively small expenditure of energy or having the appropriate body and fin shapes and sizes to enable them to swim against strong currents.

Objectives:

1. To identify and integrate important abiotic and biotic factors in understanding why selected species of river fishes are able to live in the habitats where they are found. The study is being through an integrative synthesis of morphological, hydrodynamic and presumed physiological characteristics. Consideration of the roles of other factors including competition, predation and diet will also be considered.

Results:

Chemical and physical associations among riverine fish have been analyzed by species richness and total abundance of all species as well as species within families. Cumulative species richness for all families is negatively and positively related with pH and dissolved oxygen, respectively. Cumulative abundance varies inversely with discharge and ambient ammonia and directly with depth, substratum particle size, oxygen and alkalinity. Canonical correspondence analysis has related species across all families and their relative abundance with eight environmental variables into four groups (Figure 1). The most species-rich group is associated with approximately average values for the significant variables. The group with the fewest species is associated with high oxygen and low ammonia and alkalinity. The other two groups have similar species numbers, one being associated with high ammonia and alkalinity and low oxygen. Species in the last group are found at locations where rivers are relatively wide with comparatively high oxygen and low ammonia concentrations.

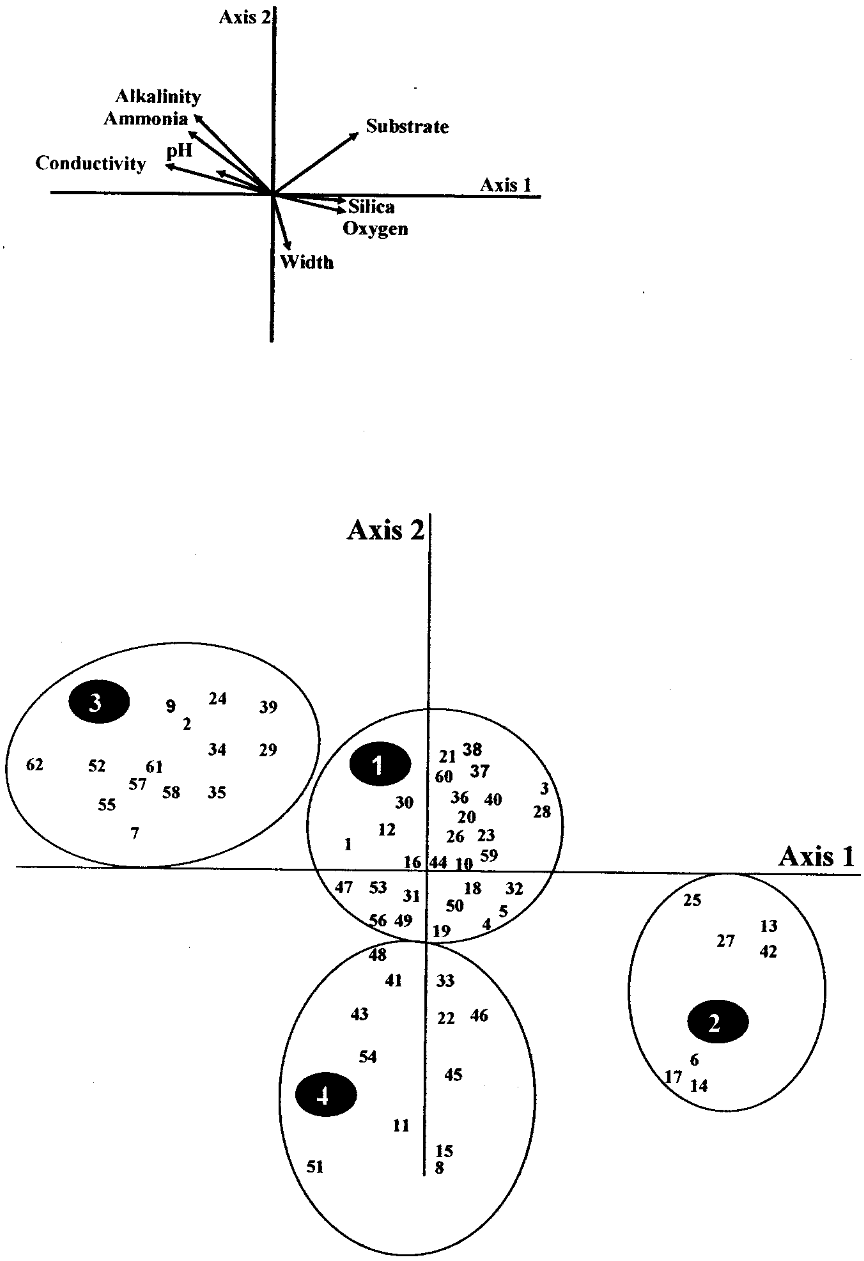


Figure 1. Distribution of fish species across all families with respect to significant habitat variables. The upper panel illustrates the significant habitat variables on axis one and two and, for each, the vector length and direction. The lower panel locates species in relation to axis one and two. Numbers indicate species (see Tonnunui & Beamish, 2009).

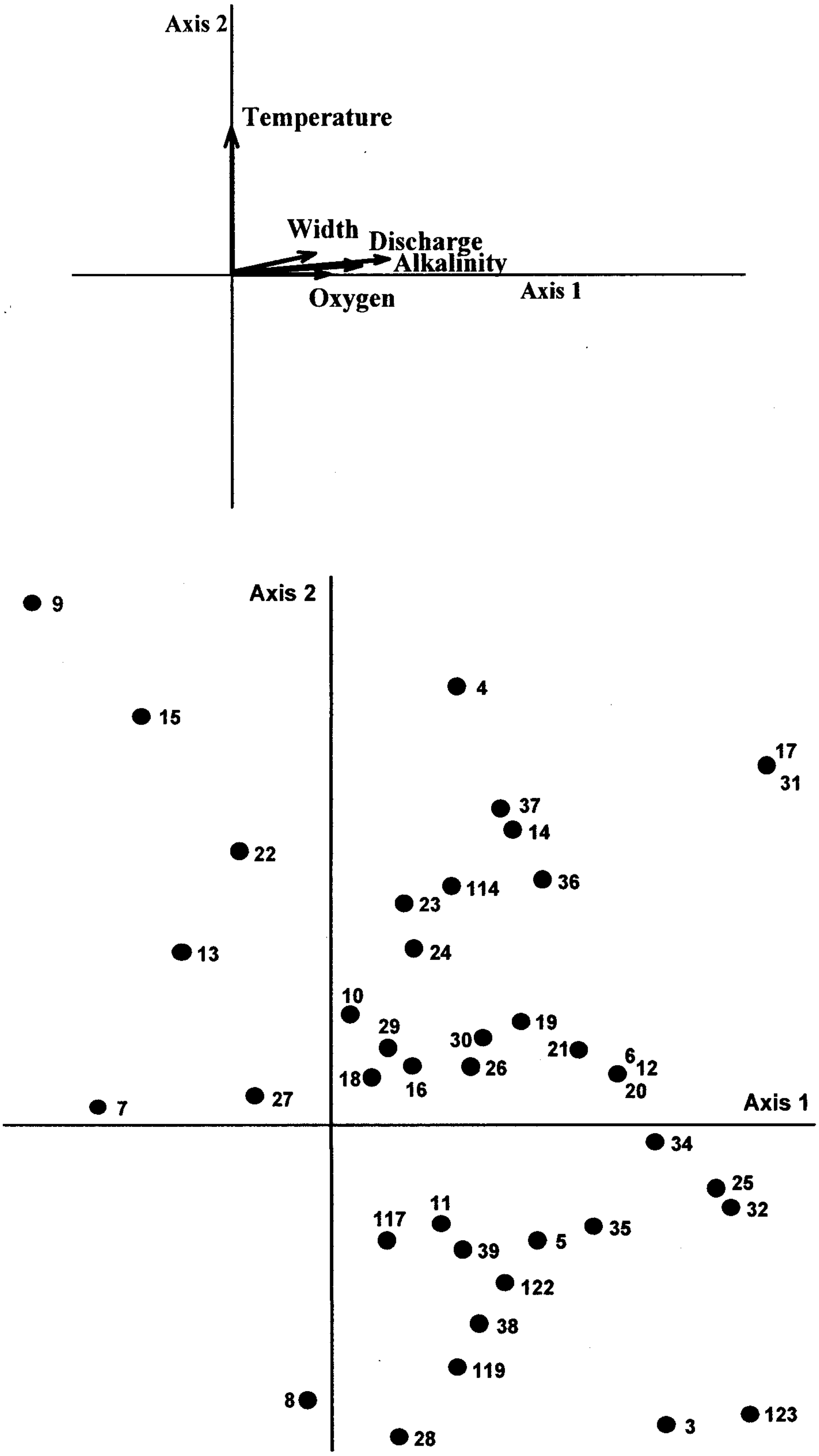


Figure 2. Distribution of species within the Family Cyprinidae with respect to significant habitat variables identified by canonical correspondence analysis. Numbers represent species in the Family Cyprinidae (Beamish et al., 2006).

Important environmental variables with respect to species within families have also been identified (e.g. Beamish et al., 2006). For example, within the Family Cyprinidae, total abundance varies directly with water velocity and inversely with discharge while species richness varies inversely with river width and directly with oxygen and alkalinity. Canonical correspondence has identified five significant habitat variables, temperature, river width, discharge, oxygen, and alkalinity that influence the distribution of individual cyprinid species (Figure 2). Similar analyses have been conducted on the other prominent families of fishes and the results published (see reference list).

Measurements have been made on density and buoyancy for many species (Table 1, the latter equated to a fish's weight in water relative to its mass in air. Density, as mass divided by weight of water displaced adjusted to a constant temperature was not significantly correlated ($P > 0.05$) with either total length or mass for any of the 30 species of fish that have so far been examined. Further, density was not correlated with habitat water velocity for any of the 10 species for which this relationship has been examined. In contrast to density, buoyancy is much greater among pelagic than benthic species based on the relatively few species and numbers of individuals measured. Buoyancy is nearly neutral among the pelagic cyprinids which is important to their swimming performance. In many of the cyprinid species examined in this study, maximum body depth was quite large relative to the non cyprinids examined. Depth, in some cases assisted by large or heavy fins serves to increase body mass and the propulsive forces needed for acceleration (Lighthill, 1975; Figure 3). A deep body may also be beneficial for maneuverability due to a reduction in inertia around the turning axis (Alexander, 1967) but equally may be associated with slow swimming speeds, a behavior observed among the deep bodied *P. partipentozona, Mystcoleucus marginatus, Puntius binotatus* and *O. hasselti.*

Cyprinids also have a deep caudal peduncle with a maximum of 21% of standard length in *Puntius partipentozona* and 13-16% in the other species. Deep caudal peduncles facilitate fast acceleration, of importance to predator avoidance and prey capture.

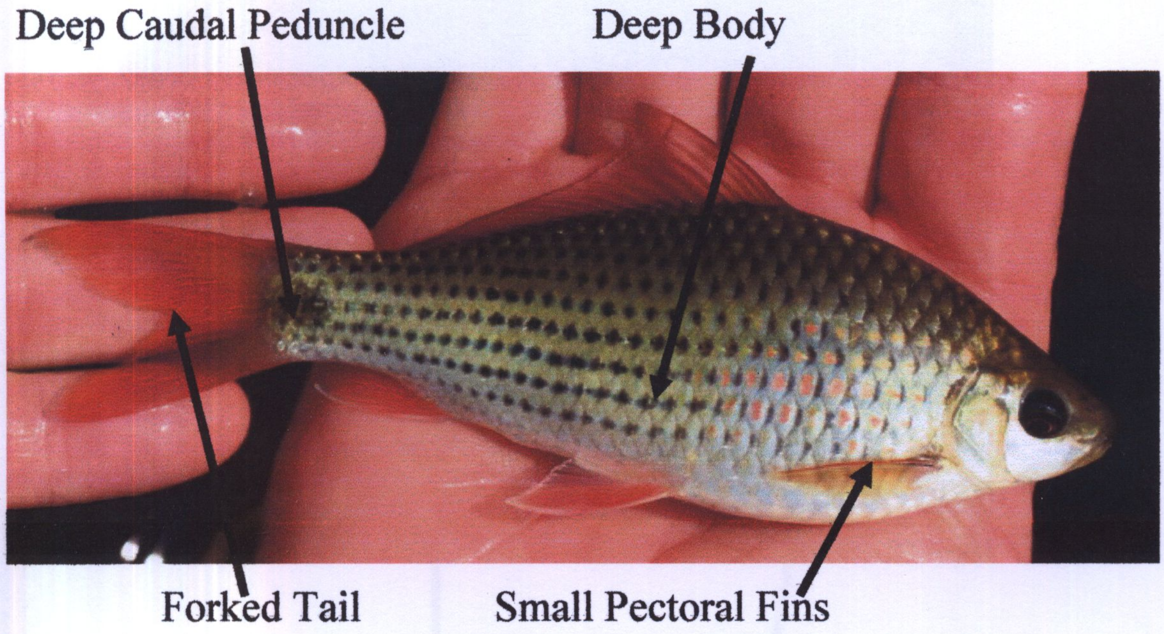


Figure 3. Illustration of the caudal peduncle and body depth of *Osteochikus hasselti*, a species in the Family Cyprinidae.

Figure 4. Illustration of the disc-shaped body of *Nandus* sp. associated with good maneuverability and slow swimming speeds.

The slightly more fusiform body shape of the *Rasbora, Devario* and *Danio*, along with a forked tail have been associated with continuous or sustained swimming but at relatively slow speeds which is consistent with their common occurrence in the slower flowing riffle regions of rivers (Figure 5). Other species such as the slow moving snakeheads or *Channa* are characterized by a rounded tail

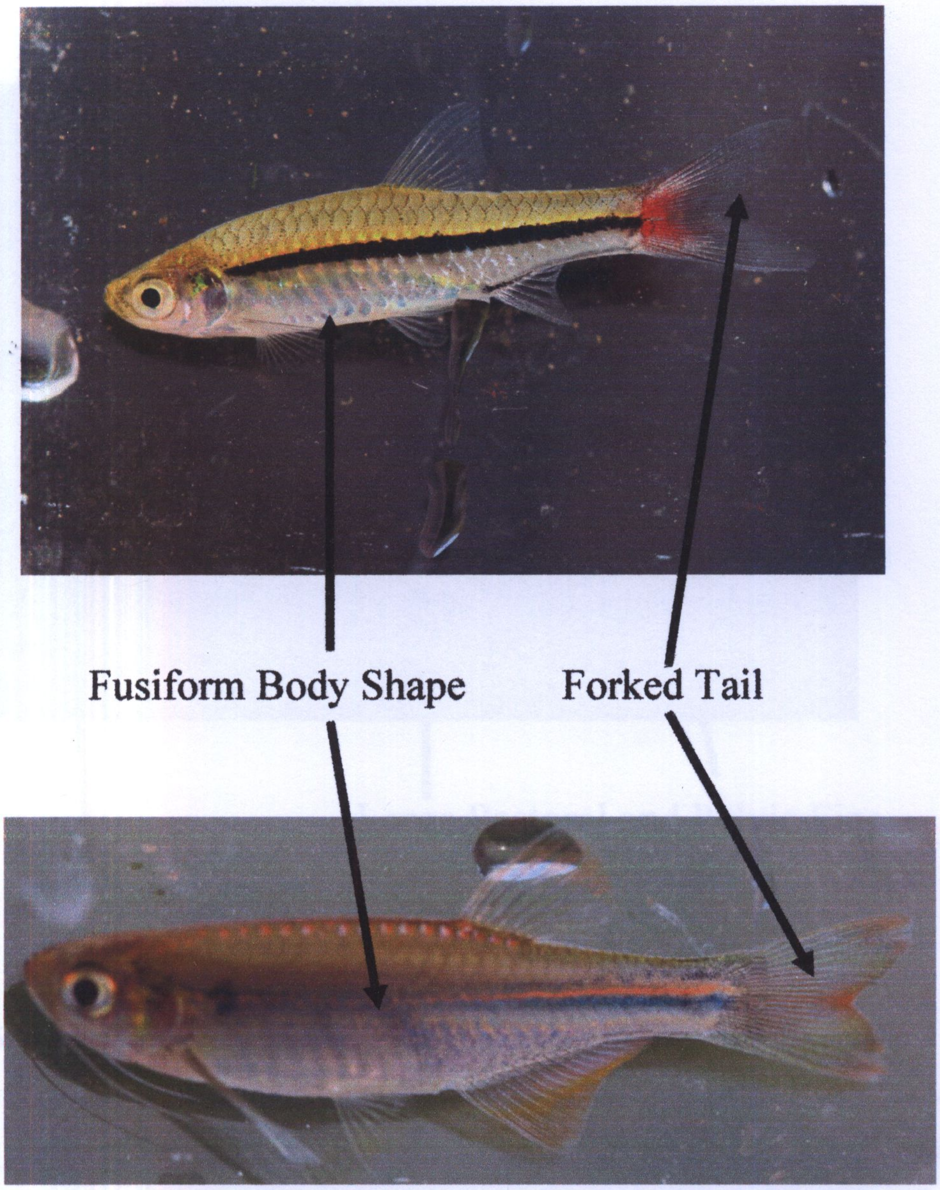


Figure 5. Fusiform body shape and forked tail in two species in the Family Cyprinidae, *Rasbora borapetenss* (upper panel) and *Danio albolineatus* (lower panel).

We have measured other body proportions including fin shape, area and location along with their angle of insertion for many species of fishes (Table 2 and 3), all relative to total and standard length and weight, and all of which are considered important to swimming performance as well as to maintaining a benthic lifestyle in fast flowing water. Currently, these measurements are being analysed and ultimately related to habitat and swimming behavior.

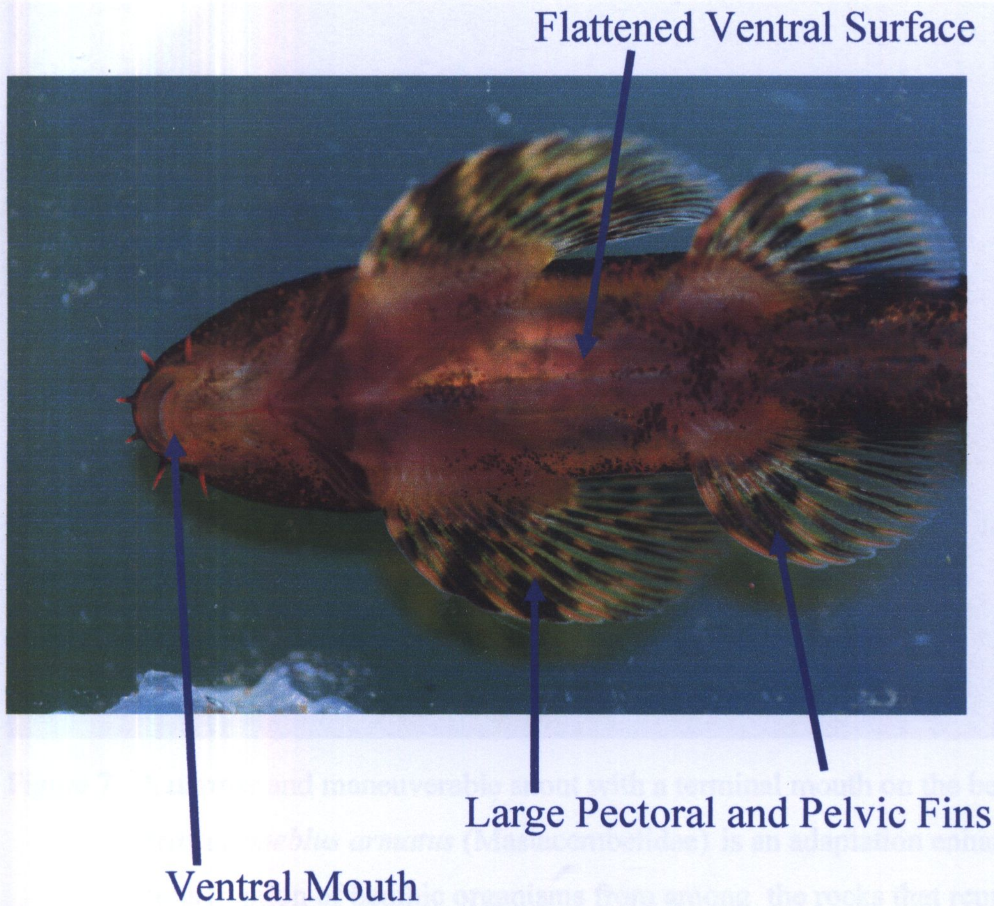


Figure 6. Ventral view of *Homaloptera smithi* (Family Balitoridae), a benthic species, showing the ventral insertion of their large pectoral and pelvic fins used as hydroplanes to hold station against the substratum in fast flowing currents. Station-holding is assisted further by a flattened ventral surface. The ventrally located mouth is an adaptation for feeding on benthic organisms.

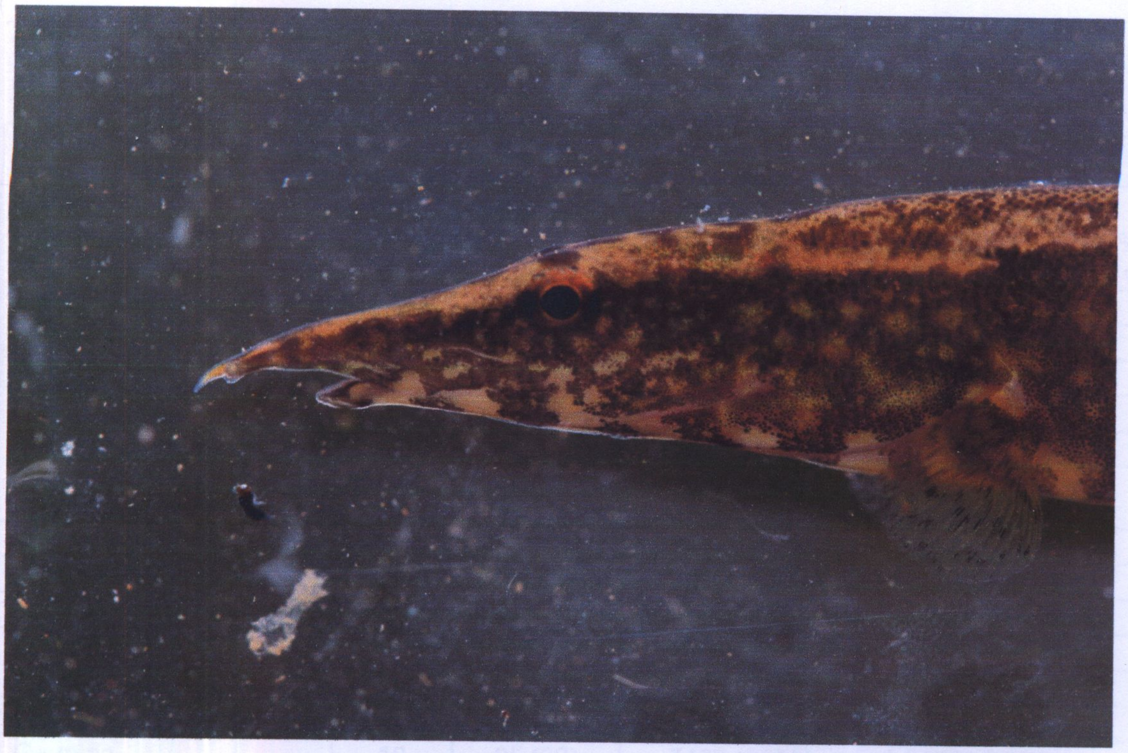


Figure 7. A narrow and maneuverable snout with a terminal mouth on the benthic *Mastacemeblus armatus* (Mastacembelidae) is an adaptation enhancing the consumption of benthic organisms from among the rocks that represent the majority of its habitat.

Measurements are also being made on benthic species including the static friction coefficient, the angle at which an immobilized fish, with its ventral surface against the bottom of the tube, begins to slide within a tube filled with water and is an indication of a species' innate capacity to adhere to the substrate. It is difficult to obtain static friction coefficient values for pelagic species as their compressed profile encourages more contact with the lateral than ventral body surface. As well some species have special structures such as suction devices along the fin rays (e.g. the balatorids) that aid in adhering to rocks and other hard surfaces on the substrate. These are being noted.

Recently Professor Dr. Wiehs, Faculty of Aerospace Engineering, Haifa, Israel, a world authority on biomechanics particularly in relation to fish swimming has agreed to collaborate on the interpretation of fish morphology in regards where species are found in rivers. He now has photos of many of the species of interest and I am awaiting his interpretation.

Table 1. Density and upthrust relationships for several fish species

Species	Sample Size	Total length Mean (SD) mm	Weight Mean (SD) mg	Density	Upthrust % initial weight
Devario acrostomus	47	62 (21)	4041 (4240)	0.9788 (0.1147)	
Rasbora borapetensis	16	40 (6)	694 (573)	1.0247 (0.0823)	87.3
Rasbora caudimaculata	4	76 (9)	4478 (1656)	1.0249 (0.0270)	
Rasbora paviei	50	66 (21)	3845 (3251)	0.9951 (0.0449)	93.8
Neolissochilus soroides	7	101 (51)	19351 (24309)	1.0235 (0.0732)	96.9
Mystacoleucus marginatus	29	89 (14)	9112 (4600)	1.0157 (0.0574)	92
Poropuntius hamploides	4	110 (25)	15723 (8259)	1.0366 (0.0096)	
Poropuntius deauratus	13	100 (27)	13276 (9698)	1.0049 (0.1009)	96.2
Puntius binotatus	50	77 (20)	5832 (4555)	1.0136 (0.0476)	95.4
Puntius orphoides	7	106 (19)	16896 (9160)	1.0081 (0.0326)	97.2
Puntius partipentazona	8	36 (4)	734 (288)	0.9842 (0.1076)	82.2
Osteochilus hasselti	14	85 (29)	9585 (11842)	1.0153 (0.0496)	
Garra sp.	10	95 (22)	7432 (3856)	1.0158 (0.0711)	
Acanthocobitis zonalternans	10	45 (3)	801 (223)	1.0202 (0.0771)	
Homaloptera smithi	22	54 (16)	1597 (1527)	1.0213 (0.0568)	
Homaloptera sp.	15	49 (5)	1047 (357)	1.1259 (0.0730)	
Schistura desmotes	22	51 (11)	1154 (634)	1.0779 (0.0975)	
Acanthopsis sp.	10	127 (60)	13941 (12365)	1.0735 (0.0643)	
Pseudomystus siamensis	3	83 (21)	6950 (4487)	0.9914 (0.0475)	
Glyptothorax platypogonoides	5	86 (14)	5310 (2407)	1.0863 (0.0609)	
Mystus sp.	11	82 (7)	5742 (2092)	1.0162 (0.0619	
Amblyceps foratum	4	62 (13)	1325 (744)	1.0225 (0.0599)	87
Dermogenys pusillus	28	44 (9)	277 (151)	0.9919 (0.0804)	
Xenentodon cancila	8	122 (42)	4047 (4991)	1.0181 (0.1616)	
Monopterus albus	10	221 (89)	13174 (17792)	1.0591 (0.071)	
Macrognathus circumcintus	10	148 (59)	14446 (19356)	1.0547 (0.0295)	86.1
Mastacembelus armatus	26	163 (48)	14990 (12024)	1.0507 (0.0730)	89
Oxyeleotris marmorata	13	68 (14)	3750 (2463)	1.0497 (0.0914)	
Rhinogobius sp	17	35 (4)	452 (140)	1.0426 (0.1236)	
Channa gachua	41	115 (580	25778 (54141)	1.0637 (0.0677)	94

Table 2. Body morphometrics for several river fishes

Sample size	*Homaloptera smithi* 10	*Schistura kohchangensis* 10	*Balitora sp.* 10	*Glyptothorax platypgonoides* 10
Body shape; overall / cross section	fusiform / compressed	fusiform /compressed	depressiform / triangular	depressiform / triangular
Total length, live (mm) , preserved (mm)	54.9 (7.2) 52.4 (6.8)	58.2 (10.2) 55.7 (10.2)	72.7 (16.1)	90.6 (17.9) 86.7 (19.3)
Standard length, live (mm) , preserved (mm)	45.7 (6.0) 43.5 (5.8)	54.9 (11.1) 46.4 (8.7)	59.3 (11.1)	76.4 (14.1) 70.2 (15.3)
Mass, live (mg) , preserved (mg)	1895 (811) 1774 (770)	2242 (980) 1713 (712)	2540 (1896)	6262 (3281) 5638 (3317)
Weight, (water/air %)	12.7 (2.7)			9.7 (0.3)
Condition factor, (mass/TL3)	1.067 (0.158)	0.891 (0.300)		
Density, (mass/volume)				1.1316 (0.1670)
Body width, maximum (mm)	8.87 (2.52)	7.00 (1.77)	9.19 (2.24)	10.6 (2.25)
Body depth, maximum, (mm)	8.02 (2.13)	7.98 (1.70)	8.09 (1.37)	11.85 (2.42)
Mouth location	subterminal	subterminal	subterminal	inferior
Mouth gape, (mm)	3.58 (0.59)	2.64 (0.28)	2.53 (2.00)	7.42 (1.90)
Mouth height, (mm)	1.13 (0.12)	0.90 (0.18)	0.85 (0.22)	3.23 (0.25)
Eye position and size	superior / small	superior / small	superor / small	superior / small
Caudal peduncle shape	long	long	long	
Caudal peduncle length, (mm)	16.46 (2.4)	16.1 (3.0)	23.8 (4.5)	16.2 (4.3)
Caudal peduncle depth, maximum (mm)	6.1 (1.2)	6.8 (1.4)	6.8 (1.5)	7.0 (1.7)
Caudal peduncle width, maximum, (mm)	5.3 (0.3)	4.5 (1.0)	6.2 (1.6)	5.0 (1.4)
Tail shape	emarginate	emarginate	forked	forked
Tail area, (mm2)	68.7 (16.7)	102.7 (32.2)	98.9 (35.3)	235.1 (106.4)
Dorsal fin shape and location	short / mid	short /mid	short / mid	short / anterior
Dorsal fin area, (mm2)	25.4 (4.8)	45.8 (14.3)	48.3 (18.1)	91.3 (37.6)
Pectoral fin shape and location	4 / low	1 / low	4 / fan	5 (large spine) / low
Pectoral fin area, (mm2)	47.8 (12.5)	43.4 (9.5)	89.4 (36.0)	124.4 (48.4)
Pectoral fin, insertion angle (degrees)	4.9 (0.2)	2.6 (0.4)	2.3 (0.4)	1.7 (0.5)
Anal fin location	posterior	posterior	posterior	posterior
Anal fin area, (mm2)	16.3 (2.6)	31.6 (9.6)	24.9 (11.1)	89.8 (37.0)
Pelvic fin shape and location	large / subabdominal	medium /	large / posterior	mid / posterior
Pelvic area, (mm2)	71.6 (19.1)	35.6 (9.2)	58.5 (20.4)	99.0 (34.5)
Static friction coefficient, tan of angle	50.8 (8.5)	37.4 (4.6)	33.1 (2.4)	38.1 (3.1)

Table 3. Body morphometrics for two species of river fshes.

Sample size	*Amblyceps macronatum* 10	*Channa gachua* 10
Overall body shape / cross section	fusiform / triangular	fusiform / oval / triangular
Total length, live (mm)	74.3 (9.9)	
, preserved (mm)	69.7 (8.7)	108.2 (20.1)
Standard length, live (mm)	59.7 (7.7)	
, preserved (mm)	56.1 (7.3)	90.9 (15.6)
Mass, live (mg)	2442 (947)	12000 (7060)
, preserved (mg)	2278 (844)	
Weight, (water/air %)	10.3 (0.9)	
Condition factor, (mass/TL3)	0.567 (0.043)	
Density, (mass/volume)	0.9853 (0.1269)	
Body width, maximum (mm)	6.7 (1.0)	15.6 (3.6)
Body depth, maximum, (mm)	8.0 (1.3)	15.2 (3.5)
Mouth location	terminal	terminal
Mouth gape, (mm)	5.8 (0.9)	10.1 (2.4)
Mouth height, (mm)	1.48 (0.14)	5.3 (1.0)
Eye position and size	superior / small	superior / medium
Caudal peduncle shape	short	short
Caudal peduncle length, (mm)	8.7 (1.3)	6.5 (1.0)
Caudal peduncle depth, maximum (mm)	7.8 (1.4)	9.2 (2.2)
Caudal peduncle width, maximum, (mm)	1.7 (0.2)	2.9 (0.5)
Tail shape	forked	rounded
Tail area, (mm2)	165.8 (50.4)	362.1 (148.1)
Dorsal fin location	anterior	anterior
Dorsal fin area, (mm2)	45.9 (11.6)	294.9 (121.3)
Pectoral fin shape and location	large spine / ovate / low	6 / oval / mid / low
Pectoral fin area, (mm2)	38.9 (9.9)	208.6 (76.1)
Pectoral fin, insertion angle (degrees)	- 3.0 (-0.2)	10.2 (2.7)
Anal fin location	posterior	middle
Anal fin area, (mm2)	49.3 (14.3)	193.8 (75.5)
Pelvic fin shape and location	small / posterior	small / anterior
Pelvic area, (mm2)	24.5 (5.7)	34.2 (8.3)
Static friction coefficient, tan of angle	43.4 (3.6)	46.2 (4.6)

Plan for Next Reporting Period and Expected Outcomes

I expect to prepare a manuscript summarizing these observations within the next year and will submit to an international journal for publication. Equally important, it is hoped this information will contribute understanding and guidance for the conservation of river ecosystems, particularly those ecosystems in the headwaters of Thailand's important river systems.

References

Alexander, R. McN. (1967). Functional design in fishes. London, U.K. Hutchinson University Library.

Angermeier, P.L. & I.J. Schlosser. 1989. Species- area relationships for stream fishes. Ecology 70(5): 1450-1461.

Ayala, F. J. 1969. Experimental invalidatuion of the principle of competitive exclusion. Nature. 224: 1076- 1079.

Bagenal, T. B., & Braum, E. 1968. Eggs and early life history. In IBP Handbook (No. 3): Methods for Assessment of Fish. Production in Fresh Waters (W. E. Ricker, Ed.), (160-169 pp.). London: Blackwell Scientific Publications.

Banarescu, P. 1971. Further studies on the systematics of cultrinae with reidentification of type specimens (Pisces, Cyprinidae). Rev. Roum. Biol-Zoologie16, 9-19.

Beamish, F. W. H. (1964a). Respiration of fishes with special emphasis on standard oxygen consumption. Part III. Influence of oxygen. Canadian Journal of Zoology 52: 355-366.

Beamish, F. W. H. (1964b). Respiration of fishes with special emphasis on standard oxygen consumption. Part IV. Influence of carbon dioxide and oxygen. Canadian Journal of Zoology 52: 847-856.

Beamish, F.W.H., R.W. Griffiths, C. Kongchaiya, P. Sa-ardrit & P. Sonchaeng. 2005. Seasonal fish abundance in three Thailand streams: influence of discharge. Journal of Tropical Biology 14: 37-60.

Beamish, F.W.H. & P. Sa-ardrit. 2006. Siluriform fishes and their habitat in small rivers in central Thailand. Journal of Tropical Freshwater Biology 15:1-21.

Beamish, F. W. H. & P. Sa-ardrit. 2007. Abundances and habitat sensitivities of some fishes in Thailand. Journal of Tropical Freshwater Biology. 16(1): 57-73.

Beamish, F.W. H., P. Sa-ardrit & S. Tongnunui. 2006. Habitat characteristics of the Cyprinidae in small rivers in central Thailand. Environmental Biology of Fishes. 76:237-253.

Beamish, F. W. H., P. Sa-ardrit & V. Chevaporn. 2008. Habitat and abundance of Balitoridae in small rivers in central Thailand. Journal of Fish Biology 72: 2467-2484.

Brett, J. R. 1979. Environmental factors and growth. In Fish Physiology, Volume 8. Hoar, W. S., Randall, D. J. & Brett, J. R., ed., pp.599-675. Academic Press, New York.

Brewer, S. K., Rabeni, C. F., & Papoulias, D. M. 2008. Comparing histology and gonadosomatic index for determining spawning condition of small-bodied riverine fishes. Ecology of Freshwater Fish, 17, 54-58.

Burridge, M. E. 1992. Systematics of the *Acanthophthalus kuhlii* Complex (Teleostei: Cobitidae), with the Description of a New Species from Sarawak and Brunei. Copeia 1 :172-186.

Colwell, R. K. & J. A. Coddington. 1994. Estimating terrestrial biodiversity through extrapolation. Philos. Transactions of the Royal Society of London Ser. B Biological Science 345: 101-118.

Dawson, C. E. 1981. Review of the Indo-pacific Doryrhamphine Pipefish genus Doryichthys. *Japanese Journal of Ichthyology* 28 (1), 1-18.

de Vlaming, V., Grossman, G. and Chapman, F. 1982. On the use of gonadosomatic index. Comp. Biochem. Physiol., 73A: 31-39.

Dekkers, W. J. 1975. Review of the Asiatic freshwater puffers of the genus *Tetraodon* Linnaeus, 1758 (Pisces, Tetraodontiformes, Tetraodontidae). Bijdragen tot de Diekunde 45, 87- 142.

Dobyns, J. R. 1997. Effects of sampling intensity on the collection of spider (Araneae) species and the estimation of species richness. Environmental Entomology 26: 150-162.

Dudgeon, D. 1999. Tropical Asian stream zoobenthos, Ecology and conservation. Hong Kong. Hong Kong University Press.

Erickson, D.L., J.G. Hightower, and G.D., Grossman, 1985. The relative gonadal index, an alternative index for quantification of reproductive condition. Comp. Biochem. Physiol. 81A: 117-120.

Fang, F. 1997. *Danio maetaengensis,* a new species of cyprinid fish from Northern Thailand. Ichthyological Exploration of Freshwater, 8(1), 41-48.

Fang, F. & Kottelat, M. 1999. Danio species from Northern Laos with descriptions of three new species (Teleostei: Cyprinidae). Ichthyological Exploration of Freshwater, 10(3), 281-295.

Fitzpatrick, J. F. 1983. How to know the freshwater crustacea. United States of America.Wm. C. Brown Company.

Fry F. E. J. 1971. The effects of the environmental factors on the physiology of fish. In: Fish Physiology, Volume 6. (Edited by Hoar WS and Randall DJ), pp 1-98. Academic Press, Inc, New York.

Gilpin, M. E. & K. E. Justice. 1972. Reinterpretation of the invalidation of the principle of competitive exclusion. Nature 236: 273- 274; 299-301.

Gimaret-Carpentier, C., R. Pelissier, J.P. Pascal & F. Houllier. 1998. Sampling strategies for the assessment of tree spoecies diversity. Journal of Vegetation Science 9: 161- 172.

Gorman, O. T. & J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59: 507- 515.

Hartley, B., Barber, H. G. and Carter J. R. 1996. An atlas of British diatoms, Biopress, Bristol.

Hugueny, B. 1989. West African rivers as biogeographic islands: species richness of fish communities. Oecologia 79: 236- 243.

Huston, M. 1979. A general hypothesis of species diversity. The American Naturalist, 113 (1): 81-101.

Karasuta, J. 1993. Systematic revision of Southeastern Asiatic cyprinid fish genus *Osteochilus* with description of two new species and a new subspecies. Kasetsart University Fishery Research Bullatin, 19.

Kottelat, M. 1984. Revision of the Indonesian and Malaysian Loaches of the subfamily Neomacheilinae. Japanese Journal of Ichthyology 31, 225-260.

Kottelat, M. 1988. India and Indochinese species of *Balitora* (Osteichthyes: Cypriniformes) with descriptions of two new species and comments on the family-group names balitoridae and Homalopteridae. *Revue Suisse de Zoologie*, 95, 487-504.

Kottelat, M. 1989. Zoogeography of the fishes from indochinese inland waters with an annotted check-list. Bulletin Zoologisch Museum 12, 1-55.

Kottelat, M. 1990. Indochinese Nemacheilines, a Revision of nemacheiline Loaches *(Pisces: Cypriniformes)* of Thailand, Burma, Laos, Cambodia and Southern Viet Nam. Munchen: Verlag Dr. Frieddrich Pfeil.

Kottelat, M.1994. Diagnoses of two new species of fighting fishes from Thailand and Cambodia (Teleostei: Belontiidae). Ichthyological Exploration of Freshwater, 5(4), 297-303.

Kottelat, M. 1998. *Homaloptera yuwonoi*, a new species of hillstream loach from Borneo, with a new generic name for *H. thamicola* (Teleostei: Balitoridae). Ichthyological Exploration of Freshwaters 9, 267-272.

Kottelat, M. 2000. Diagnoses of a new genus and 64 new Species of fishes from Laos (Teleostei: Cyprinidae, Balitoridae, Bagridae, Syngnathidae, Chaudhuriidae and Tetraodontidae). Journal of South Asian Natural History 5, 37-82.

Kottelat, M. & Lim, K.K.P. 1993. A review of the eel-loaches of the genus *Pangio* (Teleostei: Cobitidae) from the Malay Peninsula, with descriptions of six new species. Raffles. Bull. Zool., 41, 23-249.

Lee, P. G. and Ng, P. K. L.1994.The systematics and ecology of snakeheads (Pisces: Channidae) in Peninsular Malaysia and Singapore. *Hydrobiologia* 285, 59-74.

Lighthill, M. J. 1975. Mathematical biofluiddynamics. Philadelphia, Pennsylvania; Society of Industrial and Applied Math.

Lind, O.T. 1974. Handbook of Common Methods in Limnology. Saint Louis. The C.V. Mosby Company.

Lowe-McConnell, R.H. 1987. Ecological studies in tropical fish communities (3rd ed.). United State of America: CambridgeUniversity.

Lyons, J. 1992. The length of stream to sample with a towed electrofishing unit when fish species richness is estimated . North American Journal of Fishery Management 12: 198-203.

Mahon, R. 1984. Divergent structures in fish taxocenes of north temperate streams. Canadian Journal of Fish and aquatic Sciences 41: 330-350.

McCafferty, W. P. 1981. Aquatic Entomology: The Fisherman's and Ecologist's Illustrated Guilde to Insect and Their Relatives. Science Books International, Boston, MA.

McCann, K. S., A. Hastings & D. R. strong. 1998. Trophic cascades and trophic trickles in pelagic food webs. Proceedings of the Royal Society London B, 265: 205- 209.

Mackie, G.L. 2004. Applied aquatic ecosystem concepts. Kendall/Hunt Publ. Comp. xxvi + 757 p.

McGehee, R. & R. A. Armstrong. 1977. Some mathematical problems concerning the ecological principle of competitive exclusion. Journal of Differential Equations 23: 30- 52.

Merritt , R.W. and Cummins, K. W. 1996. An introduction to the Aquatic Insects of North America, 3 rd ed. Kendall/Hunt, Dubuque, IA.

Mizuno, T. 1979. Illustrations of the freshwater plankton of Japan. Hoikusha publishing, Japan.

Moreno, C. E. & G. Halffter. 2001. On the measure of sampling effort used in species accumulation curves.. Journal of Applied Ecology 38: 487- 490.

Morse, J. C., Lianfang, Y. and Lixin, T. 1984. Aquatic insects of China useful for monitoring water quality, 2 nd ed. Kendall/Hunt, Dubuque, USA.

Moyle, P. B. & B. Herbold. 1987. Life history patterns and community structure in stream fishes of Western North America.: comparisons with Eastern North America and Europe. Pp. 25-34. In W.J. Matthews & D.C. Heins (ed.) Community and Evolutionary Ecology of North American Stream Fishes, University of Oklahoma Press, Norman.

Musikasinthorn, P. (1998). Rediscovery of the Pangasiid Catfish *Helicophagus typus* in Borneo. Nat. Hist. Bull. Siam. Soc., 46, 197-201.

Musikasinthorn, P. 2003. Channoidei (Snakeheads) Grzimek's Animal Life Encyclopedia. 4, 437-447.

Neave, H. M., R.B. Cunningham, T.W. Norton & H. A. Nix. 1997. Preliminary evaluation of sampling strategies to estimate the species richness of diurnal terrestrial birds using Monte Carlo simulation. Ecological Model 95: 17- 27.

Nelson, J. S. 1994. Fishes of the World, 3rd edn. New York, NY: Jonh Wiley.

Ng, P. K. L. & Kottetat, M. 2000. A review of the genus Amblyceps (Osteichthyes: Amblycipitidae) in Indochina, with descriptions of five new species. Ichthyological Exploration of Freshwater, 11(4), 335-348.

Ng, P. K. L. & Lim, K.K.P. 1990. Snakeheads (Pisces: Channidae): Naturalhistory biology and economic importance. Essay in Zoology. Department of Zoology, National University: Singapore.

Oberdorff, T., J-F. Guegan & B. Hugueny. 1995. Global scale patterns of fish species richness in rivers. Ecography 18: 345- 352.

Patton, T. M., Hubert, W.A., Rahel, F.J. & Gerow, K.G. 2000. Effort Needed to Estimate species richness in small streams on the Great Plains in Wyoming. North American Journal of Fisheries Management, 20, 394-398.

Pennak, R. W. 1989. Fresh – water invertebrate of the United States: Protozoa to mollusca (3rd ed.). wiley interscience: United States of America.

Plafkin, J. M., Barbour, M. T., Porter ,K. D., Gross, S.K. & Hughes, R.M. 1986. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. Asswssment and Watershed Protection Division,Washington, D.C.

Prescott, G. W. 1970. How to know the freshwater algae (3rd ed.). United States of America: Wm. C. Brown Company.

Rainboth,W. J. 1996. Fishes of the Cambodian Mekong. FAO species identification field guide for fishery purposes. Food and Agriculture Organization United Nations (FAO), Rome.

Roberts, T. R.1986. Systematic review of the Mastacembelidae or Spiny Eels of Burma and Thailand, with description of two new species of Macrognathus. Japanese Journal of Ichthyology 33, 95-109.

Roberts, T. R. 1992. Systematic revision of the Southeast Asia fish genus *Osphronemus*, with descriptions of two new species. Ichthyological Exploration of Freshwater, 2, 351-360.

Roberts, T. R. 1994. Systematic revision of Asian bagrid catfishes of the genus *Mytus sensu* strieto, with a new species from Thailand and Cambodia. Ichthyological Exploration of Freshwater, 2(3), 241-256.

Roberts, T. R.1994. Systematic revision of tropical asian glassperches (Ambassidae) with descriptions of three new species. Natural History Bulletin of the Siam Society 42, 263- 290.

Robert, T. R. & Kottelat, M. 1993. Revision of the Southeast Asia freshwater fish family Gyrinocheilidae. Ichthyological Exploration of Freshwater, 4(4), 375-383.

Rheman, S., Islam, M. L., Shah, M. M. R., Mondal, S., & Alam, M. J. 2002. Observation on the fecundity and gonadosomatic index (GSI) of Grey Mullet (*Liza parsia* (Ham.). Journal of Biological Sciences, 2(10), 690-693.

Rybczynski, S. M., Walters, D. M., Fritz, K. M. and Johnson, B. R. 2007. Comparing trophic position of stream fishes using stable isotope and gut content analyses. Ecology of Freshwater Fish 17, 199-206.

Sale, P. F. 1977. Maintenance of high diversity in coral reef fish communities. American Naturalist 111: 337- 359.

Smith, H. M. 1945. The fresh-water fishes of Siam, or Thailand. Bulletin of the U.S. National Museum, Number 188.

Smith, K. L. & M. L. Jones. 2005. Watershed-level sampling effort requirements for determining riverine fish species composition. Canadian Journal of Fisheries and Aquatic Science.

Sonthirat, S. 1976. Revision of the Southeastern Asiatic cyprinid fish genus *Cyclocheilichthys.* Doctoral Dissertation, University of Michigan, Michigan.

Tarvainen, M., Vuorio, K. & Sarvala, J. 2008. The diet of ruffe *Gymnocephalus cernuus* (L.) in northern: new insights from stable isotope analyses. Journal of Fish Biology 72 : 1720-1735.

Tongnunui, S. & F.W. H. Beamish. 2009. Environmental sensitivities of fishes from small rivers in Eastern Thailand. Environmental Biology of Fishes.

Vidthayanon, C., Karnasuta, J. & Nabhitabhata, J. 1997. Diversity of freshwater fish in Thailand. Office of Environmental Policy and Planing: Bangkok.

Ward-Campbell, B. M. S. & F.W. H. Beamish. 2005. Ontogenetic changes in morphology and diet in the snakehead, *Channa limbata*- a predatory fish in western Thailand. Environmental Biology of Fish 72(3): 251-257.

Ward-Campbell, B. M. S., F.W.H. Beamish and C. Kongchaiya. 2005. Morphological characteristics in relation to diet in five co-existing Thai fish species. Journal of Fish Biology 67: 1266-1279.

Wiens, J. A. 1977. On competition and variable environments. American Scientist 65: 592-597.

Wiggins, G. B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera).University of Toronto Press, Canada.

Xu, J., Xie P., Zhang, M., Zhou, Q., Zhang L., Wen Z. and Cao, T. 2007. Icefish (Salangidae) as an indicator of anthropogenic pollution in freshwater systems using nitrogen Isotope analysis. Bull Environment Contam Toxicol. 79, 323-236.

Yule, C. M. and Sen, Y. H. 2004. Freshwater invertebrates of the Malaysian Region. Academy of science Malaysia, Malaysia.

Zakaria-Ismail, M. 1994. Zoogeography and biodiversity of the freshwater fishes of Southeast Asia. Hydrobiologia, 285,41-48.

Zakaria-Ismail, M. & Sabariah, B. 1994. Ecological study of fishes in a small tropical stream (Sungai, Kanching, Selangor, peninsular Malaysia) and its tributaries. Malaysian Journal of Science, 15A, 3-7.