Cotutelle

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Presented & Defended by: **Apinun SUVARNARAKSHA**

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Biology of two keystone fish species and fish assemblage patterns and modeling approaches in tropical river basin: Case study of Ping River Basin, Thailand

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Résumé

La région Indo-Birmane est un formidable hotspot de diversité biologique, mais il existe un manque évident de connaissances fiables sur la diversité des poissons, la biologie et l'histoire de vie des communautés, ainsi que des approches de modélisation des données. Ce travail de thèse apporte des informations sur la diversité des poissons et de la distribution dans une zone de montagne de haute et de basse altitude dans la partie supérieure du bassin du fleuve Chao Phraya, en Thaïlande. Des données de terrain ont été collectées sur quatorze années entre Janvier 1996 et avril 2009, couvrant 272 enquêtes dans 10 sous-bassins hydrographiques fournissant la richesse spécifique et des indices de diversité. Cette thèse a été divisée en 3 niveaux principaux : le niveau taxonomique (niveau descriptif), la biologie des poissons (niveau descriptif et prédictif), et la diversité des assemblages de poissons en fonction des facteurs environnementaux (niveau prédictif).

Tout d'abord, concernant l’étude de la diversité des poissons (publication 1, P1): la raréfaction a été utilisée pour extrapoler la richesse spécifique et le nombre optimal d'espèces dans le bassin supérieur du fleuve Chao Phraya. Deux cent une espèces réparties dans 104 genres et 34 familles ont été collectées, dont 16 espèces exotiques. Les poissons sont dominés par la famille des Cyprinidae, suivie par les Balitoridae et les Cobitidae, caractéristiques de la zone de haute altitude. Le taux d'endémisme global dans la zone a été estimé à environ 10%. La plupart des espèces de poissons est particulièrement caractéristique des habitats rhithroniques.

Ensuite, nous avons étudié la dynamique de population des espèces de poissons clefs de la zone d'étude à savoir, (1) l'histoire de vie d’un cyprinidae *Henicorhynchus siamensis* (Sauvage, 1881) d’un petit réservoir (Publication 2; P2) et (2) la biologie de la reproduction et la conservation de l’espèce vulnérable des cours d’eau thaïlandais *Oreoglanis siamensis* aux contreforts de l’Himalaya (Publication 3; P3). Les deux espèces sont des représentants de l'état écologique des écosystèmes lentiques et lotiques. *H. siamensis* est une espèce riverine migratrice qui s’adapte bien à des conditions de réservoir (eau stagnante) et c’est un poisson économiquement important en apportant une source de protéines à des populations rurales de la région. La reproduction, le régime alimentaire et la croissance de *H. siamensis* ont été étudiés.

Par exemple, on sait que la ponte est en saison humide, la taille de maturité est d'environ 200 mm, et l'espèce se nourrit de phytoplancton, etc. Par contre, *O. siamensis* est une espèce vulnérable et endémique, qui vit dans eaux rapides froides de haute montagne. La période de frai est la saison sèche. La taille de maturité est de 68,9mm pour mâles et de 82,4mm pour les femelles et le taux de fécondité est d'environ 31 œufs de grande taille ($\phi \cong 3$ mm).

Enfin, nous avons étudié les relations entre paramètres biologiques et paramètres environnementaux, visant à expliquer les assemblages des poissons dans la zone d'étude (Publication 4; P4). Les patrons de diversité des assemblages de poissons dans la zone amont du bassin de la rivière Ping-Wang ont été étudiés. Des outils mathématiques (par exemple, SOM, ANN) ont été utilisés pour analyser les relations entre paramètres environnementaux (physico-chimiques et paramètres géomorphologiques dans le bassin de la rivière longitudinal et la diversité des poissons. Les arbres de classification et de régression (CART) ont montré que les paramètres géo-morphologiques ont été plus importants dans le modèle de prédiction à la fois pour la richesse spécifique et l'indice de diversité de Shannon. Les paramètres physico-chimiques sont moins importants, et exprimés surtout par l'altitude. Les poissons ont été classés dans 4 groupes d'assemblage à savoir, montagne, piémont, zone de transition et de plaine. Enfin, les effets de barrage sur les assemblages de poissons de rivière ont été montrés dans la Publication 5 (P5). Le SOM (self-organizing map) a été utilisé pour classer les communautés de poissons. Trois communautés de poissons ont été obtenues, à savoir de réservoir, de ruisseau et de la zone intermédiaire. Les communautés des réservoirs caractérisées par des espèces adaptées aux conditions lentiques sont par exemple *Labiobarbus lineatus*, (Sauvage, 1878) et *Puntioplites proctozysron* (Bleeker, 1865), alors que les espèces rhéophiles sont par exemple *Rasbora paviana* Tirant, 1885 et *Channa gachua* (Hamilton, 1822). La communauté de la zone intermédiaire contenait un mélange d'espèces des deux autres communautés. Le pourcentage global de bonne prédiction par le modèle a été de 66,0% : le modèle a correctement prédit 100% des communautés de réservoir, mais très peu de communautés rhéophiles (40%).

Les communautés de poissons dans la zone d'étude sont menacées par la déforestation, la collecte des poissons d'aquarium, et la présence des espèces exotiques dans la partie supérieure. La présence des espèces évadées de l'aquaculture devrait être un facteur important en termes d'hybridation génétique. Toutefois, dans le bassin du fleuve Chao Phraya, les travaux sur l'écologie aquatique et la diversité des poissons sont peu nombreux et plus d’études scientifiques sont nécessaires pour atteindre le but ultime de l'utilisation rationnelle et durable des ressources aquatiques de cette région.

Abstract

Indo-Burma hotspot is an incredibly rich biological diversity area, but lack of reliable fish diversity, biology and life history, fish assemblage, and modeling approaches data. This present works on fish diversity and distribution in a unique high altitude mountain to lowland area in the upper part of the Chao Phraya river basin, Thailand. Fourteen years of field dataset in the basin were used, collected between January 1996 and April 2009, covering 272 surveys of 10 sub-river basins to produce species richness and diversity indices. This thesis was divided into 3 main levels viz., taxonomic level (descriptive level), biology and life history of fishes (descriptive level to predictive level), and assemblages of fish diversity as function of environmental factors (predictive level).

Firstly, fish diversity study (Publication 1; P1): the rarefaction was employed to extrapolate species richness and optimum species numbers in the upper Chaophraya river basin. Two hundred and one species in 104 genera and 34 families were collected, including 16 exotic species. Cyprinidae fish family was dominated, followed by Balitoridae and Cobitidae, implying the characteristic of high altitude area. The overall endemism in the area was found to be about 10%. Most of the fish communities were especially characterized by rhithronic habitants.

Second, there were studies investigating life history and population dynamics of the keystone fish species in the study area i.e., (1) life history of riverine cyprinid *Henicorhynchus siamensis* (Sauvage, 1881) in a small reservoir (Publication 2; P2) and (2) reproductive biology and conservation approaches of a vulnerable species Siamese Freshwater batfish (*Oreoglanis siamensis*) from foothill Himalayan, Thailand (Publication 3; P3), both species were the representative of lentic and lotic ecosystem conditions. *H. siamensis* has a well adaptation from riverine species to reservoir conditions (stagnant water) and it was an important economic fish providing protein source to rural people around the reservoir. The reproductive, feeding aspects and growth of *H. siamensis* were studied e.g. spawning season in wet season, the length of 50% maturity (about 200 mm), and feed on phytoplankton, etc. Meanwhile, *O. siamensis* is a vulnerable species and endemic species, which inhabits cold swift of high mountain streams. The spawning time occurred in dry season. Meanwhile, the

length of 50% maturity were 68.9 (males) and 82.4 (females) mm and it was a few fecundity (31.41 ± 7.67 eggs) and large eggs ($\phi \cong 3$ mm).

Thirdly, there were studies about the relationships between biological parameters and environmental parameters which were also beneficial to investigate fish diversity and assemblage patterns in the studied area (Publication 4; P4). Fish diversity and assemblage patterns in the rhitral environment of the Ping-Wang river basin were investigated. Mathematics tool models (e.g. SOM, ANN) were used for analysing of the relationship between environmental parameters (physicochemical and geo-morphological parameters and fish diversity in longitudinal in the river basin, and the prediction of its diversity. The classification and regression trees showed that the geo-morphological parameters were more significant in controlling and predicting both species richness and Shannon diversity index than the physicochemical parameters, in which altitude was the most significant. The fish assemblages were organized into 4 assemblage patterns *viz.*, mountainous, piedmont, transitory and lowland species. And lastly, the investigation of the effects of dam to the riverine fish assemblages was showed in Publication 5 (P5). A self-organizing map (SOM) was used to cluster the fish community; three fish communities were obtained characterizing reservoir-, stream- and intermediate- communities. The reservoir communities were characterized by “lentic-adapted” fish i.e. *Labiobarbus lineatus*, (Sauvage, 1878) and *Puntioplites proctozysron* (Bleeker, 1865), whereas rheophilic species, i.e. *Rasbora paviana* Tirant, 1885 and *Channa gachua* (Hamilton, 1822), were dominant in the stream community. The intermediate community contained a mixture of species from both the other communities. The overall percentage of successful prediction by the model was 66.0 %: the model was 100% accurate for the prediction of the reservoir community but very low for the stream community (40%).

Threats to fish communities were deforestation, collection for aquarium fish, and the distribution of the exotic species in the upper reaches. Meanwhile distribution of aquaculture escapes should be a concerned in terms of genetic hybridization. However, in the Chao Phraya river basin, research on the aquatic ecology and fish diversity are few and need more scientific information to reach the ultimate goal of wise and sustained uses of aquatic resources.

Part 1: Synthesis

Part 2: Publications

Part 1: Synthesis

1. General introduction

1.1 Background of the study

Tropical Southeast Asia (SEA) is among the diversity hotspots of the world, especially fishes e.g. Mekong river basin 773 species, Chao Phraya river basin 297 species and Salween river basin 147 species (Froese & Pauly, 2011). The exceptional diversity of fish in this region also supports a huge inland fishery, which is the basis of the livelihood and extremely important for food security among the rural poor people (Volbo-Jørgensen & Poulsen 2000), in which the best example from Lower Mekong basin, where an estimation of 2.2 million tonnes of wild fish are harvested annually (Hortle, 2009). However, there are very few scientific reports on the fish diversity and their related issues, such as life history of individual keystone species, patterns of fish assemblages as well as their relationships to environmental attributes of both biotic and abiotic.

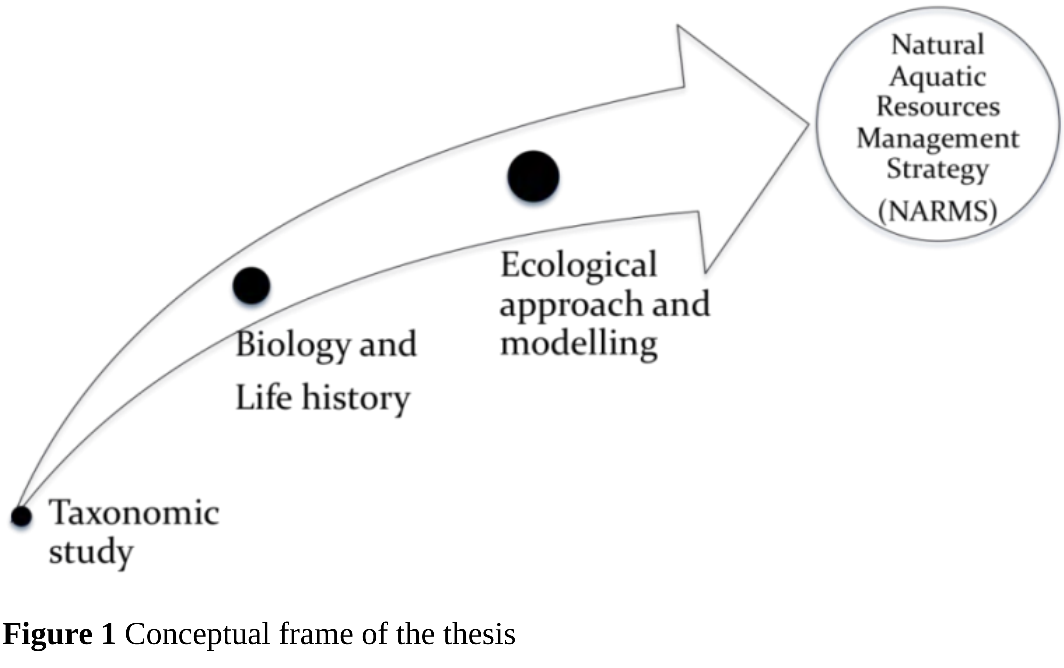

Figure 1 Conceptual frame of the thesis

In the developed countries, there is today some evidences of a reduction in the rate of anthropogenic impacts on natural ecosystems due to declining fertility and birth rates, the emergence of environmental institutions and governance, as well as changing values and behaviors (Costanza et al., 2007; Hibbard et al., 2007). However, this situation has not yet likely to be occurred in the developing countries, such as many countries in SEA, where the massive acceleration in plans for infrastructure development has become increased, especially to the river system (Hibbard et al., 2007; Dugan et al., 2010), such as land reclamation and hydropower development (Dugan et al., 2010). Allan & Flecker (1993) recognized six major threats to biodiversity in the river systems, which are directly and/or indirectly affected by a range of human disturbances as: 1) habitat loss and degradation caused by water infrastructure projects, land transformations and agricultures, which are consequent in modifications of river hydrology and connectivity as well as riparian-aquatic and in-stream habitat integrities; 2) species invasions; 3) over-harvesting; 4) secondary extinctions due to cascading effects, 5) chemical and organic pollutions; and 6) global climate changes.

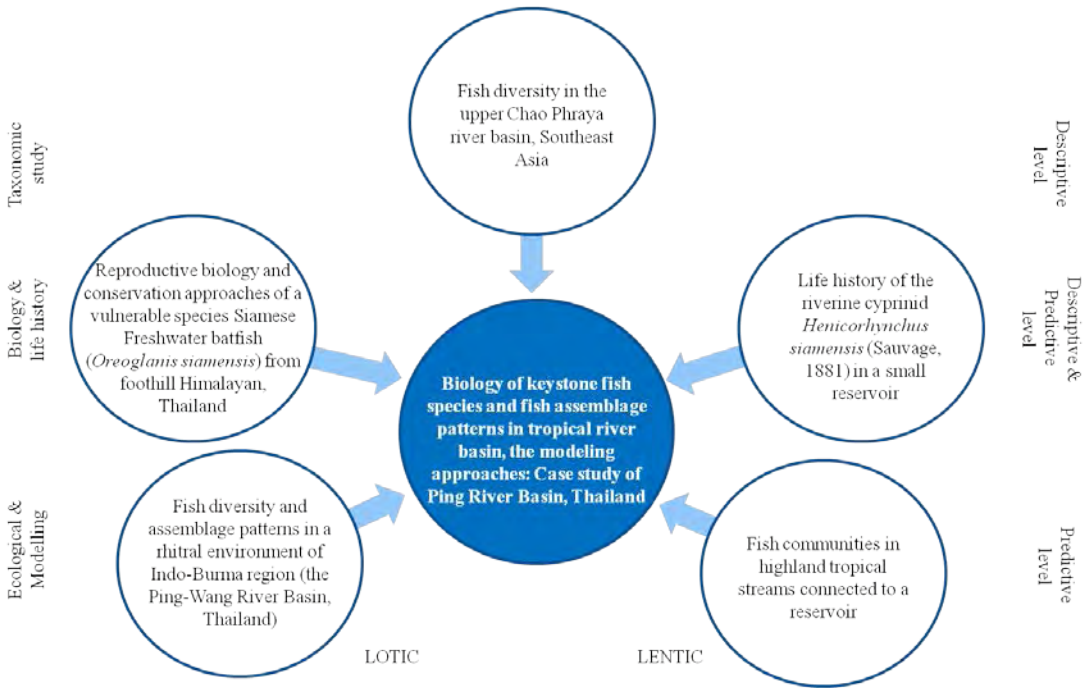

Figure 2 Flow diagram showing title of each main chapter that reflected to the conceptual frame of the study.

The status of aquatic ecosystems and their responses to human impacts are commonly described by using indicators such as existences and conditions of keystone species, status of assemblage patterns of aquatic faunas and floras and ecological integrity of the focused area (Norris & Thoms 1999; Allan 2004), which the modeling techniques could be further developed for the understanding in the larger scale and make any predictions aiming to manage natural resources and ecosystems (Guisan & Thuiller, 2005). Therefore, the major goals of this thesis were to bring various approaches from systematic (*aka* taxonomic study) to ecological modeling in aquatic science (Fig. 1) to make an understanding on the status of fish resources in the upper Chao Phraya River basin, where all the 6 threats described by Allan & Flecker (1993) are now becoming and scientific information is desired for better management.

The keystone fish species are chosen from the possibility for the representative of the lotic and lentic ecosystem conditions in Thai waters. *Henicorhynchus siamensis* is a riverine species in mainland Southeast Asia, widely distributions (see Table 1). This species can well adapt to new environmental conditions. Moreover, it can reproduce and become a dominance species in the manmade reservoir and an important protein sources for local people (*per se* A. Suvarnaraksha). Meanwhile, the *Oreoglanis siamensis* is a ripids and shooting high mountain stream species (Smith, 1945), vulnerable species (Kottelat, 1996) and low fecundity (see Table 1). It needs our knowledge to prevent and protect them from the extinction in the near future. Then, both species could be the representatives of biology of keystone fish species and fish assemblage patterns in the lotic and lentic adaptation ecosystem conditions tropical river basin Souteast Asia.

The content of the thesis is divided into 5 main topics and accordingly to be 5 publications (Fig. 2). Publication 1 illustrates how much the upper Chao Phraya River Basin is fruitful with fish diversity, in which taxonomy approach is applied for making baseline information of existence species in each sub-basin. Publications 2 and 3 are the results of the studies on biology and life history traits of the two keystone species, i.e. the endanger species *Oreoglanis siamensis* (Publication 2) and the riverine species *Henicorhynchus siameneis* that occupied the lentic environment (Publication 3). Predictive models, which showing the assemblage patterns of fishes along the river course and their relationships to environmental parameters, is presented in Publication 4. Finally, Publication 5 demonstrates the fluctuation in fish assemblage patterns induced by human disturbance, i.e. river damming.

Table 1 General comparison details of the keystone fish species of tropical Southeast Asia in this thesis.

	Henicorhynchus siamensis (Sauvage, 1881)	*Oreoglanis siamensis* (Smith, 1933)
1	High population/wide distribution (Rainboth, 1996; Lim et. al., 1999; Doi, 1997; Roberts, 1997)	Endemic species (Kottelat, 1996; Vidthayanon, 2005; Vidthayanon et al., 2009)
2	Dominance species (Rainboth, 1996; Lim et. al., 1999; Doi, 1997)	Threatened species (Kottelat, 1996; Vidthayanon, 2005)
3	Well adaptation from lotic to lentic condition (*per se* A. Suvarnaraksha)	Difficult to survived in lowland and lentic condition (Rainboth, 1996; *per se* A. Suvarnaraksha)
4	Inhabits in large river (Rainboth, 1996; Lim et. al., 1999; Doi, 1997; Roberts, 1997; Viravong, 2006)	Inhabits in brook stream (Smith, 1945)
5	High fecundity (high impact of recruitment) (Sokheng, et al., 1999; Viravong, 2006)	Low fecundity (*per se* A. Suvarnaraksha)
6	Important to natural food web (Sokheng, et al., 1999)	Consumer in the small stream (*per se* A. Suvarnaraksha)
7	Commercial species (Roberts & Warren, 1994; Sokheng, et al., 1999)	Conservation proposed (Kottelat, 1996; Vidthayanon, 2005)
8	Phytoplankton and periphyton (Rainboth, 1996)	Aquatic insect and specific food (Vidthayanon, 2005)
9	Migratory species (Singhanouvong et al., 1996a; Singhanouvong et al., 1996b; Sokheng, et al., 1999)	Non-migration species (?)

1.2 The Chao Phraya River Basin

The Chao Phraya Basin is the most important basin in Thailand. The Basin covers 30% of Thailand's land area, is home to 40% of the country's population, employs 78% of its work force, and generates 66% of its Gross Domestic Product (GDP) (Office of Natural Water Resources Committee of Thailand, 2003). The basin lies in the central of Thailand, covers an area approximately of 160,000 km^2, in which covers almost one-third of the country’s geographical area and is divided into upper, middle and lower basin. The Chao Phraya River *per se* is about 365 km long and the headwater of the Basin originates from the mountainous terrain in the northern part of the country at 2,565 m in elevation. There are four large tributaries in the upper parts (i.e. the Ping, Wang, Yom and Nan rivers (Fig. 3B)) that flow southward joining together at Nakornsawan Province to form the main Chao Phraya River (Fig. 3A).The Chao Phraya mainstem, then, flows southward through a large alluvial plain and splits into four channels (i.e. the Tha Chin, Noi, Lopburi and Chao Phraya *per se*) and enter to the Gulf of Thailand (Davikar et al., 2011). It supplies water and supports navigation, fisheries, and recreation.

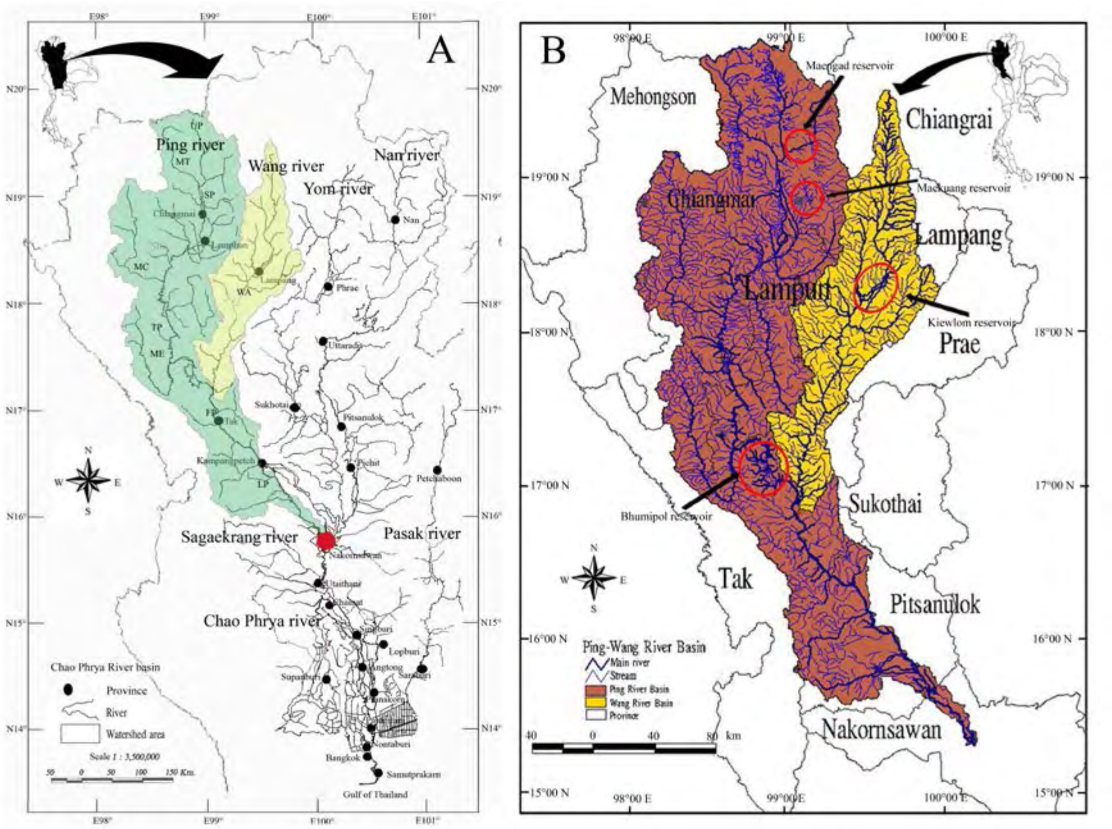

Figure 3 (A) Map of the Chao Phraya river basin with the main tributaries **(B)** The Ping-Wang river basin with its tributaries, reservoirs, and connected provinces.

1.3 Diversity of freshwater fishes in the Chao Phraya River

The freshwater fishes are ecologically classified into three groups (Berra, 2001): 1) the principal freshwater species, which they can complete their life cycle in freshwaters; 2) the marine vagrants, which are the fish that are found in freshwaters but also spend time in brackish and/or marine waters and 3) the diadromous fishes, which are undertake extensive migrations between freshwater and brackish or marine waters.

In the basin, monsoon weather dominates, with the rainy season lasting from May to October and supplementary rain from occasional westward storm depressions originating in the Pacific. The average annual precipitation in the basin ranges from a minimum of 1,000 mm in the western part to about 1,400 mm in the headwaters and up to 2,000 mm in the eastern Chao Phraya delta (Office of Natural Water Resources Committee of Thailand, 2003). Temperature ranges from 15°C in December to 40°C in April, except in high altitude locations. The basin can be classified as a tropical rainforest with high biodiversity. Southeast Asia contains the highest mean proportion of country-endemic bird (9%) and mammal species (11%) and the second-highest proportion of country-endemic vascular plant species (25%) compared to the other tropical regions of Meso-America, South America, and Sub-Saharan Africa (UNEP–WCMC, 2004). Especially freshwater fishes, in which 222 species from 36 families were recorded (Nguyen & De Silva 2006). Meanwhile the most update data in the reference global fish database, FishBase (www.fishbase.org; Froese & Pauly 2010),) ranked the Chaophrya River the seventh in term of freshwater species in the world with 318 species.

At the global scale, the freshwater fishes belong to 207 families, 2,513 genera and estimated up to 32,500 species, in which the 11,952 species are strictly to freshwater environment, and using freshwater 12,457 species (Nelson, 2006). The fish diversity in the tropical Asia is considerably higher than that of African and Latin American (Lundberg et al., 2000), where the East, South and Southeast Asia have a cumulative total freshwater species is at 7,447 species (Kottelat & Whitten, 1996; Gleick, 2000) and dominated by fishes in Families Cyprinidae (about 1,000 species), Balitoridae and Cobitidae , (together about 400 species), Gobiidae (about 300 species) and then followed by Siluridae, and Bagridae (Kottelat & Whitten, 1996; Vidthayanon, 2005; Lévêque et al. 2008).

In Thailand, fish species are reported at 836 species (Froese & Pauly 2010), in which 318 species are in Chao Phraya River Basin and 15.3% of the indigenous finfish were endemic to the basin (De Silva et al., 2007). They can be found in various habitats such as the highland streams, caves, lakes, river mainstem and estuary. It is generally accepted that the Ping-Wang River Basin contains more than three-fourths of the freshwater fishes known from Chao Phraya River Basin (Vidthayanon et al. 1997).The summary of fish species in these areas is shown in Table 2. Table 3 presents the list the species found in the Chao Phraya River Basin compared to the two adjacent river basins, i.e. the Mekong and the Salween river basins. Yap (2002) found that the Mekong fish were most similar to that of the Chao Phraya, and also found the fauna of the Mekong, mid-Mekong, lower Mekong, and Chao Phraya are equally similar to each other, reflecting recent or continuing connections and can reach the conclusion that the upper Mekong formed part of the Chao Phraya basin in the past. Valbo-Jørgensen et al., 2010). Kottelat (1989) also found that the Mekong and Chao Phraya had more than 50% of their fish fauna in common.

The overall conservation status of endemic finfish in Asia was satisfactory in that only 92 species were in some state of vulnerability, of which 37 species (6.6%) are endangered or critically endangered (De Silva et al., 2007). Four threatened species were reported from Chao Phraya River basin *viz.*, *Oreoglanis siamensis*, *Scleropages formosus*, *Yasuhikotaki asidthimunki* and *Datnioides microlepis*, which are already officially protected (Kottelat, 1996; Vidthayanon, 2005) including *Pangasianodon gigas*, which is listed in the Appendices I of CITES and Convention on the Conservation of Migratory Species of Wild Animals (CMS) (http://www.cms.int/ documents/appendix/cms_app1_2.htm #appendix _II).

Table 2. Comparison of families, genera and species number of freshwater fishes in the world by Fishbase (2010), Nelson (2006), Chao Phraya, Mekong river, Salween river and Ping-Wang river. Abbreviations: F=Families, G=Genera, S=Species, *=base on Fish base (2010)

Class	Order	World	Fish base 2010	Nelson 2006	Asia*		Chao Phraya*			Mekong*			Salween*			Ping-Wang*		
		F	S	S	F	S	F	G	S	F	G	S	F	G	S	F	G	S
Holocephali	Chimaeriformes	1	1															
Cephalaspidomorphi	Petromyzontiformes	1	33	29		9												
Elasmobranchii	Carcharhiniformes	1		1	1	7				1	1	1						
	Orectolobiformes				1					1	1	1						
	Pristiformes				1	1												
	Pristiophoriformes				1	1												
	Rajiformes	2	24							1	2	6						
	Myliobatiformes			23		7	1	2	4							1	1	2
Sarcopterygii	Ceratodontiformes	2	8	6														
Actinopterygii	Acipenseriformes	2	8	14		13												
	Albuliformes				1	1	1	1										
	Amiiformes	1	1	1														
	Anguilliformes	2	8	6	3	20				2	3	5						
	Atheriniformes	7	181	210		30				1	1	1	1	1	3			
	Batrachoidiformes	1	5	6		1				1	1	2						
	Beloniformes	3	71	98		6	1	1	2	3	5	7				2	2	2
	Characiformes	17	1794	1674														
	Clupeiformes	5	72	79		6	2	2	2	3	12	19				1	1	1
	Cypriniformes	7	3451	3268			4	63	170	4	96	412	3	49	109	4	53	115
	Cyprinodontiformes	9	964	996		12	2	2	2	1	1	1	1	1	1	1	3	3
	Elopiformes				2	7			1	1	1							
	Esociformes	2	15	10														
	Gadiformes			1	2	1												
	Gasterosteiformes	2	13	21		22				2	5	10						
	Gobiesociformes	1	9															
	Gonorynchiformes	2	31	31	1	1												
	Gymnotiformes	5	133	134														
	Hiodontiformes			2														
	Lepisosteiformes	1	4	6		1												
	Mugiliformes			1	1	7												
	Ophidiiformes	1	4	5		1												
	Osmeriformes	3	31	82	2	4												
	Osteoglossiformes	7	219	218			1	2	3	2	3	4	1	1	1	1	2	2
	Perciformes	34	2402	2040	17	295	11	20	31	20	70	118	3	4	5	12	15	22
	Percopsiformes	3	9	9														
	Pleuronectiformes	4	23	10	1	10	2	2	3	2	3	12				2	3	6
	Polypteriformes	1	16	16														
	Salmoniformes	1	161	45		21												
	Scorpaeniformes	4	75	60	2	2												
	Siluriformes	34	2835	2740		10	9	21	64	11	33	136	6	13	24	7	20	42
	Synbranchiformes	3	90	96		3	3	5	9	3	5	13	3	3	4	2	3	5
	Syngnathiformes	1	20				2	2	4									
	Tetraodontiformes	1	29	14		8	1	1	3	1	4	15				1	1	1
Total		171	12740	11952	36	507	40	124	297	60	247	764	18	72	147	34	104	201

Table 3 Fishes species found in Mekong, Chao Phraya and Salween rivers.

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
	Order Pristiformes				
	Family Pristidae				
1	*Pristis microdon* Latham, 1794	X	X	-	A
	Order Mylibatiformes				
	Family Dasyatidae				
2	*Dasyatis laosensis* Roberts & Kanasuta, 1987	X	X	-	B, D, E
3	*Himantura bleekeri* (Blyth, 1860)	-	X	-	A
4	*Himantura Chao Phraya* Monkolprasit & Roberts, 1990	X	X	-	B, E
5	*Himantura krempfi* (Chabanaud, 1923)	X	X	-	B, E
6	*Himantura signifer* Compagno & Roberts, 1982	X	X	-	B, E
7	*Pastinachus sephen* (Forsskål, 1775)	-	X	-	A
	Order Osteoglossiformes				
	Family Osteoglossidae				
8	*Scleropages formosus* (Schlegel & Müller, 1844)	X	-	X	A, B, F
	Family Notopteridae				
9	*Chitala lopis* (Bleeker, 1851)	X	X	-	B, E
10	*Chitala ornata* (Gray, 1831)	X	X	-	A, B, D, E
11	*Chitala branci* (Aubenton, 1965)	X	-	-	A, B, E
12	*Notopterus notopterus* (Pallas, 1831)	X	X	X	A, B, C, D, E, F
	Order Elopiformes				
	Family Megalopidae				
13	*Megalops cyprinoides* (Broussonet, 1782)	X	X	-	A, B
	Order Anguilliformes				
	Family Anguillidae				
14	*Anguilla bicolor* M'Clelland, 1844	X	-	X	B, F
15	*Anguilla marmorata* Quoy & Gaimand, 1824	X	-	-	B, E
16	*Anguilla bengalensis* (Gray, 1831)	-	-	X	F, H
	Family Ophichthyidae				
17	*Ophichthus rutidoderma* (Bleeker, 1852)	X	-	-	B
18	*Pisodonophis boro* (Hamilton, 1822)	X	-	-	B
19	*Pisodonophis cancrivorous* (Richardson, 1844)	X	-	-	B
	Order Clupeiformes				
	Family Clupeidae				
20	*Clupeoides borneensis* Bleeker, 1851	X	X	-	B, E
21	*Corica laciniata* Fowler, 1935	X	X	-	B, D
22	*Clupeichthys aesarnensis* Wongratana, 1983	X	X	-	B, E
23	*Clupeichthys goniognathus* Bleeker, 1855	X	X	-	B
24	*Gudusia variegata* (Day, 1870)	-	-	X	F
25	*Tenualosa ilisha* (Hamilton, 1822)	-	-	X	F
26	*Tenualosa thibaudeaui* (Durand, 1940)	X	X	-	B, E
27	*Tenualosa toli* (Valenciennes, 1847)	X	X	-	A, B
28	*Anodontostoma chacunda* (Hamilton, 1822)	X	X	-	A, B
29	*Anodontostoma thailandae* Wongratana, 1983	X	X	-	B
30	*Nematalosa nasus* (Bloch, 1795)	X	X	-	A, B
	Family Pristigasteridae				
31	*Ilisha megaloptera* (Swainson, 1839)	X	-	-	B
32	*Ophisthopterus tardoore* (Cuvier, 1829)	X	-	-	B
	Family Engraulidae				
33	*Coilia dussumieri* Valenciennes, 1848	-	-	X	F
34	*Coilia lindmani* Bleeker, 1858	X	-	-	B
35	*Coilia macrognathus* Bleeker, 1852	X	-	-	A, B
36	*Coilia ramcarati* (Hamilton, 1822)	-	-	X	F
37	*Lycothrissa crocodilus (*Bleeker, 1851)	X	-	-	A, B, E
38	*Setipinna melanochir* (Bleeker, 1849)	X	-	-	A, B, E
39	*Setipinna wheeleri* Wongratana, 1983	-	-	X	F
	Family Sundasalangidae				
40	*Sundasalanx praecox* Roberts, 1981	X	X	-	B, E
41	*Sundasalanx mekongensis* Britz & Kottelat, 1999	X	-	-	E
	Order Gonorhynchiformes				
	Family Chanidae				
42	*Chanos chanos* (Forsskål, 1775)	X	X	-	B
	Order Cypriniformes				
	Family Cyprinidae				
	Subfamily Alburninae				
43	*Longiculter siahi* Fowler, 1937	X	X	-	A, B
44	*Paralaubuca barroni* (Fowler, 1934)	X	X	-	A, B, D, E
45	*Paralaubuca harmandi* Sauvage, 1883	X	X	-	A, B, D, E
46	*Paralaubuca riveroi* (Fowler, 1935)	X	X	-	A, B, D, E
47	*Paralaubuca stigmabrachium* (Fowler, 1934)	X	X	-	A, B, D
48	*Paralaubuca typus* Bleeker, 1864	X	X	-	A, B, D, E
	Subfamily Danioninae				
49	*Amblypharyngodon chulabhornae* Vidthayanon & Kottelat, 1990	X	X	-	B, E
50	*Amblypharyngodon mola* (Hamilton, 1822)	-	-	X	C, F

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
51	*Amblypharyngodon atkinsoni* (Blyth, 1860)	-	-	X	C, F
52	*Aspidoparia morar* (Hamilton, 1822)	-	-	X	A, F
53	*Barilius barila* (Hamilton, 1822)	-	-	X	C, F
54	*Barilius koratensis* (Smith, 1931)	X	X	-	A, B, D, E
55	*Barilius ornatus* Sauvage, 1883	X	X	X	P
56	*Barilius pulchellus* (Smith, 1931)	X	X	-	A, B, D, E
57	*Boraras micros* Kottelat & Vidthayanon, 1993	X	-	-	E
58	*Boraras urophthalmoides* (Kottelat, 1991)	X	X	-	B
60	*Chela caeruleostigmata* Smith, 1931	X	X	-	A, E
61	*Chela laubuca* (Hamilton, 1822)	X	X	X	A, D, E, F
62	*Danio albolineatus* (Blyth, 1860)	X	X	X	F
63	*Danio erythromicron* (Annandale, 1918)	-	-	X	A, F
64	*Danio dangila* (Hamilton, 1822)	-	-	X	F
65	*Danio kyathit* Fang, 1998	-	-	X	F
66	*Danio roseus* Fang & Kottelat, 2000	X	-	-	E
67	*Devario acrostomus* Fang & Kottelat, 1999	X	X	-	E
68	*Devario aequipinnatus* M'Clelland, 1839	X	-	X	F
69	*Devario annandalei* Chaudhuri, 1908	X	X	X	F
70	*Devario browni* (Regan, 1907)	-	-	X	F
71	*Devario laoensis* (Pellegrin & Fang, 1940)	X	-	X	B, E
72	*Devario regina* (Fowler, 1934)	X	X	X	A, B, D, E, H
73	*Diptychus kaznakovi* Nikolskii, 1933	X	-	X	F
74	*Esomus longimanus* (Lunel, 1881)	X	X	-	A, B, E
75	*Esomus metallicus* Ahl, 1824	X	X	X	A, B, D, E
76	*Inlecypris auropurpurea* (Annandale, 1918)	-	-	X	F
77	*Leptobarbus hoevenii* (Bleeker, 1851)	X	X	X	A, B, E, F, H
78	*Luciosoma bleekeri* Staindachner, 1879	X	X	-	A, B, D, E
79	*Luciosoma setigerum* (Valenciennes, 1842)	X	X	-	A, B, D, E
80	*Macrochirichthys macrochirus* Val., 1844	X	X	-	A, B, D, E
81	*Microrasbora rubescens* Annandale, 1918	-	-	X	F
82	*Oxygaster anomarula* van Hasselt, 1823	X	-	-	B
83	*Oxygaster pointoni* (Fowler, 1934)	X	X	-	A, B, D, E
84	*Parachela maculicauda* (Smith, 1934)	X	X	-	A, B, E
85	*Parachela oxygastroides* (Bleeker, 1852)	X	X	-	A, B, D, E
86	*Parachela siamensis* (Günther, 1868)	X	X	-	B, E
87	*Parachela williaminae* Fowler, 1934	X	-	-	A, B, D, E
88	*Raiamas guttatus* (Day, 1870)	X	X	X	B, E, F
89	*Rasbora argyrotaenia* (Bleeker, 1850)	X	X	-	A
90	*Rasbora aurotaenia* Tirant, 1842	X	X	-	B, E
91	*Rasbora borapetensis* Smith, 1934	X	X	-	A, B, D, E
92	*Rasbora caudimaculata* Volz, 1903	X	-	-	B
93	*Rasbora daniconius* (Hamilton, 1822)	X	X	X	B, D, E, F
94	*Rasbora dorsinotata* Kottelat & Shu, 1987	X	X	-	E
95	*Rasbora dusonensis* (Bleeker, 1851)	X	X	-	B, E
96	*Rasbora hobelmani* Kottelat, 1984	X	-	-	B, E
97	*Rasbora myersi* Brittan, 1954	X	X	-	A, B, D
98	*Rasbora pauciperforata* Weber & de Beaufort, 1916	X	X	-	B
99	*Rasbora paucisquamis* Ahl, 1935	X	-	-	B
100	*Rasbora paviana* (Tirant, 1885)	X	X	-	A, B, D, E
101	*Rasbora rasbora* (Hamilton, 1822)	-	-	X	A, F
102	*Rasbora rubrodorsalis* Donoso-Büchner & Schmidt, 1997	X	X	-	E
103	*Rasbora spilocera* Rainboth & Kottelat, 1987	X	-	-	B, E
104	*Rasbora sumatrana* (Bleeker, 1852)	X	X	-	A
105	*Rasbora tornieri* Ahl, 1922	X			B
106	*Rasbora trilineata* Steindachner, 1870	X	X	-	A, B, D, E
107	*Salmostoma sardinella* (Valenciennes, 1844)	-	-	X	F
108	*Sawbwa resplendens* Annandale, 1918	-	-	X	F
109	*Trigonostigma espei* (Meinken, 1967)	X	X	-	B
110	*Trigonostigma heteromorpha* (Duncker, 1904)	X	X	-	A
111	*Thryssocypris tonlesapensis* Roberts & Kottelat, 1984	X	-	-	B
	Subfamily Leuciscinae				
112	*Aaptosyax grypus* Rainboth, 1991	X	-	-	B, E
	Subfamily Hypophthalmichthyinae				
113	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	X	X	-	E
114	*Hypophthalmichthys nobilis* (Richardson, 1845)	X	X	-	E
	Subfamily Gobioninae				
115	*Abbottina rivularis* (Basilewsky, 1855)	X	-	-	E
	Subfamily Acheilognathinae				
116	*Acheilognathus deignani* Smith, 1945	X	-	-	A, E
	Subfamily Cyprininae				
117	*Albulichthys albuloides* (Bleeker, 1855)	X	X	-	A, B, E
118	*Amblyrhynchichthys truncatus* (Bleeker, 1850)	X	X	-	A, B, D E
119	*Balantiocheilos melanopterus* (Bleeker, 1850)	X	X	-	A, B, D, E

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
120	*Bangana behri* (Fowler, 1937)	X	X	-	B, E
121	*Bangana devdevi* (Hora, 1936)	-	-	X	F
122	*Bangana elegans* Kottelat, 1998)	X	-	-	E
123	*Bangana lippus* (Fowler, 1936)	X	X	-	E, K
124	*Barbichthys laevis* (Sauvage, 1878)	X	X	-	A, B, D, E
125	*Barbichthys nitidus* (Sauvage, 1878)	X	X	-	
126	*Barbonymus altus* (Günther, 1868)	X	X	-	A, B, D, E
127	*Barbonymus balleroides* (Valenciennes, 1842)	X	X	-	B, E
128	*Barbonymus gonionotus* (Bleeker, 1850)	X	X	-	A, B, D, E
129	*Barbonymus schwanenfeldii* (Bleeker, 1853)	X	X	-	A, B, D, E
130	*Catla catla* (Hamilton, 1822)	-	-	X	F
131	*Catlocarpio siamensis* Boulenger, 1898	X	X	-	A, B, D, E
132	*Chagunius baileyi* Rainboth, 1986	-	-	X	F
133	*Cirrhinus caudimaculatus* (Fowler, 1934)	X	X	-	AF
134	*Cirrhinus cirrhosus* (Bloch, 1795)	X	X	X	E, F
135	*Cirrhinus jullieni* Sauvage, 1878	X	X	-	A, B, D, E
136	*Cirrhinus microlepis* Sauvage, 1878	X	X	-	A, B, D, E
137	*Cirrhinus molitorella* (Valenciennes, 1844)	X	X	-	E
138	*Cirrhinus prosemion* Fowler, 1934	X	-	-	E
139	*Cirrhinus rubirostris* Roberts, 1997	-	-	X	F
140	*Cosmochilus harmandi* Sauvage, 1878	X	X	-	A, B, D, E
141	*Crossocheilus atrilimes* Kottelat, 2000	X	X	X	E
142	*Crossocheilus burmanicus* Hora, 1936	-	-	X	F
143	*Crossocheilus cobitis* (Bleeker, 1853)	X	X	-	A, B, E
144	*Crossocheilus oblongus* (Valenciennes, 1842)	X	X	-	B, E
145	*Crossocheilus reticulatus* (Fowler, 1934)	X	X	-	A, B, E
146	*Crossocheilus siamensis* (Smith, 1931)	X	X	-	B
147	*Ctenopharyngodon idella* (Valenciennes, 1844)	X	X	-	E
148	*Cyclocheilichthys apogon* (Valenciennes, 1842)	X	X	X	B, E, F
149	*Cyclocheilichthys armatus* (Valenciennes, 1842)	X	X	-	A, B, D, E
150	*Cyclocheilichthys enoplos* (Bleeker, 1850)	X	X	-	A, B, D, E
151	*Cyclocheilichthys furcatus* Sontirat, 1985	X			B, E
152	*Cyclocheilichthys heteronema* (Bleeker, 1853)	X	X	-	B, E
153	*Cyclocheilichthys lagleri* Sontirat, 1985	X	X	-	B, E
154	*Cyclocheilichthys microlepis* (Bleeker, 1851)	X			B
155	*Cyclocheilichthys repasson* (Bleeker, 1853)	X	X	-	A, B, D, E
156	*Cyprinus intha* Annandale, 1918	X	-	X	F
157	*Cyprinus carpio* Linnaeus, 1758	X	X	-	A, B, E
158	*Discherodontus schroederi* (Smith, 1945)	X	X	-	A
159	*Discherodontus ashmeadi* Fowler, 1937	X	X	-	A, D, B
160	*Discherodontus halei* (Duncker, 1904)	-	X	-	J
161	*Epalzeorhynchos bicolor* (Smith, 1931)	X	X	-	Q
162	*Epalzeorhynchos frenatum* (Fowler, 1934)	X	X	-	B, E
163	*Epalzeorhynchos kalopterus* (Bleeker, 1851)	-	X	-	A
164	*Epalzeorhynchos munense* (Smith, 1934)	X	X	-	A, B, E
165	*Garra cambodgiensis* (Tirant, 1884)	X	X	-	A, B, D, E
166	*Garra fasciacauda* Fowler, 1937	X	X	-	B, D, E
167	*Garra fisheri* (Fowler, 1937)	X	X	-	A, B
169	*Garra fuliginosa* Fowler, 1934	X	X	-	A, B
170	*Garra imberbis* Vinciguerra, 1890	X	-	X	C
171	*Garra nasuta* McClelland, 1838	X	X	X	F
172	*Garra notata* Blyth, 1860	-	-	X	F
173	*Garra salweenica* Hora & Mukerji, 1934	-	-	X	H
174	*Hampala dispar* Smith, 1934	X	X	-	A, B, D, E
175	*Hampala macrolepidota* (Valenciennes, 1842)	X	X	X	A, B, D, E, F
176	*Hampala salweenensis* Doi & Taki, 1994	-	-	X	F, K
177	*Henicorhynchus caudimaculatus* (Fowler, 1934)	X	X	-	B
178	*Henicorhynchus cryptopogon* Fowler, 1934	X	X	-	B
179	*Henicorhynchus lineatus* (Smith, 1945)	X	X	-	E
180	*Henicorhynchus lobatus* Smith, 1945	X	X	-	A, E
181	*Henicorhynchus ornatipinnis* (Roberts, 1997)	X	-	-	E
182	*Henicorhynchus siamensis* (de Beaufort, 1937)	X	X	-	A, B, E
183	*Hypsibarbus lagleri* Rainboth, 1996	X	X	-	B, E
184	*Hypsibarbus pierrei* (Sauvage, 1880)	X	X	-	B, E
185	*Hypsibarbus suvatti* Rainboth, 1996	X	X	-	B
186	*Hypsibarbus vernayi* (Norman, 1925)	X	X	-	B, E
187	*Hypsibarbus wetmorei* (Smith, 1931)	X	X	-	B, E
188	*Hypsibarbus salweenensis* Rainboth, 1990	-	-	X	F
189	*Labeo barbatulus* (Sauvage, 1878)	X	-	-	E
190	*Labeo calbasu* (Hamilton, 1822)	-	-	X	F, H
191	*Labeo chrysophekadion* (Bleeker, 1850)	X	X	X	A, B, D, F, H
192	*Labeo dyocheilus* (McClelland, 1839)	X	X	X	D, F, H
193	*Labeo erythropterus* Valenciennes, 1842	X			D

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
194	*Labeo indramontri* Smith, 1945	X	X	-	A
195	*Labeo pierrei* (Sauvage, 1880)	X	X	-	E, F
196	*Labeo rohita* (Hamilton, 1822)	X	X	-	E
197	*Labeo yunnanensis* Chuadhuri, 1911	X	X	-	E
198	*Labiobarbus lineata* (Sauvage, 1878)	X	X	-	A, D, L
199	*Labiobarbus leptocheila* (Valenciennes, 1842)	X	X	X	A, B, E, F
200	*Lobocheilos bo* (Popta, 1904)	X	X	-	A
201	*Lobocheilos cryptopogon* (Fowler, 1935)	-	X	-	A
202	*Lobocheilos davisi* (Fowler, 1937)	X	-	-	B
203	*Lobocheilos delacouri* (Pellegrin & Fang, 1940)	X	-	-	B
204	*Lobocheilos fowleri* (Pellegrin & Chevey, 1936)	X	-	-	P
205	*Lobocheilos gracilis* (Fowler, 1937)	X	X	-	A, B
206	*Lobocheilos melanotaenia* (Fowler, 1935)	X	X	-	A, B, E
207	*Lobocheilos nigrovittatus* Smith, 1945	-	X	-	A
208	*Lobocheilos quadrilineatus* (Fowler, 1935)	X	X	-	A, B
209	*Lobocheilos rhabdoura* (Fowler, 1934)	X	X	-	A, B, E
210	*Lobocheilos thavili* (Smith, 1945)	X	X	-	A
211	*Mekongina erythrospila* Fowler, 1937	X	-	-	A, B, D, E
212	*Mystacoleucus argenteus* (Day, 1888)	-	-	X	A, F, H
213	*Mystacoleucus atridorsalis* Fowler, 1937	X	-	-	A, B, E
214	*Mystacoleucus chilopterus* Fowler, 1935	X	X	-	A, D, E
215	*Mystacoleucus ectypus* Kottelat, 2000	X	-	-	E
216	*Mystacoleucus greenwayi* Pellegrin & Fang, 1940	X	X	-	D, E
217	*Mystacoleucus marginatus* (Valenciennes, 1842)	X	X	-	A, B, D, E
218	*Neolissochilus blanci* (Pellegrin & Fang, 1940)	X			B
219	*Neolissochilus dukai* (Day, 1878)	X	X	X	A
220	*Neolissochilus soroides* (Duncker, 1904)	X	X	-	B
221	*Neolissochilus stracheyi* (Day, 1871)	X	X	X	A, B, E, F
222	*Neolissochilus vittatus* (Smith, 1945)	X	-	X	A
223	*Onychostoma gerlachi* (Peters, 1881)	X	X	-	G
224	*Oreichthys cosuatis* (Hamilton, 1822)	-	X	X	A, F
225	*Oreichthys parvus* Smith, 1933	X	X	-	E
226	*Osteobrama belangeri* (Valenciennes, 1844)	-	-	X	F
227	*Osteobrama feae* Vinciguerra, 1890	-	-	X	F, H
228	*Osteochilus enneaporos* (Bleeker, 1852)	X	-	-	B
229	*Osteochilus hasseltii* (Valenciennes, 1842)	X	X	X	A, D, E, F
230	*Osteochilus lini* Fowler, 1935	X	X	-	A, D, E
231	*Osteochilus melanopleurus* (Bleeker, 1852)	X	X	-	A, D, E
232	*Osteochilus microcephalus* (Valenciennes, 1842)	X	X	X	E
233	*Osteochilus schlegeli* (Bleeker, 1851)	X	-	-	A
234	*Osteochilus waandersii* (Bleeker, 1852)	X	X	-	A, D, E
235	*Poropuntius bantamensis* (Rendahl, 1920)	X	X	-	A, D
236	*Poropuntius deauratus* (Valenciennes, 1842)	X	X	-	A, D
237	*Poropuntius carinatus* (Wu & Lin, 1977)	X	-	X	E
238	*Poropuntius chondrorhynchus* (Fowler, 1934)	X	X	X	F
239	*Poropuntius consternans* Kottelat, 2000	X	X	-	E
240	*Poropuntius genyognathus* Roberts, 1998	-	-	X	F, H
241	*Poropuntius hathe* Roberts, 1998	-	-	X	H
242	*Poropuntius huguenini* (Bleeker, 1853)	X	X	-	A, D
243	*Poropuntius kontumensis* (Chevey, 1934)	X	-	-	B
244	*Poropuntius laoensis* (Günther, 1868)	X	-	-	E
245	*Poropuntius malcolmi* (Smith, 1945)	X	X	-	E
246	*Poropuntius normani* Smith, 1931	X	X	-	E
247	*Poropuntius scapanognathus* Roberts, 1998	-	-	X	F, H
248	*Probarbus jullieni* Sauvage, 1880	X	X	-	A, B, D, E
249	*Probarbus labeamajor* Roberts, 1992	X	-	-	B, E
250	*Probarbus labeaminor* Roberts, 1992	X	-	-	B, E
251	*Puntioplites bulu* (Bleeker, 1851)	X	-	-	A, Q
252	*Puntioplites falcifer* Smith, 1929	X	-	-	E
253	*Puntioplites proctozysron* (Bleeker, 1865)	X	X	-	A, B, D, E
254	*Puntioplites wanndersi* (Bleeker, 1858-59)	X	-	-	B, E
255	*Puntius aurotaeniatus (Tirant, 1885)*	X	X	-	E
256	*Puntius binotatus (Valenciennes, 1842)*	X	X	X	A, D
257	*Puntius brevis (Bleeker, 1860)*	X	X	-	E
258	*Puntius chola (Hamilton, 1822)*	-	-	X	F
259	*Puntius jacobusboehlkei (Fowler, 1958)*	X	X	-	E
260	*Puntius masyai Smith, 1945*	X	X	-	A
261	*Puntius orphoides (Valenciennes, 1842)*	X	X	-	A, D, E
262	*Puntius partipentazona Fowler, 1934*	X	X	-	E
263	*Puntius rhombeus* Kottelat, 2000	X	X	-	E
264	*Puntius sophore* (Hamilton, 1822)	-	-	X	F
265	*Puntius stoliczkanus* (Day, 1871)	X	X	X	A, E, F
266	*Puntius ticto* (Hamilton, 1822)	X	X	X	F

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
267	*Scaphiodonichthys acanthopterus* (Fowler, 1934)	X	X	-	A, D, E
268	*Scaphiodonichthys burmanicus* Vinciguerra, 1890	X	X	X	A, F, H
269	*Scaphognathops bandanensis* Boonyaratpalin & Srirungroj, 1971	X	-	-	D, E
270	*Scaphognathops stejnegeri* (Smith, 1931)	X	-	-	A, D, E
271	*Sikukia gudgeri* (Smith, 1934)	X	X	-	A, B, D, E
272	*Sikukia stejnegeri* Smith, 1931	X	X	-	A, B, E
273	*Thynnichthys thynnoides* (Bleeker, 1852)	X	X	-	A, B, D, E
274	*Tor brevifilis* (Peters, 1881)	X	-	X	A, E, F
275	*Tor douronensis* (Valenciennes, 1842)	X	X	-	A, D
276	*Tor soro* (Cuvier & Valenciennes, 1842)	X	X	-	A
277	*Tor tambra* (Valenciennes, 1842)	X	-	X	A, D, E
278	*Tor tambroides* (Bleeker, 1854)	X	X	X	A, D, E, F, H
	Family Balitoridae				
	Subfamily Balitorinae				
279	*Annamia normani* (Hora, 1930)	X	-	-	D, E
280	*Balitora annamitica* Kottelat, 1988	X	-	-	E
281	*Balitora brucei* Gray, 1833-34	-	X	-	A
282	*Balitora burmanica* Hora, 1932	-	-	X	F
283	*Balitora meridionalis* Kottelat, 1988	X	-	-	B
284	*Hemimyzon nanensis* Doi & Kottelat, 1998	-	X	-	C
285	*Homaloptera bilineata* Blyth, 1860	-	-	X	F
286	*Homaloptera confuzona* Kottelat, 2000	X	-	-	E
287	*Homaloptera indochinensis* Silas, 1953	X	-	-	B
288	*Homaloptera leonardi* Hora, 1941	X	-	-	B
289	*Homaloptera maxinae* Fowler, 1937	X	X	-	B
290	*Homaloptera orthogoniata* Vaillant, 1902	X	-	-	B
291	*Homaloptera smithi* Hora, 1932	X	X	-	A, B, D, E
292	*Homaloptera modesta* (Vinciguerra, 1890)	-	X	-	A
293	*Homaloptera sexmaculata* Fowler, 1934	-	X	-	A
294	*Homaloptera tweediei*, Herre, 1940	X			B, E
295	*Homaloptera zollingeri* Bleeker, 1853	X	X	-	A, B, E
	Subfamily Nemacheilinae				
296	*Acanthocobitis botia* (Hamilton, 1822)	-	X	-	A
297	*Acanthocobitis zonalternans* (Blyth, 1860)	X	-	X	E
298	*Acanthocobitis rubidipinnis* (Blyth, 1860)			X	F
299	*Nemacheilus binotatus* Smith, 1933	X	X	-	A
300	*Nemacheilus longistriatus* Kottelat, 1990	X	-	-	E, L
301	*Nemacheilus masyae* Smith, 1933	X	X	-	A, E, L
302	*Nemacheilus pallidus* Kottelat, 1990	X	X	-	A, B, E, L
303	*Nemacheilus platiceps* Kottelat, 1990	X	X	-	A, B, E, L
304	*Neonoemacheilus labeosus* (Kottelat, 1982)	-	-	X	F, H
305	*Physoschistura pseudobrunneana* Kottelat, 1990	X	X	X	F, L
306	*Schistura alticrista* Kottelat, 1990	-	-	X	F, L
307	*Schistura atriceps* (Smith, 1945)	-	X	-	A
308	*Schistura bella* Kottelat, 1990	X	-	-	L
309	*Schistura breviceps* (Smith, 1945)	X	X	-	G, L
310	*Schistura bucculenta* (Smith, 1945)	X	X	-	A, D, E, L
311	*Schistura cincticauda* (Blyth, 1860)	-	-	X	F, L
312	*Schistura daubentoni* Kottelat, 1990	X	-	-	L
313	*Schistura defectiva* Kottelat, 2000	X	X	-	E
314	*Schistura desmotes* (Fowler, 1934)	X	X	-	A, L
315	*Schistura dubia* Kottelat, 1990	-	X	-	L
316	*Schistura geisleri* Kottelat, 1990	-	X	-	L
317	*Schistura kengtungensis* (Fowler, 1936)	X	X	-	A, E, L
318	*Schistura kohchangensis* (Smith, 1933)	X	-	-	A, L
319	*Schistura maepaiensis* Kottelat, 1990	-	-	X	H, L
320	*Schistura magnifluvis* Kottelat, 1990	X	-	-	L
321	*Schistura mahnerti* Kottelat, 1990	-	X	X	G, H, L
322	*Schistura menanensis* (Smith, 1945)	-	X	-	A, L
323	*Schistura moeiensis* Kottelat, 1990	-	-	X	H, L
324	*Schistura nicholsi* (Smith, 1933)	X	X	-	A, H, L
325	*Schistura laterimaculata* Kottelat, 1990	X	-	-	A, L
326	*Schistura oedipus* Kottelat, 1989	-	-	X	L
327	*Schistura paucicincta* Kottelat, 1990	-	-	X	F, L
328	*Schistura poculi* (Smith, 1945)	X	X	X	A, B, E, H, L
329	*Schistura reidi* (Smith, 1945)	-	-	X	A, L
330	*Schistura schultzi* (Smith, 1945)	X	X	-	A, E, L
331	*Schistura sexcauda* (Fowler, 1937)	-	X	-	A, E, L
332	*Schistura similis* Kottelat, 1990	-	-	X	L
334	*Schistura spilota* (Fowler, 1934)	-	X	-	A, L
335	*Schistura vinciguerrae* (Hora, 1935)	-	-	X	F, H, L
336	*Schistura waltoni* Fowler, 1937	-	X	-	A, L
337	*Sectoria atriceps* Kottelat, 1990	-	X	-	L

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
338	*Tuberoschistura baezigeri* (Kottelat, 1983)	-	X	-	L
339	*Vailantella maassi* Weber & de Beaufort, 1912	X	X	-	L
340	*Yunnanilus brevis* (Boulenger, 1893)	-	-	X	F, L
	Family Cobitidae				
	Subfamily Botiinae				
341	*Botia kubotai* Kottelat, 2004	-	-	X	F
342	*Botia histrionica* Blyth, 1860	-	-	X	F
343	*Botia rostrata* Günther, 1868	-	-	X	F
344	*Syncrossus beauforti* (Smith, 1931)	X	X	-	A, B, D, E
345	*Syncrossus berdmorei* Blyth, 1860	X	-	X	F
346	*Syncrossus helodes* (Sauvage, 1876)	X	X	-	A, B, D, E
347	*Yasuhikotakia caudipunctata* (Taki and Doi, 1995)	X	-	-	E
348	*Yasuhikotakia eos* Taki, 1972	X	X	-	A, B, D, E
349	*Yasuhikotakia lecontei* (Fowler, 1937)	X	X	-	A, B, D, E
350	*Yasuhikotakia longidorsalis* (Taki and Doi, 1995)	X	-	-	E
351	*Yasuhikotakia modesta* (Bleeker, 1864)	X	X	-	A, B, D, E
352	*Yasuhikotakia morleti* (Tirant, 1885)	X	X	-	A, B, D, E
353	*Yasuhikotakia nigrolineata* (Kottelat and Chu, 1987)	-	X	-	E
354	*Yasuhikotakia sidthimunki* (Klausewitz, 1959)	X	X	-	A, D, E
355	*Yasuhikotakia splendida* (Roberts, 1995)	X	-	-	E
	Subfamily Cobitinae				
356	*Acanthopsoides delphax* Siebert, 1991	X	X	X	A, E
357	*Acanthopsoides gracilentus* (Smith, 1945)	X	X	-	A, E
358	*Acanthopsoides gracilis* Fowler, 1934	X	X	-	D, E
359	*Acanthopsoides hapalias* Siebert, 1991	X	X	-	A, E
360	*Acantopsis choirorhynchos* (Bleeker, 1854)	X	X	-	A, E, D, H
361	*Acantopsis dialuzona* Van Hasselt, 1823	X	X	X	P
362	*Acantopsis spectabilis* Blyth, 1860	-	-	X	F
363	*Acantopsis thiemmedhi* Sontirat, 1999	-	X	-	G
364	*Lepidocephalichthys berdmorei* (Blyth, 1860)	X	X	X	E, F
365	*Lepidocephalichthys furcatus* (de Beaufort, 1933)	X	X	-	E
366	*Lepidocephalichthys hasselti* (Valenciennes, 1846)	X	X	X	D, E
367	*Lepidocephalichthys micropogon* (Blyth, 1860)	-	-	X	F
368	*Pangio anguillaris* (Vaillant, 1902)	X	X	-	A, D, E
369	*Pangio fusca* (Blyth, 1860)	X	X	X	A, B, E
370	*Pangio kuhlii* (Valenciennes, 1846)	X	X	-	A
371	*Pangio myersi* (Harry, 1949)	X	X	-	E
372	*Pangio oblonga* (Valenciennes, 1846)	X	X	-	B, E
373	*Pangio pangia* (Hamilton, 1822)	-	-	X	A
374	*Pangio semicincta* (Fraser-Brunner, 1940)	X	X	-	A
375	*Serpenticobitis octozona* Roberts, 1997	X	-	-	E, R
376	*Serpenticobitis zonata* Kottelat, 1998	X	-	-	R
	Family Gyrinocheilidae				
377	*Gyrinocheilus aymonieri* (Tirant, 1884)	X	X	-	A, B, D, E
378	*Gyrinocheilus pennocki* (Fowler, 1937)	X	-	-	A, B, D, E
	Order Siluriformes				
	Family Akysidae				
379	*Acrochordonichthys rugosus* (Bleeker, 1847)	X	-	-	S
380	*Akysis brachybarbatus* Chen, 1981	X	X	-	T
382	*Akysis macronemus* Bleeker, 1860	X	-	-	A
381	*Akysis maculipinnis* Fowler, 1934	X	X	-	A
383	*Akysis recavus* Ng & Kottelat, 1998	X	X	-	T
384	*Akysis subtilis* Ng & Kottelat, 1998	X	-	-	E, T
385	*Akysis varius* Ng & Kottelat, 1998	X	-	-	E, T
386	*Akysis variegatus* (Bleeker, 1846)	X	-	-	B
	Family Amblycipitidae				
387	*Amblyceps mucronatum* Ng & Kottelat, 2000	X	-	X	E
388	*Amblyceps platycephalus* Ng & Kottelat, 2000	-	-	X	H
389	*Amblyceps serratum* Ng & Kottelat, 2000	-	-	X	E, F
	Family Ariidae				
390	*Arius arius* (Hamilton, 1822)	-	-	X	F
391	*Arius acutirostris* Day, 1877	-	-	X	F
392	*Arius maculatus* (Thunberg, 1792)	X	X	-	B
394	*Arius intermedius* (Vinciguerra, 1880)	X	X	-	B
393	*Batrachocephalus mino* (Hamilton, 1822)	X	X	-	A
395	*Cochlefelis burmanica* (Day, 1870)	-	-	X	F
396	*Hemipimelodus borneensis* (Bleeker, 1851)	X	X	-	A, B, E
397	*Hemipimelodus jatius* (Hamilton, 1822)	-	-	X	F
398	*Ketangus typus* Bleeker, 1847	X	X	-	A
399	*Osteogeneisosus militaris* (Linnaeus, 1758)	X	X	-	A
400	*Hemiarius stormii* (Bleeker, 1858)	X	-	-	E
	Family Bagridae				
401	*Bagrichthys macracanthus* (Bleeker, 1854)	X	X	-	A, D, E

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
402	*Bagrichthys macropterus* (Bleeker, 1853)	X	X	-	A, D, E
403	*Bagrichthys obscurus* Ng, 1999	X	X	-	E
404	*Batasio tengana* (Hamilton, 1822)	-	X	-	O
405	*Batasio havmolleri* (Smith, 1931)	-	X	-	A, O
406	*Batasio tigrinus* Ng & Kottelat, 2001	-	X	-	O
407	*Hemibagrus filamentus* (Fang & Chaux, 1949)	X	X	-	A, B, E
408	*Hemibagrus microphthalmus* (Day, 1877)	-	X	X	A, F
409	*Hemibagrus nemurus* (Valenciennes, 1840)	X	X	-	A, B, D, E
410	*Hemibagrus planiceps* (Valenciennes, 1840)	X	-	-	A
411	*Hemibagrus variegatus* Ng & Ferraris, 2000			X	F
412	*Hemibagrus wyckii* (Bleeker, 1858)	X	X	-	A, B, E
413	*Hemibagrus wyckioides* (Fang & Chaux, 1949)	X	X	-	A, B, E
414	*Mystus albolineatus* Roberts, 1994	X	X	-	B, E
415	*Mystus atrifasciatus* Fowler, 1937	X	X	-	B, E
416	*Mystus bocourti* (Bleeker, 1864)	X	X	-	A, B, D, E
417	*Mystus cavasius* (Hamilton, 1822)	X	-	X	D, F
418	*Mystus gulio* (Hamilton, 1822)	X	X	-	A, F
419	*Mystus leucophasis* (Blyth, 1860)	-	-	X	F
420	*Mystus multiradiatus* Roberts, 1992	X	X	-	B, E
421	*Mystus mysticetus* Roberts, 1992	X	X	-	A, B, E
424	*Mystus pulcher* (Chaudhuri, 1911)	X	X	-	Q
425	*Mystus singaringan* (Bleeker, 1846)	X	X	X	B, E, F
426	*Mystus rhegma* Fowler, 1935	X	X	-	A, B, D, E
427	*Mystus wolffi* (Bleeker, 1851)	X	X	-	A, B, E
428	*Pseudomystus leiacanthus* (Weber & de Beaufort, 1912)	-	X	-	A
429	*Pseudomystus siamensis* (Regan, 1913)	X	X	-	A, B, D, E
430	*Pseudomystus stenomus* (Valenciennes, 1839)	X	X	-	A
431	*Rita sacerdotum* Anderson, 1879	-	-	X	F, H
432	*Sperata acicularis* Ferraris & Runge, 1999	-	-	X	F, H
	Family Clariidae				
433	*Clarias batrachus* (Linnaeus, 1785)	X	X	X	A, B, D, E, F
434	*Clarias gariepinus* (Burchell, 1851)	X	X	-	B, E
435	*Clarias leiacanthus* Bleeker, 1851	-	X	-	A
436	*Clarias macrocephalus* Günther, 1864	X	X	-	A, B, D, E
437	*Clarias meladerma* Bleeker, 1847	X	X	-	A, B, E
438	*Clarias nieuhofi* Valenciennes, 1840	X	X	-	A, B
	Family Heteropneustidae				
439	*Heteropneustes kemratensis* (Fowler, 1937)	X	X	X	A, B, D, E, F
	Family Pangasiidae				
440	*Helicophagus leptorhynchus* Ng & Kottelat, 2000	X	X	X	E
441	*Helicophagus waandersii* Bleeker, 1858	X	X	-	A, B, D
442	*Pangasianodon hypophthalmus* (Sauvage, 1878)	X	X	-	A, B, D, E
443	*Pangasianodon gigas* Chevey, 1930	X	X	-	A, B, D, E
444	*Pangasius bocourti* (Sauvage, 1880)	X	X	-	A, B, E
445	*Pangasius conchophilus* Roberts & Vidthayanon, 1991	X	X	-	E
446	*Pangasius djambal* Bleeker, 1846	X	-	-	B
447	*Pangasius krempfi* Fang & Chaux, 1949	X	X	-	E
448	*Pangasius larnaudii* Bocourt, 1851	X	X	-	A, B, D, E
449	*Pangasius macronema* Bleeker, 1851	X	X	-	A, E
450	*Pangasius micronemus* Bleeker, 1847	X	X	-	A, E
451	*Pangasius myanmar* Roberts & Vidthayanon, 1991	-	-	X	F
452	*Pangasius pangasius* (Hamilton, 1822)	-	-	X	D, F
453	*Pangasius pleurotaenia* (Sauvage, 1878)	X	X	-	A, B, E
454	*Pangasius polyuranodon* Bleeker, 1852	X	X	-	A, B, E
455	*Pangasius sanitwongsei* Smith, 1931	X	X	-	A, B, D, E
	Family Plotosidae				
456	*Plotosus canius* Hamilton, 1822	X	X	X	A, B, E, F
457	*Plotosus lineatus* (Thunberg, 1791)	-	X	-	A
	Family Schilbeidae				
458	*Clupisoma prateri* Hora, 1937	-	-	X	F
459	*Clupisoma sinense* (Huang, 1981)	X	-	-	E
460	*Eutropiichthys burmannicus* Day, 1877	-	-	X	F
461	*Laides longibarbis* (Fowler, 1934)	X	X	-	D, E
462	*Laides hexanema* (Bleeker, 1852)	X	X	-	A, B, D, E
463	*Proeutropiichthys taakree macropthalmos* (Blyth, 1860)	-	-	X	F
	Family Siluridae				
464	*Belodontichthys dinema* (Bleeker, 1851)	X	X	-	A, B, D, E
465	*Belodontichthys truncatus* Kottelat & Ng, 1999	X	X	-	A, B, E
466	*Ceratoglanis pachynema* Ng, 1999	X	X	-	B, E
467	*Hemisilurus mekongensis* Bonbusch & Lundberg, 1989	X			B, E
468	*Kryptopterus bicirrhis* (Valenciennes, 1840)	X	X	-	A, B, D, E
469	*Kryptopterus cheveyi* Durand, 1940	X	X	-	A, B, D, E
470	*Kryptopterus cryptopterus* (Bleeker, 1851)	X	X	-	A, B, D, E

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
471	*Kryptopterus dissitus* Ng, 2001	X	X	-	U
472	*Kryptopterus geminus* Ng, 2003	X	X	-	V
473	*Kryptopterus limpok* (Bleeker, 1852)	X	X	-	A, B, E
474	*Kryptopterus macrocephalus* (Bleeker, 1858)	X	X	-	B, E
475	*Kryptopterus moorei* Smith, 1945	X	X	-	A, B, E
476	*Kryptopterus schilbeides* (Bleeker, 1858)	X	X	-	A, B, D
477	*Micronema hexapterus* (Bleeker, 1851)	X	X	-	A, B, E
478	*Ompok bimaculatus* (Bloch, 1794)	X	X	X	A, B, E, D, F
479	*Ompok eugeneiatus* (Vaillant, 1893)	X	X	-	A, B, E
480	*Ompok hypophthalmus* (Bleeker, 1846)	X	X	-	A, B, E
481	*Ompok pabda* (Hamilton, 1822)	-	-	X	H
482	*Ompok pabo* (Hamilton, 1822)	-	-	X	F
483	*Phalacronotus apogon* (Bleeker, 1851)	X	X	-	A, B, D, E
484	*Phalacronotus bleekeri* (Günther, 1864)	X	X	-	A, B, D, E
485	*Phalacronotus micronemus* (Bleeker, 1846)	X	X	-	A, B, E
486	*Pterocryptis cochinchinensis* (Valenciennes, 1840)	X	-	-	A, E
487	*Pterocryptis bokorensis* (Pellegrin & Chevey, 1937)	X		-	B
488	*Pterocryptis torrentis* (Kobayakawa, 1989)	X		-	B
489	*Silurichthys hasselti* Bleeker, 1858	X		-	A
490	*Silurichthys phaiosoma* (Bleeker, 1851)	X		-	A
491	*Wallago attu* (Bloch & Schneider, 1801)	X	X	X	A, B, D, E, F
492	*Wallago leerii* Bleeker, 1851	X	X	-	A, B, D, E
	Family Sisoridae				
493	*Bagarius bagarius* (Hamilton, 1822)	X	X	X	A, B, D, E
494	*Bagarius suchus* Roberts, 1983	X	X	-	E
495	*Bagarius yarrelli* Sykes, 1838	X	X	X	A, B, F
496	*Caelatogranis zonatus* Ng & Kottelat, 2005	-	-	X	F
497	*Erethistes maesotensis* Kottelat, 1983	-	-	X	F
498	*Exostoma berdmorei* Blyth, 1860	-	X	X	F
499	*Gagata cenia* (Hamilton, 1822)	-	-	X	A
500	*Gagata gasawyuh* Roberts & Ferraris, 1998	-	-	X	F
501	*Gagata melanopterus* Roberts & Ferraris, 1998	-	-	X	F
502	*Glyptothorax burmanicus* Prashad & Mukerji, 1929	-	-	X	H
503	*Glyptothorax buchanani* Smith, 1945	-	X	-	A
504	*Glyptothorax callopterus* Smith, 1945	-	X	-	A
505	*Glyptothorax dorsalis* Vinciguerra, 1890	-	-	X	F, H
506	*Glyptothorax fuscus* Fowler, 1934	X	X	X	A, B, E
507	*Glyptothorax lampris* Fowler, 1934	X	X	-	A, B
508	*Glyptothorax laosensis* Fowler, 1934	X	X	-	E
509	*Glyptothorax major* (Boulenger, 1894)	X	-	-	A
510	*Glyptothorax minimaculatus* Li 1984	-	-	X	H
511	*Glyptothorax prashadi* Murerji, 1932	-	X	-	A
512	*Glyptothorax rugimentum* Ng & Kottelat, 2008	-	-	X	H
513	*Glyptothorax trilineatus* Blyth, 1860	X	X	X	A, B, D, F
514	*Glyptothorax zanaensis* Wu, He & Chu, 1981	X	-	X	E
515	*Oreoglanis colurus* Vidthayanon, Saenjundaeng & Ng, 2009	-	X	-	N
516	*Oreoglanis heteropogon* Vidthayanon, Saenjundaeng & Ng, 2009	-	-	X	N
517	*Oreoglanis laciniosus* Vidthayanon, Saenjundaeng & Ng, 2009	-	-	X	N
518	*Oreoglanis nakasathiani* Vidthayanon, Saenjundaeng & Ng, 2009	-	X	-	N
519	*Oreoglanis siamensis* Smith, 1933	-	X	-	A, N
520	*Oreoglanis sudarai* Vidthayanon, Saenjundaeng & Ng, 2009	-	X	-	N
521	*Oreoglanis suraswadii* Vidthayanon, Saenjundaeng & Ng, 2009	X	-	-	N
522	*Oreoglanis tenuicauda* Vidthayanon, Saenjundaeng & Ng, 2009	-	X	-	N
523	*Oreoglanis vicinus* Vidthayanon, Saenjundaeng & Ng, 2009	-	X	-	N
524	*Pareuchiloglanis feae* (Vinciguerra, 1890)	X	-	X	W
525	*Pareuchiloglanis kamengensis* (Jayaram, 1966)	X	-	X	W
526	*Pseudecheneis sulcata* (McClelland, 1842)	-	-	X	F
	Order Atheriniformes				
	Family Phallostethidae				
527	*Phenacostethus smithi* Myers, 1928	X	X	-	A
528	*Neostethus siamensis* Myers, 1937	X	X	-	A
	Order Beloniformes				
	Family Adrianichthyidae				
529	*Oryzias javanicus* Bleeker, 1854	X	-	-	B, Q
530	*Oryzias latipes* (Temminck and Schlegel, 1846)	X	-	X	X
531	*Oryzias mekongensis* Uwa & Magtoon, 1986	X	X	-	E
532	*Oryzias minutillus* Smith, 1945	X	X	X	A
533	*Oryzias sinensis* Chen, Uwa & Chu, 1989	X	-	X	E
	Family Belonidae				
534	*Xenentodon cancila* (Hamilton, 1822)	X	X	X	A, B, F, G
535	*Xenentodon canciloides* (Bleeker, 1853)	X	-	-	A, D, E
536	*Strongylura strongylura* (van Hasselt, 1823)	-	X	-	A
	Family Hemirhamphidae				

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
537	*Dermogenys pusilla* van Hasselt, 1823	X	X	-	A, B, E
538	*Hyporhamphus limbatus* (Valenciennes, 1846)	X	X	-	A
539	*Zenachopterus buffonis* (Valenciennes, 1845)	X	X	-	A
540	*Zenachopterus dunckeri* Mohr, 1926	X	X	-	A
541	*Zenachopterus ectuntio* (Hamilton, 1822)	X	X	-	A
	Order Cyprinodontiformes				
	Family Aplocheilidae				
542	*Aplocheilus panchax* (Hamilton, 1822)	-	X	X	A, F
	Family Poeciliidae				
543	*Gambusia affinis* (Baird and Girard, 1853)	X	X	-	A, E
545	*Gambusia holbrookii* (Girard, 1859)	-	X	-	A
546	*Poecilia reticulata* Peters, 1859	X	X	-	E
	Order Gasterosteiformes				
	Family Indostomidae				
547	*Indostomus paradoxus* Prasad & Mukerji, 1929	X	X	X	F
548	*Indostomus spinosus* Britz & Kottelat, 1999	X	-	-	E
	Family Syngnathidae				
549	*Doryichthys boaja* (Bleeker, 1851)	X	X	-	A, E
550	*Doryichthys contiguus* Kottelat, 2000	X	-	-	E
551	*Doryichthys deokhatoides* (Bleeker, 1853)	X	X	-	A
552	*Doryichthys martensii* (Peters, 1868)	X	X	-	A
553	*Hipichthys spicifer* (Rüppell, 1838)	X	X	-	A
554	*Ichthyocampus carce* (Hamilton, 1822)	X	X	-	A
555	*Microphis brachyurus* (Bleeker, 1853)	X	X	-	Y
	Order Synbranchiformes				
	Family Chaudhuridae				
556	*Chaudhuria caudata* Annandale, 1918	X	X	-	E
	Family Mastacembelidae				
557	*Macrognathus aral* (Bloch & Schneider, 1801)	-	-	X	F
558	*Macrognathus aculeatus* (Bloch, 1786)	X	-	-	A, D
559	*Macrognathus caudiocellatus* (Boulenger, 1893)	-	-	X	F
560	*Macrognathus circumcinctus* (Hora, 1924)	X	X	-	A, E
561	*Macrognathus maculatus* Cuvier, 1831	X	-	-	Q
562	*Macrognathus semiocellatus* Roberts, 1986	X	X	-	A, E
563	*Macrognathus siamensis* (Günther, 1861)	X	X	-	A, E
564	*Macrognathus taeniagaster* (Fowler, 1835)	X	X	-	A
565	*Macrognathus zebrinus* (Blyth, 1858)	-	-	X	F
566	*Mastacembelus alboguttatus* Boulenger, 1893	-	-	X	F
567	*Mastacembelus armatus* (Lacepède, 1800)	X	X	X	A, B, D, E, F
568	*Mastacembelus erythrotaenia* Bleeker, 1870	X	X	-	A
569	*Mastacembelus favus* Hora, 1823	X	X	-	A
570	*Mastacembelus tinwini* Britz, 2007	-	-	X	Z
	Family Synbranchidae				
571	*Monopterus albus* (Zuiew, 1793)	X	X	X	D, E, F
572	*Monopterus cuchia* (Hamilton, 1822)	-	-	X	F
573	*Ophisternon bengalense* (McClelland, 1845)	X	-	-	Q
	Order Perciformes				
	Family Ambassidae				
574	*Ambassis buruensis* Bleeker, 1856	X	-	-	Q
575	*Ambassis gymnocephalus* (Lacepède, 1802)	X	X	-	Q
576	*Ambassis kopsi* Bleeker, 1851	X	-	-	Q
577	*Parambassis apogonoides* (Bleeker, 1851)	X	-	-	E
578	*Parambassis lala* (Hamilton, 1822)	-	-	X	F
579	*Parambassis ranga* (Hamilton, 1822)	-	-	X	A, F
580	*Parambassis siamensis* (Fowler, 1937)	X	X	-	A, B, D, E
581	*Parambassis vollmeri* Roberts, 1995	-	-	X	F
582	*Parambassis wolffii* (Blyth, 1860)	X	X	-	A, B, E
	Family Centropomidae				
583	*Lates calcarifer* (Bloch, 1790)	X	X	X	A, F
	Family Polynemidae				
584	*Polynemus longipectoralis* Weber & de Beaufort, 1922	X	X	-	E
585	*Polynemus multifilis* Schlegel, 1845	X	X	-	Q
586	*Polynemus paradiseus* Linnaeus, 1758	X	X	-	A
	Family Scieanidae				
587	*Boesemania microlepis* (Bleeker, 1858-59)	X	X	-	A, B, D, E
588	*Johnius coitor* (Hamilton, 1822)	-	-	X	F
589	*Otolithoides pama* (Hamilton, 1822)	-	-	X	F
590	*Otolithoides biauritus* (Cantor, 1849)	-	-	X	F
	Family Toxotidae				
591	*Toxotes chatareus* (Hamilton, 1822)	X	X	X	A, E, F
592	*Toxotes microlepis* (Günther, 1860)	X	X	-	A, D
	Family Lobotidae				
593	*Datnioides microlepis* Bleeker, 1853	X	X	-	A, D

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
594	*Datnioides polota* (Hamilton, 1822)	X	X	-	A
595	*Datnioides pulcher* (Kottelat, 1998)	X	X	-	E
596	*Datnioides undecimradiatus* (Roberts & Kottelat, 1994)	X	-	-	E
	Family Nandidae				
597	*Badis ruber* Schreitmüller, 1923	X	-	X	E, F
599	*Dario hysginon* Kullander & Britz, 2002	-	-	X	F
600	*Nandus nandus* (Bleeker, 1851)	X	X	-	A, D
601	*Nandus nebulosus* (Gray, 1835)	X	X	-	A, D
602	*Nandus oxyrhynchus* Ng, Vidthayanon & Ng, 1996	X	X	-	E
603	*Pristolepis fasciata* (Bleeker, 1851)	X	X	-	A, B, D, E
	Family Cichlidae				
604	*Oreochromis niloticus* (Linnaeus, 1758)	X	X	X	E, H
	Family Gobiidae				
605	*Brachygobius mekongensis* Larson & Vidthayanon, 2000	X	-	-	E
606	*Calamiana aliceae* (Smith, 1945)	X	X	-	A
607	*Eugnathogobius siamensis* (Fowler, 1934)	X	X	-	A
608	*Glossogobius aureus* Akihito & Meguro, 1975	X	X	-	E
609	*Glossogobius giuris* (Hamilton, 1822)	X	X	X	F
610	*Gobiopterus chuno* (Hamilton, 1822)	X	X	-	A, E
611	*Papuligobius ocellatus* (Fowler, 1937)	X	X	-	A, E
612	*Rhinogobius chiengmaiensis* (Fowler, 1934)	-	X	-	G
613	*Rhinogobius mekongianus* (Pellegrin & Fang, 1940)	X	X	-	E
	Family Eleotridae				
614	*Oxyeleotris marmorata* (Bleeker, 1852)	X	X	-	A, B, D, E
	Family Odontobutididae				
615	*Neodontobutis aurarmus* (Vidthayanon, 1995)	X	-	-	E
	Family Anabantidae				
616	*Anabas testudineus* (Bloch, 1792)	X	X	X	A, E, F
	Family Helostomatidae				
617	*Helostoma temmincki* Cuvier, 1831	X	X	-	A
	Family Osphronemidae				
618	*Betta imbellis* Ladiges, 1975	X	-	-	AA
619	*Betta pi* Tan, 1998	X	-	-	AB
620	*Betta prima* Kottelat, 1994	X	-	-	E
621	*Betta pugnax* (Cantor, 1849)	X	-	-	AD
622	*Betta simplex* Kottelat, 1994	-	X	-	
623	*Betta smaragdina* Schaller, 1986	X	X	-	E
624	*Betta splendens* Regan, 1909	X	X	-	A
625	*Colisa labiosa* (Day, 1877)	-	-	X	F
626	*Osphronemus exodon* Roberts, 1994	X	-	-	E
627	*Osphronemus goramy* Lacepède, 1802	X	X	-	A, B, D, E
628	*Paraspherichthys ocellatus* Prashad & Mukerji, 1929	-	-	X	F
629	*Parosphromenus paludicola* Tweedie, 1952				
630	*Trichogaster leerii* (Bleeker, 1852)	X	X	-	A, B
631	*Trichogaster microlepis* (Günther, 1861)	X	X	-	E
632	*Trichogaster pectoralis* Regan, 1909	X	X	-	A, B, E
633	*Trichogaster trichopterus* (Pallas, 1770)	X	X	X	A, B, E
634	*Trichopsis pumila* (Arnold, 1937)	X	X	-	A, E
635	*Trichopsis schalleri* Ladiges, 1962	X	-	-	E
636	*Trichopsis vittata* (Cuvier, 1831)	X	X	X	A, B, E
	Family Channidae				
637	*Channa aurolineata*	-	-	X	F
638	*Channa gachua* (Hamilton, 1822)	X	X	X	A, B, D, E
639	*Channa harcourtbutleri* (Annandale, 1918)	-	-	X	F
641	*Channa lucius* (Cuvier, 1831)	X	X	-	A, B, D, E
641	*Channa marulius* (Hamilton, 1822)	X	-	-	A, E
642	*Channa melasoma* (Bleeker, 1851)	X	-	-	A, D
643	*Channa micropeltes* (Cuvier, 1831)	X	X	-	A, D, E
644	*Channa oreintalis* (Schneider, 1801)	X	-	-	K
645	*Channa striata* (Bloch, 1795)	X	X	X	A, B, D, E, F
	Order Pleuronectiformes				
	Family Soleidae				
646	*Achiroides leucorhynchos* Bleeker, 1851	X	X	-	A
647	*Achiroides melanorhynchus* (Bleeker, 1850)	X	X	-	A
468	*Brachirus harmandi* (Sauvage, 1878)	X	X	-	A, D, E
649	*Brachirus orientalis* (Schneider, 1801)	X	-	-	A
650	*Brachirus panoides* (Bleeker, 1851)	X	-	-	A
651	*Brachirus siamensis* (Sauvage, 1878)	X	X	-	A, E
	Family Cynoglossidae				
652	*Cynoglossus feldmanni* (Bleeker, 1853)	X	X	-	E
653	*Cynoglossus microlepis* (Bleeker, 1851)	X	X	-	A, B, E
	Order Tetraodontiformes				
	Family Tetraodontidae				

Table 3 Fishes species of Mekong, Chao Phraya and Salween rivers (Continued).

	Order/Family/Species	Mekong	Chao Phraya	Salween	Ref.
654	*Auriglobus nefastus* Roberts, 1982	X	X	-	E
655	*Carinotetraodon lorteti* (Tirant, 1885)	X	X	-	E
656	*Tetraodon abei* Roberts, 1998	X	X	-	X
657	*Tetraodon baileyi* Sontirat, 1989	X	-	-	E
658	*Tetraodon biocellatus* Tirant, 1885	X	X	-	E
659	*Tetraodon cambodgiensis* (Chabanaud, 1923)	X	X	-	E
660	*Tetraodon cutcutia* Hamilton, 1822	-	-	X	C, D, F
661	*Tetraodon cochinchinensis* (Steindachner, 1866)	X	X	-	E
662	*Tetraodon fluviatilis* (Hamilton, 1822)	X	-	-	A, D
663	*Tetraodon leiurus* (Bleeker, 1851)	X	X	-	A, D
664	*Tetraodon nigroviridis* (Procé, 1822)	X	X	-	A, E
665	*Tetraodon palembangensis* Bleeker, 1852	X	X	-	A
666	*Tetraodon suvattii* Sontirat, 1989	X	X	-	E
667	*Tetraodon turgidus* (Kottelat, 2000)	X	-	-	E
	Total species	509	420	190	

Note: For abbreviations A = Smith (1945); B = Rainboth (1996); C = Jayaram (1999); D = Taki (1974); E = Kottelat (2001); F = Vidthayanon et al. (2005); G=Suvarnaraksha et al. (2004); H = Suvarnaraksha et al. (2010); I = Last & Compagno (1999); J = Doi & Taki (1994); K = Zhang, Yue & Chen (2000); L = Kottelat (1990); M = Freyhof & Serov (2001); N = Vidthayanon, Saenjundaeng, & Ng (2009); O = Ng & Kottelat (2001); P = Doi (1997); Q = Monkolprasit et al. (1997); R = Kottelat (1998); S = Ng & Ng (2001); T = Ng & Kottelat (1998); U = Ng (2002); V = Ng (2003); W = He (1996); X = Roberts (1998); Y = Dawson (1985); Z = Britz (2007); AA = Kottelat et al. (1993); AB = Tan (1998); AD = Tan & Tan (1996); AE = Kottelat (1994); AF= Roberts (1997)

1.4 Biology and life history traits of the tropical freshwater fishes

The freshwater ecosystems in tropical Asia are rich of fauna and flora species and there are very complexities, especially fishes. The diverse groups of fishes are also resulted in the wide range of morphological, behavioural, and life history attributes that characterise the constituent species, which is due to the fact that various habitats are embedded in inland waterbodies (Mims et al., 2010). The life history of recent fish species have evolved from basal ancestors to survive, feed, reproduce and die in a given ecological niche within a given aquatic ecosystem (Froese, 2005). Understanding the life history of individual fish species includes what it eats, how fast it grows and how old and large it gets when it matures and how successfully it reproduces, and other aspects of its biology (Matthews, 1998; Froese, 2005).

In the tropical river system, most fishes breed during the rainy season (Alkins-Koo, 2000; Ballesteros et al., 2009), however, a few breed during the dry season (Pusey et al., 2002; Torres-Mejia & Ramírez-Pinilla, 2008) or throughout the year (Alkins-Koo, 2000). Variation in reproductive seasonality has been associated with several factors, such as availability of nursery areas, availability of food for adults or juveniles, competition for breeding sites, phylogenetic inertia and hydrological cycle in the river system (Ballesteros et al., 2009). Generally, most fish in the river system cannot complete its in a single habitat, when requirements for reproduction and for feeding at different life stages cannot be met in the same place, then fishes have to move between places to survive (Baran & Jutagate 2010). One classification of fish species relates to the ability to complete their life cycle dependant on access to the riverine environments. Obligatory riverine species spawn only in the river corridor, while facultative (non-obligatory) riverine species can realize their life history strategy in both stagnant and flowing waters (Schiemer & Waidbacher 1992; Kruk & Penczak, 2002). Thus, almost all obligatory riverine fish species suffer severely from dam construction without effective fish paasages, including the local extirpation of many of them (Penczak & Kruk 2000; Kruk & Penczak, 2002), in which this problem is among the most concern issues in Thailand, where a numbers of damming project are proposed including in the Ping-Wang River basin (Jutagate et al., 2011).

Food consumption studies in fish populations have received attention among aquatic ecologists and fisheries biologists, mainly to assess trophic relationships in aquatic ecosystems (Christensen & Pauly, 1993; Amarasinghe et al., 2010). Welcomme et al. (2006) mentioned that there is flexibility in diets of many freshwater fish, which may be related to fish size, season and location within the system or most likely a combination of all three (Pusey et al., 1995). Moreover, dietary composition of many tropical freshwater species also showed that they are mostly omnivorous (Guruge, 2002). The highest feeding activities of tropical fishes usually occur during the rainy seasons when the availability of prey is relatively higher (Prejs & Prejs, 1987; Ballesteros et al., 2009). Kramer (1978) proposed the theory that the reproductive season of tropical freshwater fish would be synchronized with food consumption, which could be confirmed on the importance of feeding to sustain the fish stock and renew the next generations. Therefore, numbers of individual in fish stock would decline if critical food resources are limited or eliminated by any disturbances (Welcomme et al., 2006)

Fishes have indefinite growth (i.e. the size is increasing continuously, albeit different rate, throughout their lives) and the maximum life span may be taken as the age corresponding to 95% of the asymptotic size of the von Bertalanffy growth function (Froese, 2005). The von Bertalanffy growth function (VBGF) is based on a bioenergetic expression of fish growth and VBGF is the most important model and widely used to describe the average “size-at-agea wide variety of aquatic organisms (Cailliet et al., 2006) and the function is generally expressed as Equation 1

$$L_t = L_\infty \left[1 - e^{-(K(t-t_0)}\right] \text{----------------------- (1)}$$

where L_t is length at time t, L_∞ is the asymptotic length, K is the growth coefficient and t_0 is the theoretical age at length zero. Moreover, if there are strong seasonal changes in temperature, the modified version of the VBGF (Equation 2) was used, which incorporates seasonal oscillation in growth (Herrmann et al., 2009). Two more parameters were incorporated into the VBGF, when seasonality was taken into account: firstly, C, which is between 0 and 1 indicates the magnitude of the seasonal growth pattern and secondly, t_s, the time from birth to the start of growth oscillations

$$L_t = L_\infty \left[1 - e^{-(K(t-t_0)-CK/2\pi)\{\sin 2\pi(t-t_0)-\sin 2\pi(t-t_0)\}}\right] \text{---------------------- (2)}$$

Froese & Binohlan (2000) mentioned that about 7,000 species of fishes are consumed by humans, knowing on life history traits on growth and maturity, which is essential for proper management of exploited populations, is available for only about 1,200 species, which could be hampered efforts to sustainable uses the fish stocks. For example, maximum sustainable yield and the fishing mortality rate that produces the maximum yields can be estimated by using the key life-history parameters of fish species such as growth coefficient (K), the length at sexual maturity relative to asymptotic length incorporated with length at captured and natural mortality rate and sometimes, the stock recruitment relationship (Beddington & Cooke, 1983; Kirkwood et al., 1994; Beddington & Kirkwood, 2005). Meanwhile, life span and age at first maturity are two important parameters in conservation management (Froese & Binohlan, 2000).

1.5 Freshwater ecological study and fish assemblages

River ecology of tropical Southeast Asia is dominated by flow seasonality imposed by monsoonal rains with profound consequences for fishes and zoobenthos (Dudgeon, 2000). Thus, fluctuations and changes in discharge patterns affect the abundance, species composition and viability of living aquatic resources resident in the river. Also, along the river gradient, the variations in geo-morphological characteristics of the river as well as environmental variables (both biotic and abiotic) are the major factors that govern fish communities both in terms of species richness and distribution of individual species (Orrego et al., 2009; Alexandre et al., 2010; Kimmel & Argent, 2010). Moreover, environment favour specific suites of traits, resulting in the evolution of life history strategies or tactics that enable a species to cope with a range of ecological problems (Froese, 2005; Mims et al., 2010).

Under natural conditions, a river is characterized by either a continuous succession of fish species along the spatial gradient or a staggered succession (Orrego et al., 2009). In a fluvial ecosystem, species composition is highly influenced by parameters such as altitude, gradient, current velocity, and temperature (Campos, 1985; Orrego et al., 2009). Meanwhile, along the downstream gradient the River Continuum Concept (Vannote et al., 1980) relates community structure and river functional changes, with physical factors such as flow regime, temperature, food availability, and river morphological conditions (Orrego et al., 2009). Generally, fishes show high adaptability to their habitat environment, whereas their morphological and ecological characteristics change correspondingly (He et al., 2010). Meanwhile, the distribution range of fishes along an upstream–downstream gradient within a river basin is determined by the ecological requirements of each fish species (Ferreira & Petrere, 2009).

Distinguishing fish assemblages along the river gradient is very difficult because prostine environment does not exist any more due to anthropogenic stresses and invasion of non-native species (Vannote et al., 1980; Kruk et al., 2007).

Moreover, temporal variability in fish assemblages is also common and driven by similar processes that impact on fish population dynamics via immigration, emigration, spawning, recruitment and mortality (King et al., 2003; Balcombe et al., 2006). The global growing concern about pervasive impacts of human modifications to riverine ecosystems (Allan & Flecker 1993; Malmqvist & Rundle, 2002), has led to increasing recognition of the need for quantitative procedures for assessing aquatic ecosystem and monitoring biotic responses to remedial management. Many theoretical classifications of running waters, notably fish-based classifications, have been proposed since the end of the 19th century (e.g. Huet, 1959) and becoming much more concern because the deviation between the observed assemblage type and the one expected in undisturbed (theoretical) conditions provides an assessment of their ecological status (Lasne et al., 2007). Recently, Welcomme et al., (2006) proposed environmental guilds of freshwater fishes along the river gradient (using location in river system, reproductive, behavioural, and ecological traits) as a tool for riverine ecological assessment.

To evaluate the status and any changes in fish assemblages in each section and/or time, diversity indices are commonly used and the commonest indicator is the number of species found, i.e. species richness (Oberdorff et al., 2002; de Thoisy et al., 2008; He, 2010). This indicator is an integrative descriptor of the animal community, influenced by a large number of natural environmental factors as well as anthropogenic disturbances, including the geological history of the area, environmental stability, ecosystem productivity and heterogeneity (He et al., 2010). It is suggested that if the physical aspects of the stream are relatively stable, they are responsible for the consistent pattern in biological community structure (Orrego et al., 2009) although there may some other factors could be influenced such as competition, predation as well as point and non-point pollution sources (Ibarra et al., 2005; Orrego et al., 2009).

1.6 Objectives of this Thesis

Because of natural functioning aquatic ecosystems have important intrinsic values and also provide many goods, services and long-term benefits to human society (Baron et al., 2002), hence their protection, remediation and restoration is of critical importance. However, in Chao Phraya River basin, research on the aquatic ecology and fish diversity are few and it needs more scientific information to reach the ultimate goal of wise and sustained uses of aquatic resources. This thesis was divided into 3 main levels viz., taxonomic level (descriptive level), biology and life history of fishes (descriptive level to predictive level), and assemblages of fish diversity and environmental factors (predictive level). The first level is the investigation fish diversity in the upper Chao Phraya River basin; a part of Indo-Burma hotspot region (Publication 1; **P1**). At the second level, investigation of life history and population dynamics of the keystone fish species in the study area i.e., (1) life history of riverine cyprinid *Henicorhynchus siamensis* (Sauvage, 1881) in a small reservoir (Publication 2; **P2**) and (2) reproductive biology and conservation approaches of endanger species stream sisorids (*Oreoglanis siamensis*) (Publication 3; **P3**). The *H. siamensis* is a well adaptation from riverine species to reservoir conditions and it was an important economic fish for fisherman in this reservoir. Meanwhile, *O. siamensis* is a vulnerable species, which inhabits cold swift of highn mountain streams and attaches itself to rock surfaces facing the current. Both species were the representative of lentic and lotic ecosystem conditions. The lentic *H. siamensis* was a riverine species but it was well adapted to the reservoir. And the lotic *O. siamensis* was an endemic and vulnerable species, restrict to the habitat and high elevations. Finally, the third level, investigation of the relationships between biological parameters and environmental parameters which are also benefit to investigate fish diversity and assemblages patterns in the studied area (Publication 4; **P4**) and lastly the investigation of the effects of dam to the riverine fish assemblages (Publication 5; **P5**).

2. GENERAL MATERIALS AND METHODS

2.1 Studied sites and data collection

This study was conducted in the Ping - Wang river basin, located in upper Chao Phraya river basin (the largest river of Thailand). The Ping basin is one of the largest drainage basins of the Chao Phraya river basin with a total length of 658 km and draining 33,896 km and extends to 44,688 km if included the Wang river basin. The Wang river is 440 km long and has a catchment area 10,791 km^2 (Takeuchi et al., 2005). The Wang river flows southwestward to join the lowland of Ping river in Tak province and they combine to form a large watershed area between 15°42' and 19°48' North and 98°04' and 100°08' East. The highest altitude of the sampling sites in this thesis is at 1,700 m ASL and connected to the lower Chao Phraya river basin at the altitude of 40 m ASL.

Table 2 Descriptions of the sub-basins in the Ping-Wang River Basin and sampling protocols

Sub-basin	Geographic Coordinate	Bottom types	Elevation (m ASL)	Distance from the sea (km)	Water depth (m)	Stream width (m)	Collecting period
Upping Ping (UP)	19°07'-19°48' N 98°47'-99°17' E	G, P, R, S	684 ± 228.3	1,026 ± 24.1	0.4 ± 0.2	7 ± 0.5	2008
Maetang (MT)	19°10'-19°45' N 98°27'-98°55' E	G, P, R, S	756 ± 166.2	1,067 ± 36.0	0.6 ± 0.4	13 ± 11.2	2000-2001 2003-2004
The second Ping (SP)	18°31'-19°33' N 98°24'-99°22' E	G, P, R, S	553 ± 160.2	982 ± 41.0	1.9 ± 6.0	74 ± 230.5	1996, 2003-2004, 2008
Maeklang (MK)	18°24'-18°35' N 98°28'-98°41' E	G, P, R, S	1,070 ± 213.4	877 ± 4.6	0.3 ± 0	11 ± 5.4	2008
Maecheam (MC)	17°57'-19°09' N 98°04'-98°37' E	G, P, R, S	627 ± 207.3	927 ± 53.9	0.7 ± 0.4	21 ± 17.4	2007-2008
The third Ping (TP)	17°48'-18°43' N 98°14'-98°44' E	G, S, M	261 ± 11.5	704 ± 43.8	2.8 ± 1.2	424 ± 224.6	2005-2006, 2009
Maeteon (ME)	17°13'-18°02' N 98°14'-98°34' E	G, P, R, S	804 ± 229.2	847 ± 43.0	0.5 ± 0.2	8 ± 3.8	2008
The forth Ping (FP)	15°50'-17°49' N 98°39'-100°02' E	G, S, M	120 ± 33.5	580 ± 68.4	2.7 ± 0.5	359±77.5	2009
Lower Ping (LP)	15°42'-16°10' N 99°27'-100°08' E	G, S, M	48 ± 8.0	425 ± 16.0	3.2 ± 1.3	258 ± 27.7	2009
Wang river (WA)	17°07'-19°24' N 99°00'-100°06' E	G, S, M	408 ± 123.8	833 ± 225.2	0.9 ± 0.9	28 ± 48.2	2009

Note Bottom types: R = Rocky, G = Gravel, P = Pebble, S = Sandy, M = Muddy

The collection of fishes and environmental variables for **P1** and **P4** was conducted in the mainstem of Ping and Wang rivers as well as their asscociated tributaries. Various habitats found in the studied area are presented in **Figure 4**. There were a total of 272 sampling sites from 10 sub-basins (Fig. 5A) viz., upper Ping (UP), Maetang (MT), the second Ping (SP), Maeklang (MK), Maecheam (MC), the third Ping (TP), Maeteon (ME), the forth Ping (FP), lower Ping (LP), and Wang river (WA). The locations and fundamental geographical characteristics of each sub-basin are provided in **Table 2.**

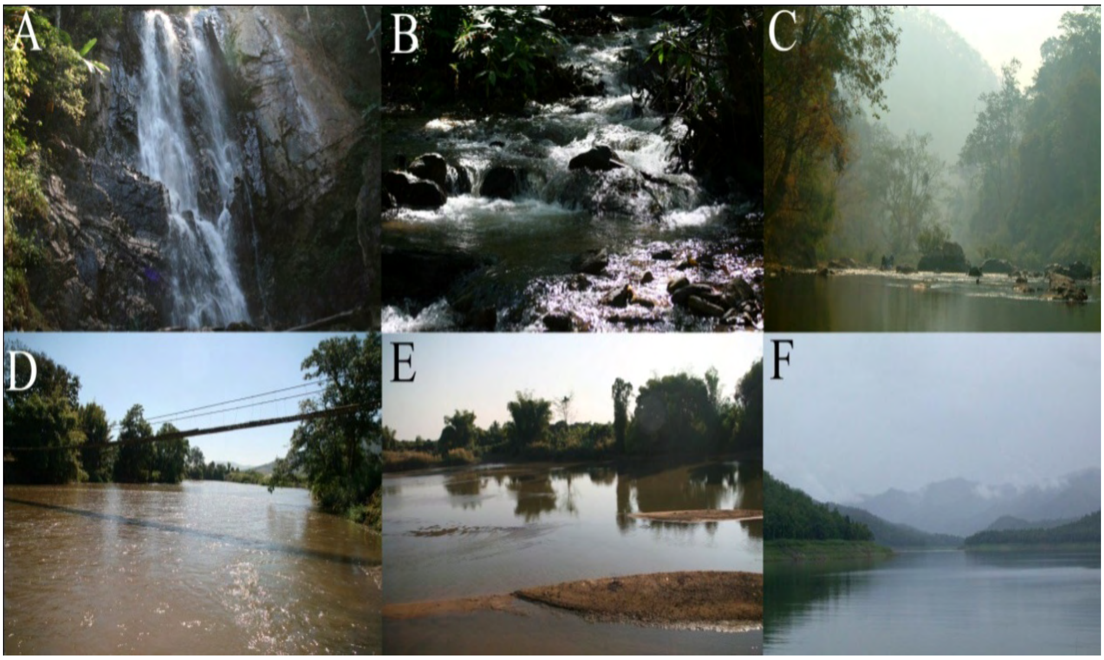

Figure 4 Various freshwater ecosystems found in Ping-Wang River basin. A: Waterfall and mountainous habitats, B: Shooting flow stream in first order stream, C: Secondary order stream with rock and gravel bed was located in mountainous stream, D: Secondary order stream with sandy bottom was located in lowland area, E: River mainstream located in lower part of Ping-Wang rivers and F: Reservoir

Note: Habitats A, B, C, D, and E were sampling area for **P1 and P4**; meanwhile data for **P2 and P5** was from the reservoir. Habitats A and B were also the sampling area of **P5**.

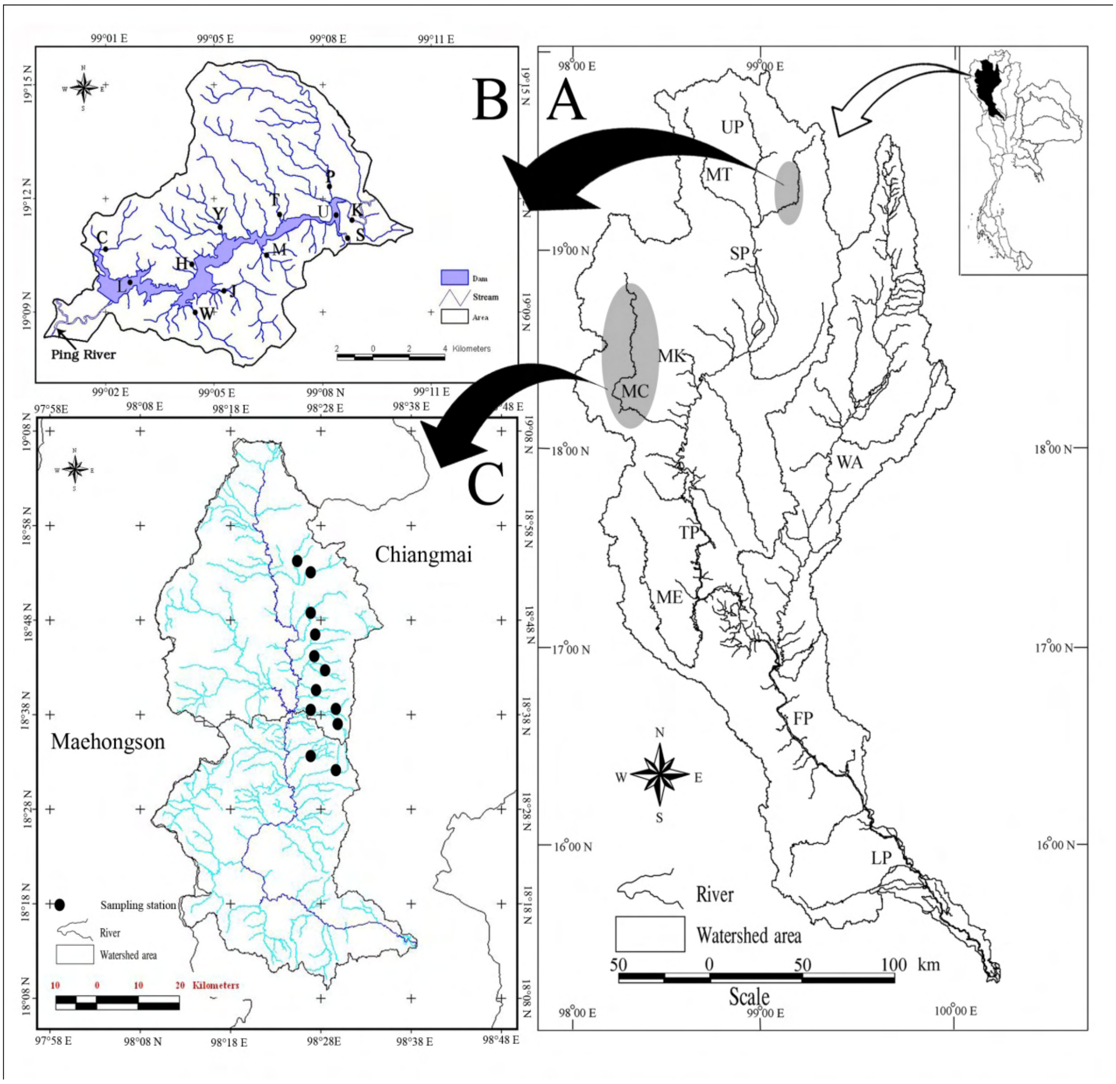

Figure 5 Maps of the studied area; **A**: The Ping-Wang basin and its sub-basins (**P1** and **P4**), **B**: the Mae-ngad reservoir (**P2** and **P5**), and **C**: Maecheam stream and the sampling sites (**P3**)

Note: (a) abbreviations for the sub-basins: UP=upper Ping, MT=Maetang, SP=second Ping, MK=Meklang, MC=Maechaem, TP=the third Ping, ME=Maeteon, FP=the fourth Ping, LP=lower Ping, and WA=Wang river

(b) abbreviations for the sampling sites in the Maengad reservoir: K= Huay Mekhod, P = Huay Mepang, S = Huay Mesoon, T = Huay Tontong, M = Huay Mekua, H = Huay Phakub, J = Huay Mejog, W = Huay Panwa, C = Huay Chompoo, L = lower part of the reservoir, U = upper part of the reservoir.

P2 and **P5** were focused on the Mae-ngad reservoir, a small high land reservoir of upper Ping river in Chiangmai province (19º15.18 N, 099º 03.35 E to 19º 15.25 N, 099º 17.43 E, Fig. 5b). The dam is multi-purposes as hydropower and irrigation, and fisheries is a secondary benefit. Its elevation ranges from 412 to 425 m ASL with a catchment area of 1,309 km^2, a water surface of 16 km^2 and it can store water up to 265 million m^3. It is dammed across the Mae-ngad stream, one of the first order stream tributaries of the Ping river basin. The maximum depth of the reservoir area is 30 m with a mixed clay and silt bottom. Meanwhile, the depth of the tributary streams, connected to the reservoir, ranges between 0.25-2.0 m and there are various bottom types (i.e. rock, gravel, sand, silt and mud) along the stream gradient.

Fifteen sampling sites in the mountainous area of Maecheam first order stream (Fig. 5C) were selected for **P3** to collect *Oreoglanis siamensis*. Maecheam stream locates in the west wing of Ping river and lies between 282 and 2,565 m from ASL. It is a major upper tributary sub-basin of the Ping river, which locates 117 km South-West from Chiangmai city. The Maechaem sub-basin is bounded by coordinates 18° 06’ - 19°10’ N and 98°04’ - 98°34’ E, and includes a total area of 3,853 km^2. The climate of this mountainous basin is defined by large variations in seasonal and annual rainfall that are influenced by Pacific-born typhoons, superimposed on the south-west monsoon (Walker, 2002). The orographic effect induces an altitudinal increase of spatial rainfall distribution (Dairaku et al., 2000; Kuraji et al., 2001). The average annual temperature ranges from 20 to 34°C and the rainy season is from May to October.

2.2 Fish sampling

For **P1** and **P4**, the long-term database on fish distribution and environmental data was compiled during the ichthyological surveys in the Ping-Wang river-system between January 1996 and April 2009. The sampling sites were distributed among 10 sub-basins in the river-system, where a Digital Elevation Model (DEM) was used to define and divide the geographical range of the Ping-Wang river-system into sub-basins by ArcView GIS 9.2, according to the catchment area and fish sample spots. Collections of fish samples were taken at every habitat types in every selected site. Samplings were done by various methods i.e. beach seine net, cast net, multi-mesh gillnets as well as the electro-fishing with an AC shocker powered (Honda EM 650, DC 220 V 550BA 450VA, 1.5–2 A, 50 Hz), which was placed on the riverbank together with block nets and scoop nets. Sampling sites were chosen on the basis of accessibility, similarity in habitat types, and to maximize the diversity of habitat types (pools, cascade, falls, riffles, and stagnant water) at each sub-basin. The environmental parameters (**Table 3**) were measured by standard methods (APHA, 1991). All specimens were preserved in 10% formalin and then taxonomical classified, counted and measured at Maejo Aquatic Resources Natural Museum (MARNM), Chiangmai, Thailand.

Table 3 Environmental parameters and methods of measurement in this study.

No.	Environmental Parameters	Methods/Equipments
	Water qualities/Physicochemical parameters	
1	Water temperature (WT; °C)	YSI 556 (multi-probe system)
2	Conductivity (CON; mg/l)	YSI 556 (multi-probe system)
3	Total dissolved solids (TDS; mg/l)	YSI 556 (multi-probe system)
4	Dissolved oxygen (DO; mg/l)	YSI 556 (multi-probe system)
5	Nitrite (NIT; mg/l)	APHA (1989) protocols
6	Ammonia (AMM; mg/l)	APHA (1989) protocols
7	Phosphorus (PHO; mg/l)	APHA (1989) protocols
8	pH	YSI 556 (multi-probe system)
9	Alkalinity (ALK; mg/l)	APHA (1989) protocols
10	Hardness (HAR; mg/l)	APHA (1989) protocols
11	Current velocity (CUR; m/s)	Flow meter (G.O. Environmental model 1295)
12	Depth (DEP; m)	Meter Tape
13	Width (WID; m)	Meter Tape
14	Discharge (DIC; m^3/s)	Q=AV; Area of channel X Average velocity of flow
15	Altitude (ALT; m ASL)	GPS GarmineTrex VISTA
	Geo-morphometric parameters	
16	Distance from the sea (DIS; km)	ArcView GIS 9.2
17	Watershed area (WSH; km^2)	ArcView GIS 9.2
18	Forest area (FOR; %)	ArcView GIS 9.2
19	Agricultural area (AGR; %)	ArcView GIS 9.2
20	Urban area (URB; %)	ArcView GIS 9.2

For **P2** and **P5**, data collection was conducted in the Mae-ngad reservoir. Fishes were sampled monthly from October 2002 to September 2003 from 10 sites in the tributaries and 2 stations in the reservoir (Fig. 5B). Two stations in the reservoir were a littoral zone where most of fish occupied (Prchalová et al., 2003, Brosse et al., 2007). Meanwhile, the central area of the lake is a steep shore and very deep. Therefore, very few samples are expected. For **P5**, data was obtained by the 12 fishermans using gill nets and the targeted species was *Henicorhynchus siamensis* (Fig. 6). The gill net assemblies were composed of five 30 m^2 nets (10 m long X 3 m deep) with stretched mesh sizes of 10-30 mm. The nets were surface-set at twelve sites, which were equally distributed over the coastal area of the reservoir, using one gill net assembly per sampling site. All the nets were set overnight between 16h00 and 18h00 and lifted between 06h00 and 08h00. At least 120 *H. siamensis* were randomly sampled monthly from July 2003 to June 2004 (1,364 fish in total). Individuals were measured for total length (*L*, to the nearest 1 mm) and weighed (*W*, to the nearest 0.1 g). For **P5** Data collection was focused in the tributaries connected to the reservoir. Fish samplings were conducted by using electro-fishing, i.e. a gasoline-powered electroshocker (DC, 250 V, 1.5–2 A, 50 Hz), each sampling was done with two replications for 30 to 45 minutes interval and the area cover was about 100 m^2. In addition, gill net (20 x 1.2 m^2, mesh size 4 cm stretched mesh) was also concurrently conducted in reservoir during the night time. The water quality parameters (Table 3) were also recorded at each sampling station by the similar protocols as in **P4.**

Lastly, **P3**, the study was conducted with Maechaem stream. *Oreoglanis siamensis* (Fig. 7) were sampled monthly from October 2007 to September 2008 from 15 sites in the East part tributaries of Maechaem stream. Fish samplings were conducted by electrofishing (Honda EM 650, DC 220 V 550BA 450VA, 1.5–2 A, 50 Hz) in the upper Maechaem river system. Each tributaries sampling site was done at 45 to 60 minutes intervals or the area covered was about 100 m^2, I was collected with various microhabitat, substrate type i.e. rocky, sandy, and gravel, and habitat type (riffle, pool, and run) to cover all species distributions. The skin diving was carried out to observe the abundance and behavior of the fish. Fish captured in each part were kept separate after selected *O. siamensis* and fixed in 10% formalin and the life specimens was released to the their habitat after measurement and weight. Then, *O. siamensis* was identified and separated from the other species, sacrificed in a lethal

Figure 6. The specimen of *Henicorhynchus siamensis* used to study in **P2**. (TL=215 mm)

Figure 7. The specimen of *Oreoglanis siamensis* study in **P3**. A: Top view, B: lateral view, and C: Sucking mouth *O. siamensis.* (TL=108 mm).

solution of anesthetic, and conditioned in ice for transportation. The process in evening at the rest room and the following data were obtained: (i) total length (TL) to the nearest 0.1 mm (ii) total weight (WT) to the nearest 0.01 g (iii) sex (iv) gonad weight (GW) to the nearest 0.01 g. Gonads were removed from the visceral cavity, Prior to the preservation of the ovaries/testis were classified in a macroscopic scale of gonadal development, for both sexes; for female size and colour of oocytes was also registered and, for males sperm liberation when pressing the abdomen. According to these characteristics, the following classification was considered: females – 2nd stage, immature, mature, and ripe; and males – 2nd stage, immature, mature, and ripe. Thereafter, ovaries were fixed in Bouin solution for oocytes measurements and total ripe eggs counts. The specimens were fixed in 10% formalin and preserved in 70% ethanol. Specimens were deposited at the Maejo Aquatic Resources Natural Museum.

2.3 Data analyses

2.3.1 Diversity and abundance (P1, P4 and P5)

Fishes were identified into species level by using various documents (e.g. Smith, 1945; Taki, 1974; Rainboth, 1996; Kottelat, 2001; Nelson, 2006). Ranks of individual species were presented as the percentages of relative abundance (%RA) and occurrence frequency (%OF). The diversity indices (Magurran, 2004) *viz.*, species richness, Shannon-Wiener diversity index (*H'-index*) and evenness (*J'*) (Weaver & Shannon, 1949) were calculated for each sub-basin. Under the assumption that species richness increase with the sample size, I rarefied species richness to the same number of individuals and a rarefaction curve was used to estimate species richness in each sub-basin (Hulbert, 1971), and the rarefactions values (*R*) were computed by using EstimateS v. 8.2.0 (Colwell, 2009).

$$R = \sum_{i=1}^{S}\left[1-\left(\frac{N-m_i}{n}\right)/\left(\frac{N}{n}\right)\right] \text{ ---------- (3)}$$

2.3.2 Biology aspects, life history, and population dynamics (P2 and P3)

The length (L) –weight (W) relationships $W = aL^b$, of the two selected keystone *species H. siamensis* and *O. siamensis*, where estimated where a and b are specific values for each species. The relationship was done to examine whether the weight increased proportionally with length, i.e. isometric growth, for each species. The length frequency distribution (LFD with 1.0 cm interval), for each species, was constructed for further analysis on the von Bertalnaffy's growth function (VBGF).

Reproductive biology was studied in the aspects of gonad development, gonadosomatic index (GSI), fecundity and length at 50% maturity (L_{50}). Gonads (i.e. ovaries and testes) were collected monthly and the stages of gonad development were examined by mean of histological study, and fixed in 10% formalin/acetic acid/calcium chloride (FAACC) for 1 month before being embedded in paraffin and stained with haematoxylin-eosin. The samples were then cut into sections (7 μm) and observed under a light microscope. The stages of maturity of the gonads were graded into 5 stages (I to V) (Bagenal & Braum, 1978), where fish that showed stage III and above were considered to be mature. Spawning season was estimared during the period following peak in GSI. GSI was calculated as (100 x Gonad- Weight ⁄ Body Weight). Stages IV and V ovaries were selected for fecundity examination by fixing in Gilson's fluid, shaken vigorously and stored in the dark for at least a fortnight before the total egg numbers were estimated by sub-sampling using the gravimetric method (Bagenal & Brown, 1978). Then, the relationships between fecundity with length and weight were examined. L_{50} was estimated by using the logistic function (Chen & Paloheimo, 1994) as in Equation 4

$$P = \frac{1}{1 + e^{(a - bL)}} \text{ ------------------ } (4)$$

where P is proportion of mature in each length clas; a and b are constants and when they were calculated, the percentage at 50% maturity was replaced in the equation (4) to obtain the length at 50% maturity. While, the condition factor (k) of the experimental fish was estimated from the relationship in the equation (5) (Williams, 2000):

$$K = \frac{100W}{L^3} \text{.................................} (5)$$

where K=condition factor, W= weight of fish (g), and L= length of fish (mm). Fecundity (Bagenal & Braum, 1971) was determined after counting all vitellogenic oocytes from ripe ovaries and correlated to TL and TW in equation (6).

$$F=aTL^{b}, \text{ and } F=aTW^{b} \text{ ....(6)}$$

where F=fecundity, TL=total length, TW=total weight, while *a* and *b* are specific constant values.

Feeeding of fish was studied by examining the stomach contents. Stomachs were dissected and opened longitudinally and the digestive tracts fixed in 10% formalin. The stomach contents were squeezed out and diluted to a 1 ml. The suspended matter was then placed into a Sedgewick rafter-counting cell and examined under light microscopy. The food items were identified to the lowest possible taxonomic unit. For diet preference analysis, the percentages of frequency of occurrence (O%), number (N%) and index of relative importance (IRI%; Equations 7 and 8) (Hyslop, 1980) were applied for each diet item (*i*).

$$IRI_i = N\% \times O\% \text{ ------------- (7)}$$

and

$$IRI\% = \left(\frac{IRI_i}{\sum_{i=1}^{n} IRI_i} \right) \times 100 \text{ ---------- (8)}$$

Length frequency distribution (LFD) data was used for growth performance estimation. The von Bertalanffy growth function (VBGF) with seasonal oscillation (Equation 2) was used to express “size at age” of the two keystone species. Analyses were carried out by the free-package: Fish Stock Assessment Tools-II (FiSAT-II; (Gayanilo et al., 2002), which the steps for estimation were already described (Amarasinghe & De Silva, 1992). Theoretical age at length zero (t_0) was derived from the equation (9) proposed by Pauly (1979):

$$\log_{10}(-t_0) = -0.392 - 0.275\log_{10} L_\infty - 1.038\log_{10} K \text{ ------------- (9)}$$

The age at the onset of the first growth oscillations (t_s) was calculated as ts = WP - 0.5, whereWP is the time of the year during which the growth rate is minimal, i.e. winter point (Gayanilo et al., 2002). The best-fitted growth curve was chosen on the basis of non-parametric scoring from the goodness of fit index (i.e. Rn value).

2.3.3 Statistical analyses and modeling methods

Because of the non-normality of the data, the non-parametric Kruskal-Wallis test was used to test the significance of equality of medians among group of the diversity indices (**P1**). Relationships between diversity indices to the individual environmetal variables were examined by simple linear regression (**P4**), where environmental variables were treated as descriptors and the diversity indices were predictors. Moreover, in **P4**, the classification and regression tree (CART: Breiman et al., 1984), which is used to optimize set of environmental parameters and aimed at predicting diversity index, was also applied. For making CART, both response variables were *log (x+1)* transformed to stabilize variances. The optimal tree size was determined by R^2-value and the complexity parameter. Generally, CART is called a classification tree if the response variable is qualitative (e.g. fish assemblages as in **P5**) and a regression tree if the response variable is quantitative (e.g. species richness as in **P4**) (He et al., 2010).

Cluster analysis as the hierarchical agglomerative clustering by Ward's method (Ward, 1963) was used to classify sets of dissimilarities of the fish assemblages in sub-basins by using the number of individual species found in each sub-basin as inputs (**P1**). Two multivariate exploratory techniques were applied to explore the structure of categorical variables included in the studies and to identify systematic relations between variables. Firstly, a self-organizing map (SOM), which is an unsupervised algorithm of an artificial neural network (ANN) model (Kohonen, 2001) (**Fig. 8**). The SOM is widely applied in the last decade for solving problems in aquatic ecology, because it is capability of clustering, classification, estimation, prediction and data mining (Kalteh et al., 2008) Moreover, the SOM has proved to be an effective and powerful tool for describing species distributions and assemblages (Suryanarayana et al., 2008). The SOM consists of two layers viz. the input and

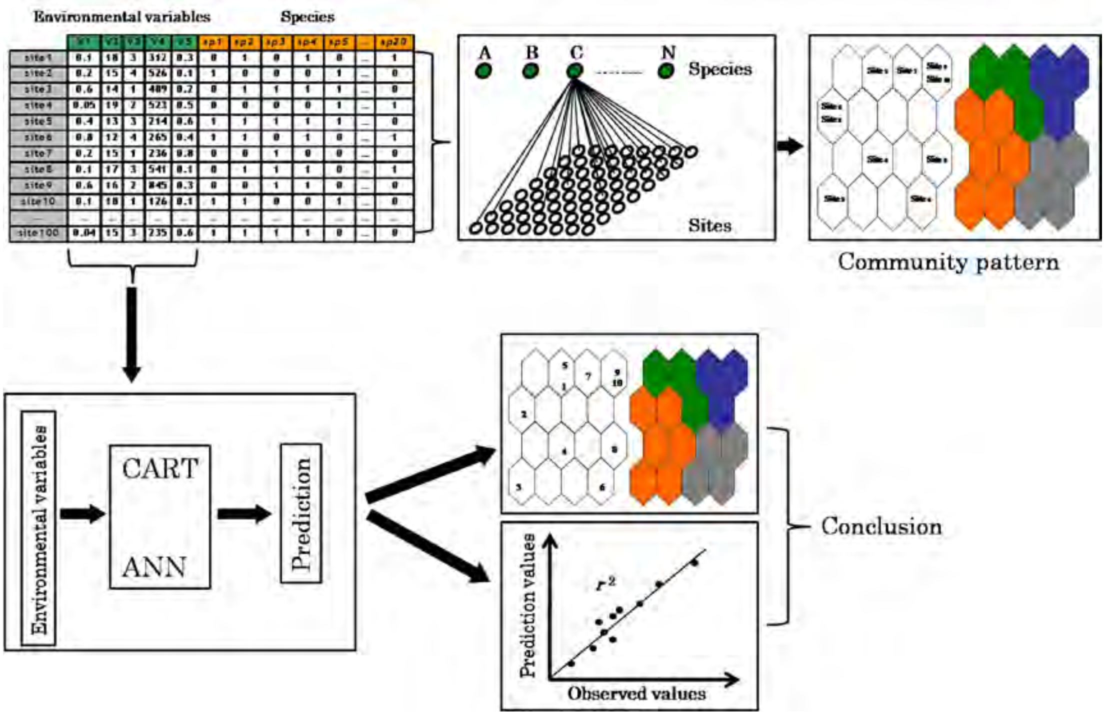

Figure 8. The schematic figure showing the general modeling process in the studies of this thesis.

output layers, which connected with the weight vectors. The input layer receives input values from the data matrix, whereas the output layer consists of output neurons, which displayed as a hexagonal lattice (Fig. 9) for better visualization. During the learning process, the SOM weights were modified to minimize the distance between weight and input vectors. The map (i.e. SOM, output layer) obtained after the learning process contains all the samples assignedto neurons. Generally, samples assigned to the same neurons, or to nearby neurons, are similar and samples assigned to distant neurons differ. Additionally, samples assigned to nearby neurons differ considerably if those neurons belonged to different clusters, which were identified with use of a hierarchical cluster analysis (Ward linkage, Euclidean distance). The detailed algorithm of the SOM can be found in (Lek and Guégan, 2000; Kohonen, 2001; Kalteh et al., 2008). The occurred probability of each species in each cluster can be approximately estimated during the learning process and seen in SOM, in which the gray scale gradient account for probabilities of occurrence, with dark corresponding to high probability and light vice versa (Park et al., 2005). The SOM was simulated and performed by MATLAB (Ver. 6.1.0) by using SOM-toolbox, which developed by the Laboratory of Computer and Information Science (CIS), Helsinki University (http://www.cis.hut.fi/projects/ somtoolbox/).

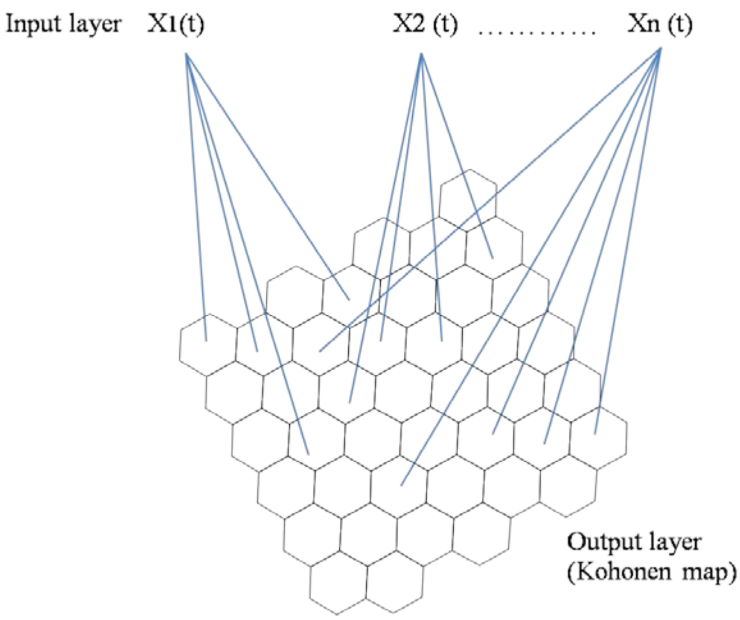

Figure 9 Representation of the non-supervised artificial neural network-SOM (Kohonen, 2001.

The SOM was used for Factorial Correspondence Analysis (FCA) to investigate significant differences in the dietary components from the stomach contents between seasons (**P2**) and spatio-temporal variations in fish assemblage patterns in the connected tributaries to the reservoir (**P5)**. Relationships between fish assemblages and environmental parameters (**P4**) were examined by Canonical Correspondence Analysis (CCA), an ordination technique designed for direct analysis of relationships between multivariate ecological data (Ter Braak, 1986). Statistical significance, for CCA, of the relationship between a set of environmental factors and fish species was taken using a Monte Carlo permutation test with 999 permutations and was accepted at P-value < 0.05. All the above analyses were analyzed by using Program R (R Development Core Team 2009) with various related packages, which were informed in each publication (i.e. **P1-P5**).

3. MAIN RESULTS

3.1 Fish diversity and ecological parameters relationships in the upper Chao Phraya river basin (P1)

The totals of 201 species were collected in 272 sampling sites in Ping-Wang river basin. The most dominants were Cypriniformes, Siluriformes and Perciformes, respectively. In terms of family, Cyprinidae was ranked first with 40.3 % (81 species), followed by Balitoridae and Cobitidae with 10.0 % and 6.5 % (20 and 13 species), respectively. Among the genera, *Schistura* in family Balitoridae was as most diverse in species. The number of genera and number of species ratio were found 1: 1.93. The five most abundant species accounted for 32.4 %RA of total fish collected. The highest %OF was found in *Channa gachua* (47.1 %). Some species that showed at a high level in number but low in %OF indicated their restricted distribution e.g. *Devario maetangensis*. Also the economic aquaculture fishes were escaped or releasing into the river and/or reservoir e.g. *Oreochromis niloticus* and *Clarias* hybrid.

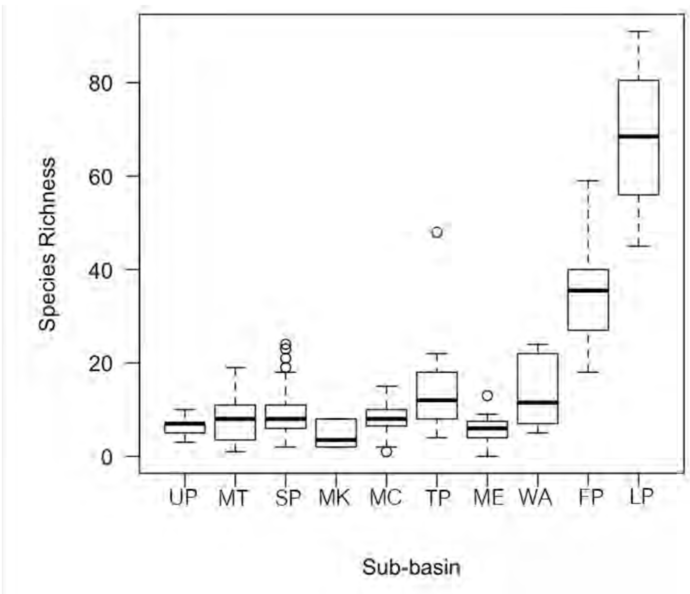

Figure 10. Species richness in each sub-basins of the Ping-Wang river basin. Abbreviation: UP=Upper Ping, MT=Maetang, SP=the Second Ping, MK=Maeklang, MC=Maecheam, TP=the third Ping, ME=Maeteon, FP=the forth Ping, LP=Lower Ping, and WA=Wang river.

Large sub-basins showed high *H'*, i.e. LP, FP and ME and the abundance of individual species were in similar proportions (Fig. 10). Although lower in *H'* index in the upper sub-basins (i.e. MK and UP), these sub-basins were characterized by the endemic species, in which the rate of species that are restricted to the basin was up to 10 % i.e. *Devario maetangensis*, *Schistura pridii*, *Oreoglanis siamensis*, and *Rhinogobius chiengmaiensis*. Five IUCN fish species were also collected, i.e. *O. siamensis*, *Himantura signifier*, *H. Chao Phraya*, *P. gigas* and *Pangasius sanitwongsei*. Sixteen exotic species were found in all sub-basins, except the upper reach of the Ping River (UP). Among them, *Gambusia affinis* was the highest % OF at 17.3 % followed by *Oreochromis niloticus* (≈ 9 %OF).

Species richness gradually increased from the upper part to the lowland area and the Kruskal-Wallis test showed that the significantly differentiated among sub-basins. All the ten rarefaction curves for the sub-basins showed signs of reaching asymptotic levels. Adequacy of sampling was assessed also by the rarefaction curve and the asymptote was reach at about 250 species, confirming that the number of sampling sites in this study was satisfactory (Fig. 11).

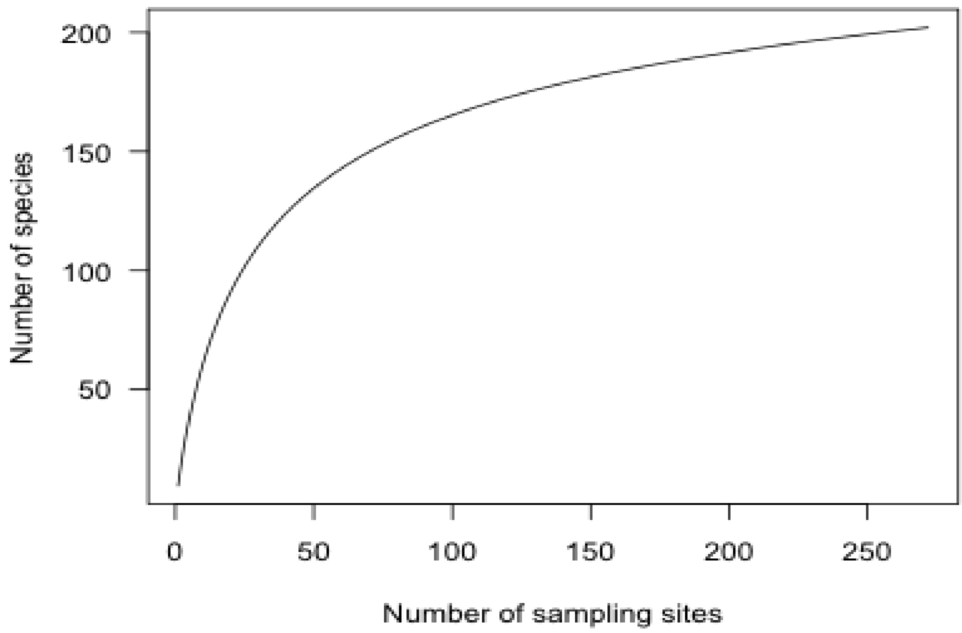

Figure 11. Rarefaction curves plot by number of species with number of sampling sites for the Ping river basin.

3.2 Some aspects of life history and population dynamics of lotic and lentic tropical fish species.

3.2.1 The life history of the riverine cyprinid *Henicorhynchus Siamensis* (Sauvage, 1881) in a small reservoir (P2).

The riverine species, *Henicorhynchus siamensis* (Sauvage 1881), is an important source of protein and an economical fish for the rural population of inland Indochina. The moderate species was 290 mm in maximum sized. Investigated in the present study were the reproductive feeding aspects and growth of *H. siamensis* living in a small reservoir. The equation derived was $W = 0.01L^{3.08}$ ($r = 0.82$) and the exponential value indicated that the growth was isometric. The histology of the gonads confirmed that *H. siamensis* has a synchronous ovary. The temporal changes in the gonadosomatic index (GSI) clearly showed a single peak in both sexes, which tended to increase in June, was highest in August (Fig. 12). The individuals were taken 1.5 years to attain the length of 50% maturity of female and male were 197.6 and 201.6 mm (Fig. 13). Fecundity ranged widely was 105,782±59,930 eggs; it was depended on the length. Relative fecundity was 1,034±116 eggs per gram of body weight; the relationship between length and fecundity (Fe) can be described by an empirical power equation: $Fe = 21{,}141L^{3.087}$ ($r = 0.762$, $n = 171$).

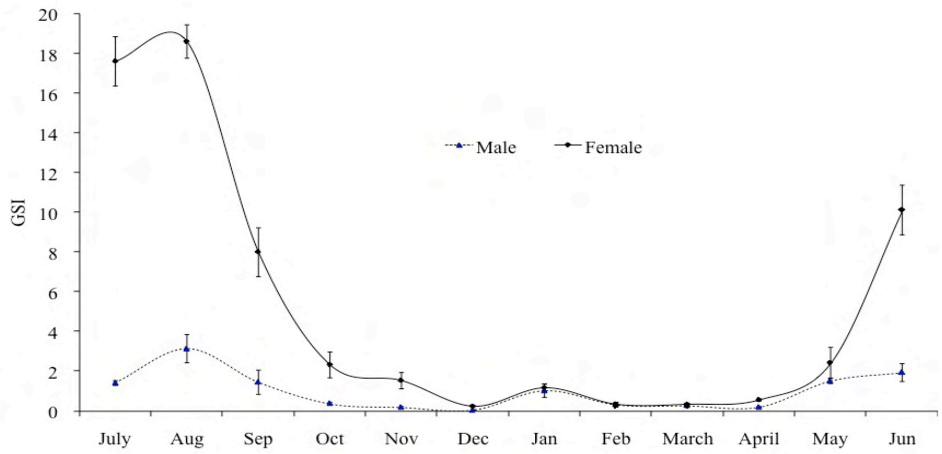

Figure 12. Gonadosomatic Index (GSI) of of male and female *H. siamensis* in Mae-ngud reservoir (July 2003 to Jun 2004).

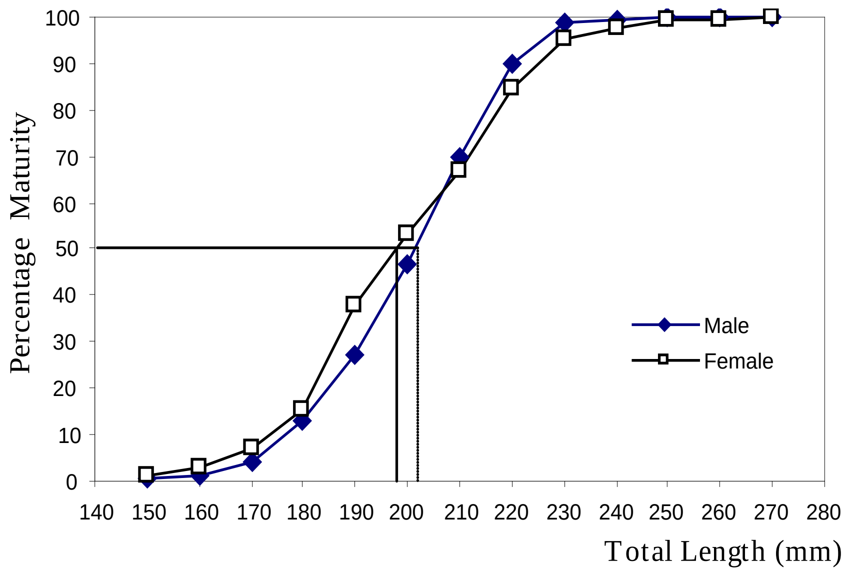

Figure 13. Percentage maturities of male and female *H. siamensis* against of fish in Mae-ngud reservoir.

Stomach contents were dominated by phytoplankton, such as *Cyclotella* sp., *Melosira varians* and *Navicula* sp. (IRI% = 21.55, 18.20 and 12.58, respectively). They were found to be the main dietary components. The factorial analysis of the temporal variation in the diet based on each month's sampling could be clearly divided into three main groups. The first group (group I) was found during the early rainy season (June and July), and dominated by Chlorophyta e.g. *Crucigenia crucifera* (Cruc). Group II was during the winter (December), characterized by few dietary items and low species diversity, and dominated by Cryptophyta, e.g. *Chilomonas* sp. (Chil). The third group was the most complex of phytoplankton; dominated by *Staurastrum* sp. (Stau), and *Cyclotella* sp. (Cycl) (Fig. 14).

The growth curve that gave the highest goodness of fit index was selected. A clear seasonally oscillating growth pattern implies that the species is sensitive to seasonal variation and that recruitment started in July. The winter point (*WP*) was 0.95, which signifies that growth slowed during December. The growth performance ($\emptyset$) index was 4.72. From the derived growth parameters, *H. siamensis* attains at least 50% of the asymptotic length of *H. siamensis* was 264.2 mm, with a 0.75 year^{1}

growth coefficient and approaches L_{∞} at about 3.5 years of age. The potential longevity, 3 ⁄ K (Pauly and Munro, 1984), of *H. siamensis* was estimated at 4 years.

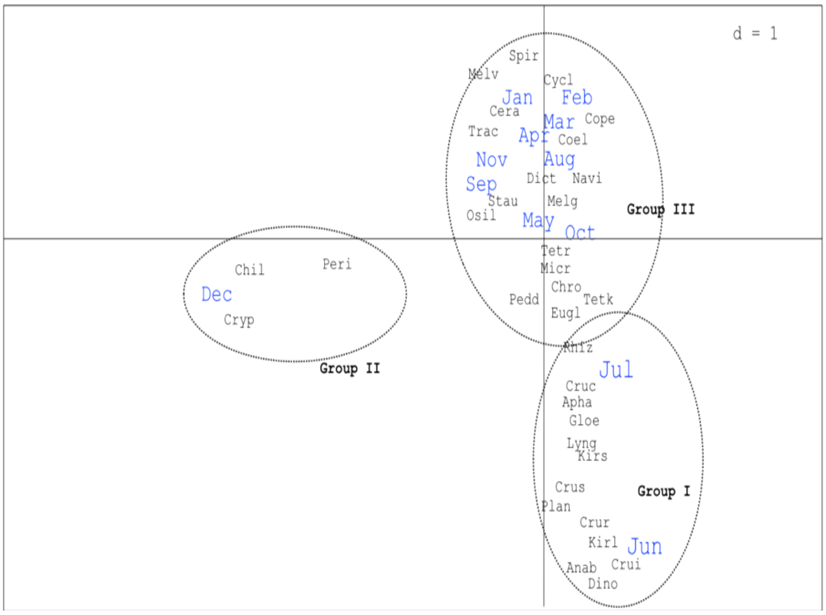

Figure 14. Composition and seasonal variability of *H. siamensis* feeding.

3.2.2 Conservation approaches and reproductive biology of vulnerable stream Sisorids (*Oreoglanis siamensis*) from foothill Himalayan, Thailand (P3).

A vulnerable and an endemic Freshwater batfish (*Oreoglanis siamensis*) were studied in 2006-2007 in a high mountain stream in northern Thailand (18° 06’ - 19°10’ N and 98°04’ - 98°34’ E). This species was examined for reproductive biology preferences. Spawning in freshwater batfish occurred in late dry-cool season to early dry-hot season (January to March) in the Maechaem river basin; at least 87.1-95.7% of female were in ripe or spawning condition in this season (Fig. 15), while the sperm of male was mature and ripe through the year (Fig. 16). Size at first maturity was 47 mm for males, and 53 for females. L_{50} estimates were 68.9 ± 1.765 mm (males) and 82.4 ± 1.369 mm (females). Maximum fecundity was 47 oocytes. Fecundity (F) varied from 18-47 (31.41 ± 7.67) for ripe females of 53-113 mm, respectively, correlation between TL and F, and W and F followed a linear relationship (F = 7.14+0.38TL; r^2 = 0.424; or F = 20.41+2.3W; r^2 = 0.491; n = 71). *O. siamensis* is a large size of eggs (Fig. 17). Then, ripe oocytes have mean diameter of 2.96 ± 0.28 mm (range = 2.5-4.2 mm; n=30). Siamese bat catfish could not clearly express the secondary sexual characteristic, it was difficult to distinguishable except during the spawning season. The sex ratio was 1:1 (χ^2-test, p<0.05).

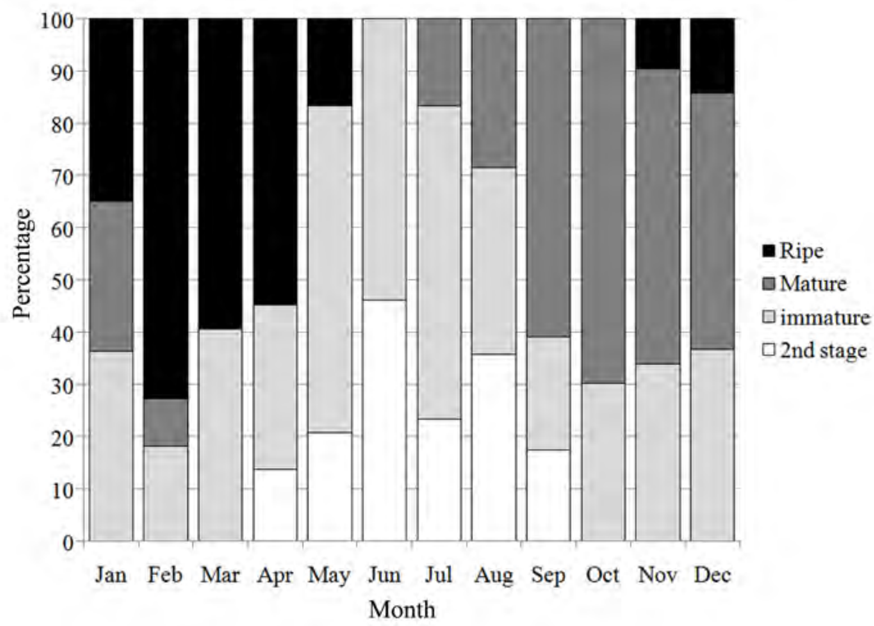

Figure 15. Percentage frequency of maturity egg stage of *O. siamensis*.

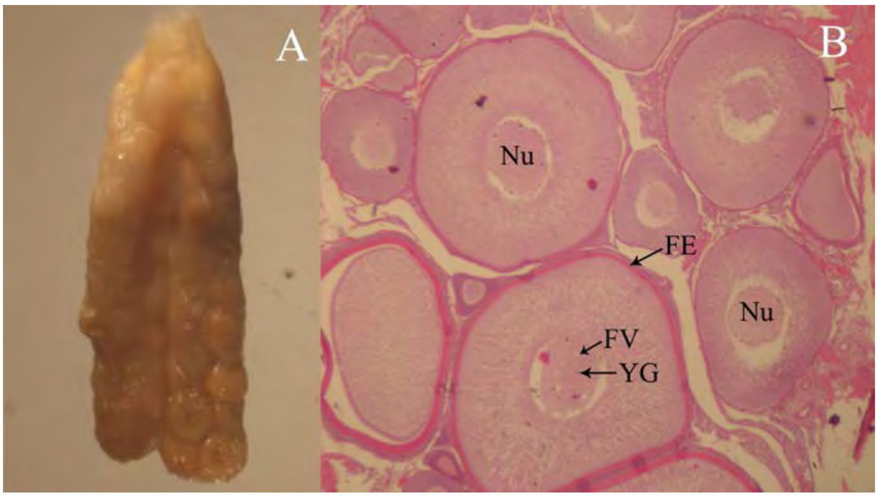

Figure 16. A: Whole ovary (length 14 mm.), B: mature stage of ovary. Abrreviations: Nu = nucleaus, FE=follicle epithelial, YG=Yolk granule, and FV = follicle vesicle.

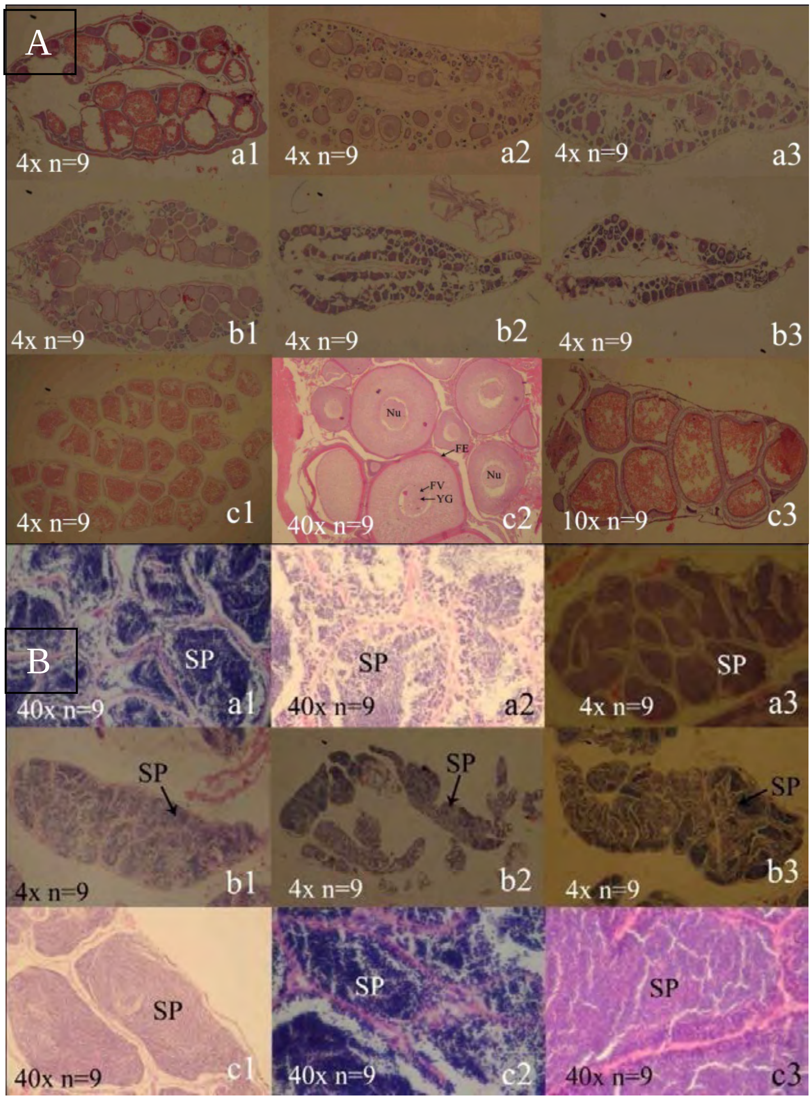

Figure 17. Histological appearance of ovary (A) and testis (B) maturation of *O. siamensis* (n=9 per month). Abbreviation (A): Nu=nucleus, FE=follicle epithelial, YG=Yolk vesicle; **Note** a) ripe and spent stage (dry-hot season), a1) late ripe stage, a2) spent stage, a3) spent stage, b) late spent, primary stage and immature stage (rainy season), b1) late spent stage, b2-3) primary stage and immature stage, and c) mature and ripe stage (dry-cool season), c1-2) mature stage, c3 ripe stage. Abbreviation (B): SP=spermatozoa, **Note** a) ripe and spent stage (dry-hot season), a1) mature stage, a2) mature stage, a3) mature stage, b) late mature, primary stage and immature stage (rainy season), b1) late mature stage, b2-3) primary stage and immature stage, and c) mature stage (dry-cool season), c1-3) mature stage, c3 ripe stage.

3.3 Fish assemblages and impacts of environmental factors

3.3.1 Fish diversity and assemblage patterns in a rhitral environment of the Indo-Burma region (the Ping-Wang River Basin, Thailand) (P4).

One hundred and ninety eight species within 11 orders, 33 families were collected in the P4. The most diverse family was Cyprinidae, followed by Balitoridae, and Cobitidae. The highest species richness, Shannon diversity index and species evenness were found in the lower part of the river-system meanwhile the minimum species richness was obtain at high altitude (Fig. 18A, B). But, the numbers of individual were scattered among sub-basin.

Only six physicochemical parameters from 20 environmental parameters were obtained, i.e. DO, water temperature, pH, conductivity, phosphorus and alkalinity showed statistically significant in their relationships to diversity parameters. However, due to extensive and high variation of the obtained data, all the linear models showed low power in prediction. And five geo-morphological parameters, i.e. altitude, distance to the sea, discharge, depth, and width, showed highly statistical significances in their relationships to diversity parameters. The diversity index and species richness of tropical fishes was depending on altitude, water depth, stream width, and distance from the sea (Fig. 18). Altitude and distance to the sea showed strongly negative relationships and the relationships trended to be exponential for both indices, implying that higher diversity was found in the lower altitude, in which closed to the sea and then sharply decline as the altitude increase (Fig. 18).

Species richness and Shannon diversity index of each individual were sampling ranged. They were fed to CART model as a response variable by using 20 environmental predictors. The geo-morphological parameters were the major factors in determining both diversity indices. For species richness, 3 parameters were included in the CART model and altitude was the major contributor in predicting species richness followed by width and distance from the sea (Fig. 19).

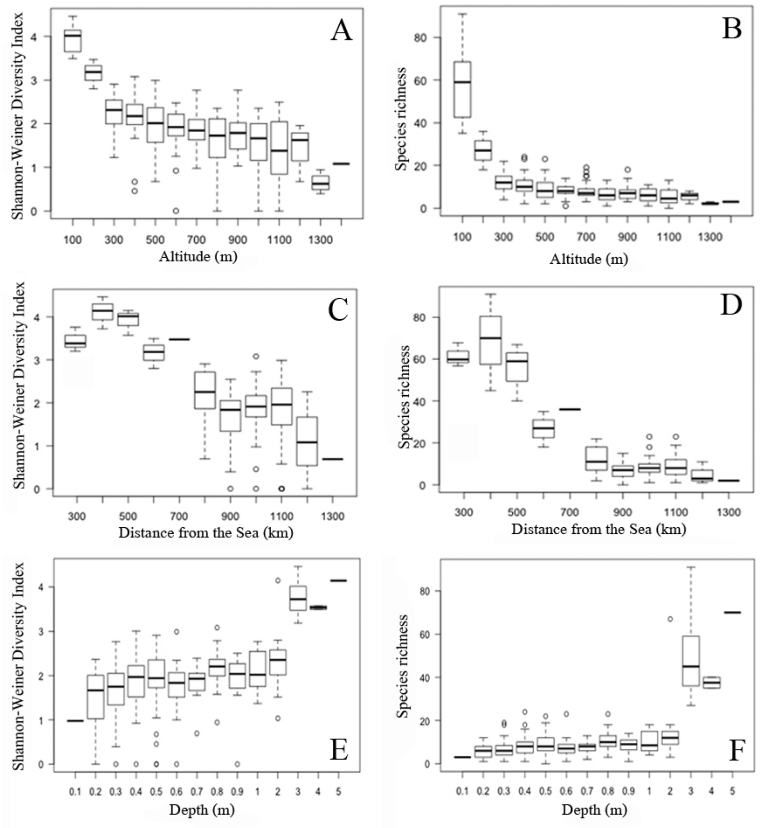

Figure 18. Some of the relations between diversity parameters and environmenatal parameters. A and B: The relation between altitude and Shannon-Weiner Diversity Index and species richness. C and D: the relation between distance from the sea (km) and Shannon-Weiner Diversity Index and species richness. E and F: The relation between water depth and Shannon-Weiner Diversity Index and species richness.

The relationships of fish assemblages and environmental parameters were loaded fifty three fish species and twenty environmental variables in the CCA analysis. The first CCA environmental axis (CCA1) was described by altitude, distance from the sea, water depth, stream width and water temperature of the basin. The first two parameters were negative correlated to CCA1 meanwhile the remaining parameters were *vice versa*. The most important variable for the second CCA environmental axis (CCA2) was watershed area. Composition of individual fish species, which related to the environmental vectors loaded to CCA, was shown the first five species with have strong positive loading to CCA1 and CCA2 e.g. *Pristolepis fasciatus*, *Barbonymus altus* and *Lepidocephalichthys hasselti.*

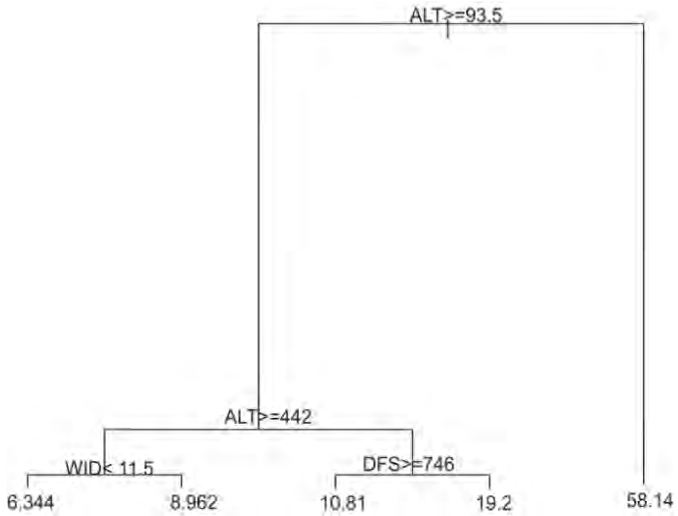

Figure 19. CART model to predict species richness in The Ping-Wang river basin.

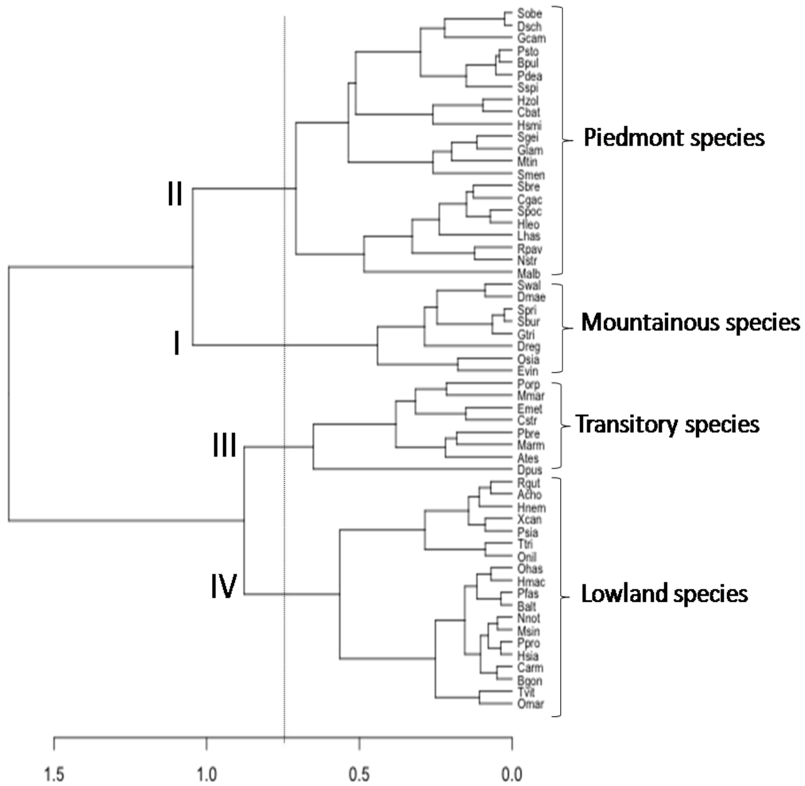

Figure 20. Dendrogram of fish assemblages in the Ping-Wang River Basin.

Distribution of fish species along the CCA axes can be classified into 4 main assemblage patterns. The first assemblage (quadrant I) was inhibited in the mountainous area of high altitude with relative low temperature and strong current velocity. The second assemblage was the shorter distance from CCA1 (quadrant II) indicated that the fish in this assemblage occupied in the lower altitude then those in the first assemblage. The remaining two assemblage patterns were positively correlated to CCA1 (quadrants III and IV) and implying that the fishes in these assemblages live in the lower portion of the river course, where the river width and depth were more than the previous two assemblages.

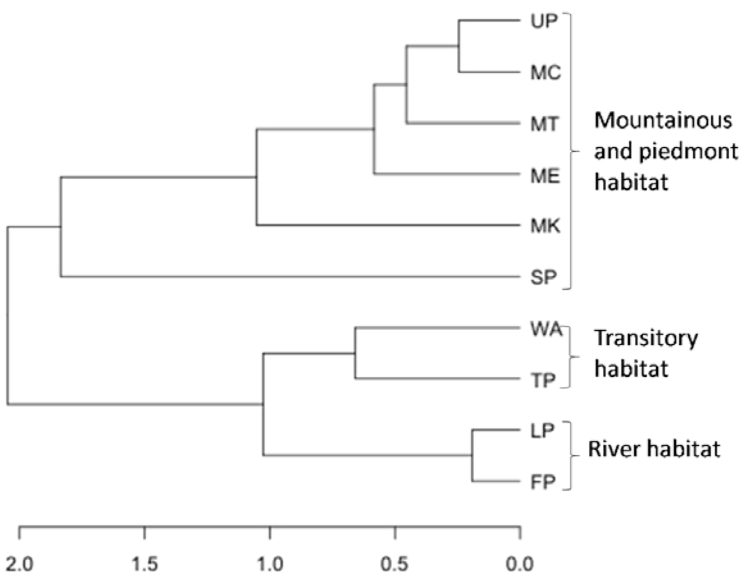

Figure 21. Cluster dendrogram summarizing similarity among sub-basins based on their fish assemblages and environmental parameters (plot by CCA site constraints values (linear combination of constraining variables)). Using Ward model (Dendrogram General tree structures).

Ward's analysis was used to refine the habitat preference of individual species after the trends from CCA analysis. In quadrant I, inhabited in the small streams in high altitude area with low temperature, were grouped together and defined as "mountainous" species e.g. *Oreoglanis siamensis* (Osia), *Devario regina* (Dreg), *Exostoma vinciguerrae* (Evin). The remaining species in quadrant I, which located closed to CCA1 axis, and all species in quadrant II were grouped and defined as "piedmont" species e.g. *Lepidocephalichthys hasseltii* (Lhas), and *Channa gachua* (Cgac). Species, which positively correlated to CCA1, were divided into two groups. Firstly, the species, which located closed to CCA1, were defined as "transitory" species e.g. *Puntius orphoides* (Porp), *Mastacembelus armatus* (Marm), *Puntius brevis* (Pbre) and *Mystacoleucus marginatus* (Mmar). Secondly, the group of species that showed the highest positives loading to CCA1 and defined as "lowland" species e.g. *Pristolepis fasciatus* (Pfas), *Barbonymus altus* (Balt), and *Mystus singaringan* (Msin) (Fig. 20). The sub-basins were shown the difference, based on their fish assemblages and environmental parameters (Fig. 21).

3.3.2 Fish communities in the highland tropical streams connected to a reservoir (P5).

Species composition of fishes and community assemblages can be changed after the change of ecosystem. Sixty-six species were collected; and dominated by Cyprinidae (34.9 %), Balitoridae and Cobitidae (10.6 %). Invertivores, carnivores and herbivores dominated the trophic guilds, respectively. The highest percentage of relative abundance (%RA) were *Henicorhynchus siamensis* (Sauvage, 1881), *Mystacoleucus marginatus* (Valenciennes, 1842) and *Puntioplites proctozysron* (Bleeker, 1865). The highest percentages of occurrence frequency (%OF) were shown by *M. marginatus*, *Oxyeleotris marmorata* (Bleeker, 1852), and *Hampala macrolepidota* Kuhl & Van Hasselt, 1823.

According to the nature of the surveys found in each community, the communities can be designated into reservoir community (RC), stream community (SC), and intermediate community (IC) (Fig. 22), in which there were highly significant variations in the community structures among communities (ANOSIM, R=0.757, $P<0.001$). The movements of fishes were migrated in difference of seasonal or the stage of life during the year.

The distributions of occurrence probability (*OP)* of individual species of each species in each community can be expressed as the community characteristics was arbitrarily set to show the dominant species in each community but two species gave the highest *OP* of all communities i.e. *M. marginatus* and *O. marmorata*. The highest

OP in SC was *Rasbora paviana* (Tirant, 1885) and *Channa gachua* (Hamilton, 1822), IC was dominated by *Cyclocheilichthys armatus* (Valenciennes, 1842), *Barilius koratensis* (Smith, 1931), and *Garra cambodgiensis* (Tirant, 1883). It is also worthy to note that the dominant species in the SC and IC were either invertivores or carnivores. Meanwhile, the RC was dominated by a number of species that were mostly herbivores e.g. *Labiobarbus lineatus*, (Sauvage, 1878), *P. proctozysron*, and *H. siamensis*, except for *Hampala macrolepidota* is a carnivorous cyprinids (Fig. 23).

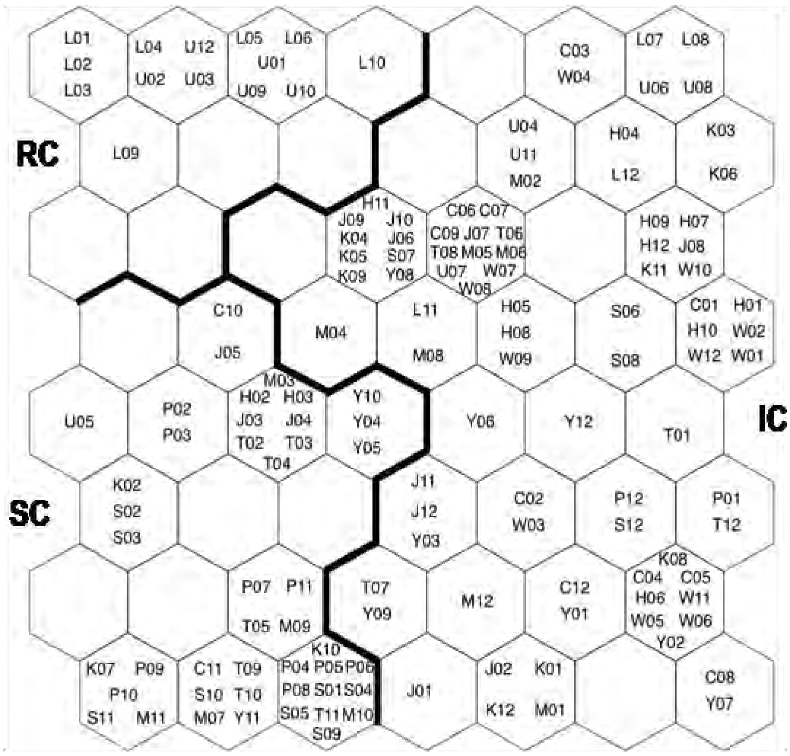

Figure 22. Distribution of surveys based on the SOM map according to the similarity of fish composition.

The prediction of community assemblages and the contribution of environmental variables were shown the average values of the physicochemical and geo-morphological variables, obtained from the three communities. Also, they were used as predictors in the CART model to discriminate the clusters of fish communities. Based on the communities and environmental variables were selected to predict the response variables. The major variables corresponding to assemblages were water depth, which separated the RC from the other communities. Meanwhile, the overlaps between the IC and SC were distinguished by physicochemical variables such as hardness, ammonia, alkalinity, orthophosphate and nitrite. The overall predictive power of this model was successfully the model could predict the assigned survey to the right community.

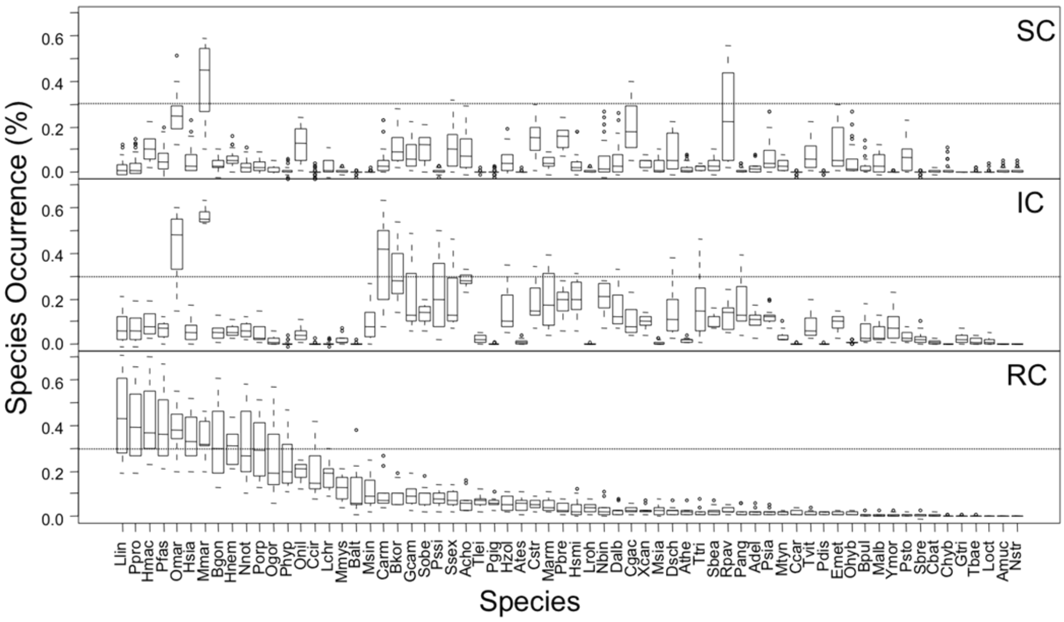

Figure 23. Community characteristics for each cluster as shown by the occurrence probability. Abbr. SC=stream community, IC=Intermediate community, RC= Reservoir community.

4. GENERAL DISCUSSION

4.1 Fish diversity and assemblage patterns in a rhitral environment.

The Ping-Wang river basin contained 201 fish species and the rarefaction curves showed that it was close to the maximum number of species occurring in the Basin. Thus, it is shown that the upper Chao Phrya river system is a high in fish species richness and the total number of species in Chao Phraya river is 420 species (Table 2), except the Mekong (1,200 species), the Yangtze (China, 320 species), the Cauvery river (India and Nepal, 265 species) and the Kapus (Indonesia, 250 species) (Nguyen & De Silva, 2006). Normally, dominance by the multi-species and ecologically diverse Cyprinidae is common in Southeast Asia, where they may contribute 40% or more of the species in a watershed (Taki 1978; Kottelat & Whitten, 1996; Ward-Campbell et al., 2005; Beamish et al., 2006; Beamish et al., 2008), and follow by the rhithronic species i.e. stream Sisorids (*Oreoglanis siamensis*, *Exostoma vinciguerrae*, and *Glyptothorax* spp.) and Balitorids (*Schistura* spp. and *Homaloptera* spp.) (Vidthayanon, 2003; Vidthayanon et al., 2009; Hu & Zhang, 2010; Ng, 2010). This is because the rhithronic species have evolved partially through highly adapted body forms and mouth structures so they occupy virtually all habitats throughout their distributions (Ward-Campbell et al., 2005). The species richness and the *H'* index were increased from the upper to the lower part of the basin. Moreover, deeper water, wider rivers and more discharges downstream are factors to increase diversity parameters (Horwitz, 1978). Low species richness in the high altitude reflects the low variability of food supplies (Tongnunui & Beamish, 2009), sub-basin size, i.e. the larger the sub-basin, but not in the study of Nguyen & De Silva (2006), the higher the species richness and the richness of nutrients, which increased natural food sources, as well as flood pulse effect in the lowland (Junk & Wantzen, 2004).

Altitude and distance from the sea were found to be among of the most key factors that govern the species richness and fish community structures in riverine ecosystem (Oberdorff et al., 1995; Welcomme et al., 2006). Residents in this area are always generally small in size and equipped with suckers or adhesive apparatuses

(Bhatt & Pande, 1991), and may also have streamlined, sucking mouth or flattened forms such as *Schistura* spp., *G. cambodgiensis*, and *O. siamensis* which were the dominated in this study and none of them were found in the lowland sub-basins.

Two out of five of IUCN and endemic fish species i.e. *Rhinogobius chiengmaiensis* and *O. siamensis* have been found so far in the Ping-Wang river basin, the uniqueness of the area, and endemism of fish should be of concern. Deforestation for agricultural purpose, indiscriminate fish collection for aquarium fish in the upper basin, and urbanization in the lowland area are among other major threats for the rhithronic habitants. Moreover, since most of the rhithronic members are mostly insectivorous (Tongnunui & Beamish, 2009), habitat degradation in the rhitral area, could lead to a decline in exogenous food sources including insects as well as their larvae (Raghavan et al., 2008).

Nile tilapia, Chinese carps, Indian major carps as an exotic species were introduced for food enhancement purposes found and no impacts are reported so far. The presence of the Poeciliids fish as *Gambusia affinis, Xiphophorus helleri* and *Poecilia reticulata* in the upstream part must be of concern since they prey on aquatic insect larvae or stream fish larvae and often with devastating consequences (Mills et al., 2004; Vitule et al., 2009). *Gambusia affinis* was an invasive species to local species in many areas (Rehage et al., 2005) and it is aggressive foragers, feeding on a variety of prey, including the eggs, fry and larvae of native biota (Goodell & Kats, 1999; Garcia-Berthou, 1999). Na-Nakorn et al. (2004) mentioned that *Clarias macrocephalus* and *C. batrachus* in the wild might be directly replaced with the *C.* hybrid, which have a higher growth rate. Thai traditional ceremonies were released e.g. *Clarias* hybrid, *Pterygoplichthys* spp., and many species into the main stream for their lucky life, but the fishes would be negative impacts to the native species (Chaichana et al., 2010).

4.2 Life history facts, biology, and population of riverine keystone species.

The change of habitat from river to lake showed variations in their spawning characteristics Türkmen et al., (2002). It was also observed that the spawning characteristics of fish of the same length, living in places with different ecological features, but belonging to the same species, had some variations. The *Henicorhynchus siamensis* in the Mekong mainstream was mature and reproduce within the first year of their life van Zalinge et al., (2004). In the current study, the length at 50% maturity of *H. siamensis* was attained after one and a half years (i.e. about 190 mm). The *H. siamensis* can develop their gonads as early as the late dry season around March to April and peak during May and June (Sokheng et al., 1999), but in this study the GSI of *H. siamensis* began to develop at the beginning of rainy season. Viravong (2006) reported that the *H. siamensis* population above the Great Khone Falls spawns earlier than the population below the falls. This is possible because of the floods and the rain occured earlier there. The average GSI increased from low values in the dry season to a maximum of about 20% immediately before spawning (July to August), but the GSI was slightly higher for the river-dwelling *H. siamensis* (Viravong, 2006).

As a member of the littoral community, *H. siamensis* is known to be a mainly plant and detritus feeder with the trophic level range between 2.0-2.19. In a newly impounded condition, which is rich in nutrients and with a dominance of planktonic algae, *H. siamensis* was shown to be restricted to a phytoplankton feeder (i.e. trophic level range is equal 2.0: Thapanand et al., 2009). The presence of a few zooplankton in stomach contents of *H. siamensis* in this study would put its trophic level slightly higher than 2.0. Feeding mostly on phytoplankton and plant materials, which have a low energetic value, means that *H. siamensis* consumes a large quantity of food and has a long feeding period during the daytime (Amarasinghe et al., 2008).

The growth of *H. siamensis* in this study provided excellent data that could be used for simple length-based analysis (Hoenig et al., 1987). Moreover, the modal groups detectable from the raw data with the apparent shifts in the modal length over time make the results of the study reliable (Ama-Abasi et al., 2004). The growth performance index (Φ') is a species-specific parameter to indicate the unreliability in the accuracy of estimated growth parameters (Pauly & Munro, 1984). The Φ' of the present study (4.19) was close to (χ^2 test, P-value > 0.05) the value from a large reservoir (4.75: Moreau et al., 2008), which meant that the estimated growth parameters were authentic. The high amplitude of oscillation (C = 0.8) of *H. siamensis* indicated that growth does not completely cease but slows down during the unfavorable period (i.e. during December), which could due to diet items, which were the lowest in number and diversity, and also, low water temperature. Similar results were obtained from a large reservoir, where C = 0.6 and WP = 0.95 (Moreau et al., 2008). This situation is also likely to occur in the Mekong mainstream where there is a drastic decline in temperature during November to January (Prathumratana et al., 2008).

H. siamensis has shown well adapted to the lentic system, the piscimetric values on its biological traits showed to be lower than those in the lotic system. This phenomenon would relate to different in the flood pulse between the two systems. Tonle Sap population condition factor was remarkably increased during the flood season (Lamberts, 2001) as like as other Cyprinids (De Graaf, 2003). Meanwhile there is less variation in flood pulse in the regulated lake (Wantzen, et al., 2008), where the hydrological regimes are almost entirely dependent on the rainfall in the catchment areas and the demand for water for primary uses (Nissanka et al., 2000). Nevertheless, Mattson & Kaunda (1997) mentioned that the small reservoir environment is similar to a river floodplain, with large fluctuations in temperature, oxygen concentration, turbidity and water level, which are suitable to enable fish of river origin to adapt to the new environment. Moreover, the reproductive traits of *H. siamensis* such as early maturity, high fecundity, single broods and rapid egg and larval development would help them be successful in unfavorable environments (Viravong, 2006). The *r*-strategist with foraging behavior also makes *H. siamensis* a good candidate for maintaining the population in higher trophic levels in the lake similar to the case of the Thai river sprat (*Clupeichthys aesarnensis* Wongratana, 1983) into numbers of reservoirs in the LMB (Jutagate et al., 2003).

The northern Thai’s stream, like on many other tropical streams, are characterized by a steep topography, fast flow, rocky bottom, canopy cover, and high level of dissolved oxygen. Nevertheless, the fish still have to well adapt to the special habitat e.g. *Homaloptera* spp., *Balitora* spp., and *Glyptothorax* spp. (Kottelat, 2001). Also, *O. siamensis* was well adapted by flatten belly, adhesive maxillary barbel and pair fins; streamline body shape, and aerodynamic dorsal part. These characteristics were suitable to feed on the small invertebrate and aquatic insect larvae on the rocks (Vidthayanon, 2005). It could tolerate a low water temperature in high altitude might limit the growth of the *O. siamensis* food items (Han et. al., 2000). The environmental condition of *O. siamensis* was abundance along the habitats in Maechaem Stream showed that *O. siamensis* inhabited the waters between 500 to 1200 m altitudes.

The early stages such as eggs and larvae stages are the great important for fish, then the reproductive tactics in teleostean fish involving the allocation of a size-dependent reproductive effort between fecundity and egg size. The demersal species tend to produce large and few eggs, the larger eggs and the larvae hatching from them are more likely to survive than smaller ones, but Duarte & Alcaraz, 1989 reported no evidence of evolutionary trends towards greater eggs. They were reduce the variance in growing conditions, should be more dependent on the survival of the individual larvae, which increases as egg size increases. Also, *O. siamensis* is a demersal steam species, it was produce large oocytes and few numbers like some of parental care species e.g. *Xynobagrus nigri* (Olurin & Odeyemi, 2010) and *Notopterus notopterus* (*per se* A. Suvarnaraksha) or rainbow trout, Sea back trout, and brook trout (Serezli et al., 2010). While, their fecundities were very small number of eggs compare with the other glyptothorine species e.g. *Glyptothorax madraspatanum* (18 to 47 vs. 1640 to 6830) (Dobriyal & Singh, 1993). The fecundity and egg size were related, egg size is one of the important determinants of eggs and larval quantity as it is positively correlated with both survival of egg and larval and also of the growth of the larvae (Gall, 1975). The adults and juvenile were found in the same habitats, it is possible a non-migratory species.

The *O. siamensis* was spawn in the late dry-cool to dry-hot season (January to April) in Thailand, it conformed to study of Unsrisong et al., 2005, but a little bit early. Meanwhile, it was different to other lowland tropical stream species reproduction according to rainfalls regiems (Alkins-Koo, 2000; Chellappa et al., 2009). In the dry season, reduced stream flow and a reduced spate frequency ensure a more benign physical environment than during the wet season, and specific food for larvae may also be more abundant at this time also. Moreover, wet-season primary production may be reduced because of a combination of increased cloud cover associated with the monsoonal wet season and high suspended sediment loads during periods of elevated discharge, both of which limit light availability for primary producers (Pusey et al., 2001). The main habitats were in the the high elevation and canopy cover. The spawning season sufficient data on seasonal freshwater fish egg variations are not available, but the time of spawning does appear to be linked with the availability of food for the larvae in both lake and stream species (Bagenal, 1971). Then, the few number of eggs and restrict to habitat of *O. siamensis* was lead to endanger or extinct in near by future.

4.3 Fish assemblage in lotic and lentic ecosystems of Ping-Wang River Basins.

The complexity and non-linearity of the relations between the fish communities and their environment are very common (Gevrey et al., 2003) as shown by the low relationship values from the linear correlations for all environmental variables to both diversity indices. For prediction of fish diversity, it was found that geo-morphological parameters were the good predictors for species richness and Shannon diversity index compared to those physicochemical parameters. Changes in both diversity indices follow the general longitudinal pattern of river fish distribution as the lowest levels tend to be found at high altitudes, and the highest levels at mid to low altitudes (Gaston & Blackburn, 2000; He et al., 2010). The larger watershed, which suggests larger areas of habitat generally contain more species than smaller areas (Angermeier & Schlosser 1989; Han et al., 2008), the effects of land uses on fish community structure (Orrego et al., 2009; Alexandre et al., 2010), and also, which shows robust positive relationships to species richness (Connor & McCoy, 1979; Angermeier & Karr, 1983). However, due to the fact that most of the areas in this basin is intact and less disturbed by urbanization, in this study, reflected the longitudinal river gradient, which is closely related to the gradual change in habitat diversity (Ferreira & Petrere, 2009; He et al., 2010). The physicochemical parameters would be important to fish species richness and abundance in a relatively drainage system (Oberdorff et al., 1995; Guégan et al. 1998; Tongnunui & Beamish, 2009; Alexandre et al., 2010). The summary diagram of lotic environmental parameters and diversity parameters relationships were shown in the thesis e.g. distance from the sea, altitude, and dissolved oxygen were negative relationship to diversity parameters (Fig. 24). Meanwhile, the summary diagram of the lentic environmental parameters and diversity parameters relationships were shown in Figure 25. From this study, environmental factors must have an optimal level for aquatic organisms e.g. the inverse sigmoid curve of Figure 24 was slowly decreased, and/or rapidly descend in particular session (non scale).

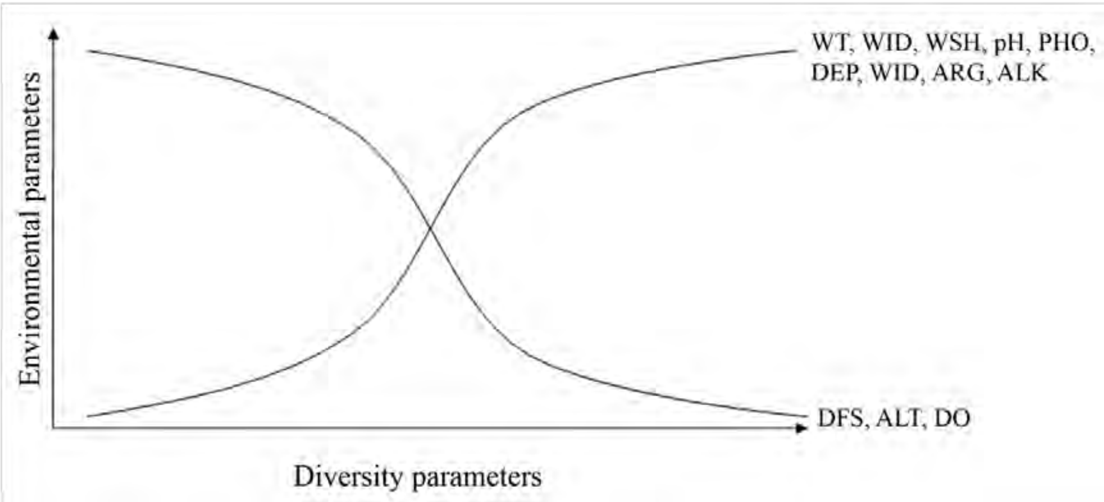

Figure 24. Summary diagram of relationships of environmental parameters and diversity parameters in lotic condition of this thesis (non scale). Diversity parameters are *H'*=Shannon Weiner diversity index, *S*=species richness, *D*=Simpson Dominance index and *J*=Species evenness. Environmental parameters are WT, WID, WSH, pH, PHO, DEP, DIC, AGR, ALK, DFS, ALT, and DO. Abbreviation: 1. Negative relationship to diversity parameters group i.e. DFS=distance from the sea, ALT=altitude, DO=dissolved oxygen, 2. positive relationship to diversity parameters group; WID=width, DIC=discharge, DEP=depth, pH=per hydrogen, PHO=phosphorus, AGR=agricultural area, ALK=alkaline.

Distinct patterns of fish assemblages along the longitudinal river gradient reflects the homogenous spatial units within the river basin (Welcomme et al., 2006; Ferreira & Petrere, 2009) and the results from ordination and classification showed four fish assemblage patterns from the headwater to lowland river reaches: mountainous, piedmont, transitory and lowland assemblages. The assemblage of mountainous species showed their restricted occurrence in a high altitude area, with associated riffles and rapids, there were adapted their morphological for survive in the strong flow conditions (Casatti & Castro, 2006). Assemblage diversity in the piedmont could also be explained by the potentially large number of modes of exploitation of resources, corresponding with highly differentiated patterns of habitat use, i.e. Competitive Exclusion Principle, CEP (Herder & Freyhof, 2006). The CEP theory also supports the assemblage pattern of the "transitory" species, where various habitats are also found and rheophilous cyprinid always dominate (Allouche, 2002) and also, was used to describe the lowland assemblage (Rainboth 1996; Kottelat, 1998), where the lentic cyprinids and other limnophilic fishes dominated (Allouche, 2002; Beamish et al., 2006). However, upstream movement of some lowland species is sometimes observed especially for reproduction (Silva & Davies, 1986; Ferreira & Petrere, 2009; Tongnunui & Beamish, 2009). This phenomenon supports the pattern of species addition for the shifting in species composition (Huet, 1959; Petry & Schulz, 2006).

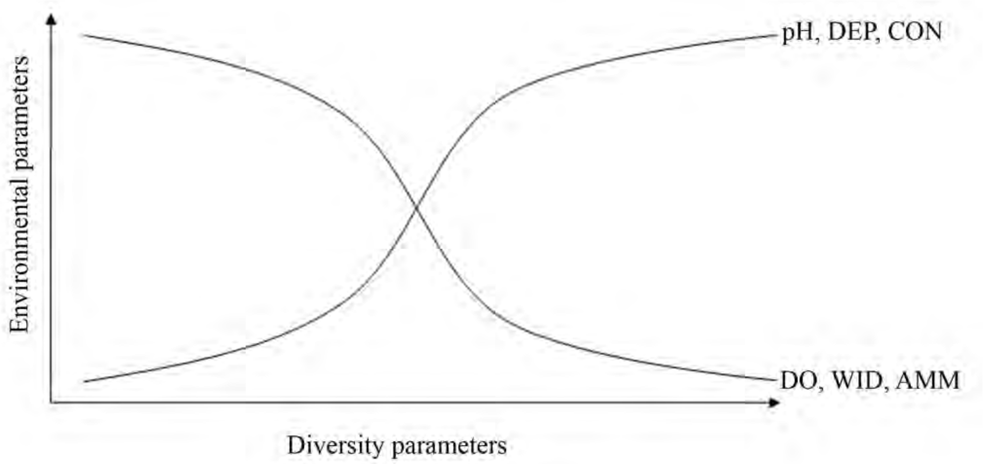

Figure 25. Summary diagram of relationships of environmental parameters and diversity parameters in reservoir of this study (non scale). Environmental parameters are DO=dissolved oxygen, WID=width, AMM=ammonia, DEP=depth, pH=per hydrogen, and CON=conductivity, while; diversity parameters i.e. *H'*=Shannon Weiner diversity index, *S*=species richness, *D*=Simpson Dominance index and *J*=Species evenness.

Species composition of fishes (Özcan & Balik, 2009) and community assemblages were changed after the change of ecosystem. The tropical Southeast Asia river basins fish species are dominated by cyprinids followed by silurids (Matin-Smith & Tan, 1998; Campbell, et al 2006; Nguyen & De Silva 2006) but being followed by the Balitoridae and Cobitidae, as in this study, is unique for the stream areas in the region (Kottelat, 1998). *Henicorhynchus siamensis* was the highest percentage of relative abundance. Differences in the observed communities can be provided as an assessment of the ecological status (Lasne et al. 2007). The three communities, i.e. stream- (SC), reservoir- (RC), and intermediate community (IC) were divided the fish groups, where the hydrological regime was the major factor controlling fish community patterns (Welcomme & Halls 2005). The fish communities were different in the dry cold and dry hot season, which coincided that made the difference between the RC and SC. The water surface of the reservoir was increase in during rainy season, this case also improves the connectivity between the reservoir and the tributaries and that increases the aquatic biodiversity (Amoros & Bornette, 2002; Falke & Gido, 2006) as seen in the results in the intermediate community (IC).

The variation in the occurrence probability (*OP*) of individual species in each cluster indicated the preferred habitat of the species. In the SC, the members were mostly rheophilic species e.g. *Barilius koratensis*, and *Garra cambodgiensis*, commonly found in small to medium-sized streams in upland areas (Kottelat, 1998), they were sensitive to catastrophic and habitat flows (Welcomme et al., 2006). Meanwhile *C. gachua* lives in the backwaters of first order streams (Taki, 1978) and *R. paviana* is usually found in shallow and moderately flowing streams (Kottelat, 1998). In the RC, the species found were the lentic-adapted species e.g. *Henicorhynchus siamensis* and *Labiobarbus lineatus*, the so called “facultative reservoir species”: they are generally native to the lower portions of a river course (Falke and Gido, 2006). Also, variations and high overlaps among communities could be due to some species moving in and out of the tributaries during their life cycle (Borcherding et al., 2002). For example, *Henicorhynchus siamensis* migrate upstream annually to spawn on shallow gravel beds at the confluence or in small rivers during short periods in rainy season (Sokheng et al., 1999; de Graaf et al., 2005). This is why these fish also showed sample *OP* in the IC. Meanwhile, high *OP* in all communities of *O. marmorata* and *M. marginatus* could be caused by movement either for feeding or spawning purposes (Kottelat, 1998).

The community structure in the headwater depends on abiotic- rather than biotic- factors (Schlosser, 1987). Prchalová et al., (2009) mentioned that the complexity of species composition in a reservoir, increased heading towards the tributary and peaked close to or at the tributary part of reservoir, which agreed with our results obtained for the complexity of the *OP* in the IC. Other selected variables in the CART to discriminate between the SC and IC were related to the major nutrients in the ecosystem i.e. phosphorus and nitrogen, both nutrients always increase during the rainy season and are released from upstream to downstream as well as from the land to the water body and then stimulate primary productivity in the ecosystem (Allen, 2001; Wondie et al., 2007). This phenomenon is eventually made more complex in the fish community in the area, at least for feeding purpose (Hoeinghaus et al., 2008). The one hundred percent predictive power for the RC indicated that the community assemblages in that area were relatively stable, while the low predictive power for the SC implied the movement of downstream species into the stream (Grossman et al., 1990).

5. CONCLUSION

This study was the investigation of the taxonomic level, biology and life history, and ecological approaches of the keystone species in the lotic and lentic waters in the upper Chao Phraya river basin. The lack of fish diversities was reported in case of the Indo-Burma hotspot (Southeast Asia), especially upper Chao Phraya river basin. Fourteen years of field dataset in the Basin were used, which covered 272 surveys of 10 sub-river basins, collected between January 1996 and April 2009 to perform species richness and diversity indices. Twenty physicochemical water quality- and geo-morphological- parameters were also examined at each sampling. Similarities among sub-basins were examined by Ward‘s agglomerative method. Rarefaction was employed to extrapolate species richness and optimum numbers of the surveys. The longitudinal distribution in lotic conditions of fish was presents information of fish diversity and distribution in a unique high altitude mountain (Inthanon highest point of Thailand 2,565 masl, Chiangmai province) to lowland area (Nakornsawan province, the end of Ping-Wang River Basin 40 masl). Two hundred and one species in 104 genera and 34 families were collected, including 16 exotic species. The Cyprinidae (76 species) was dominated families, followed by Balitoridae (20 species) and Cobitidae (13 species), implying the characteristic of high altitude area. The overall endemism in the area was found at about 10%. Ward‘s method showed distinct differences between the upper- and lowland sub-basins. The rarefaction curve of each sub-basin reached the asymptote indicating the actual numbers of species were close to the species collected in this study.

The prediction of the structure of fish assemblages in rivers and reservoirs are very important goal in ecological research, both from a purely theoretical point of view and from an applied one. Moreover, it will be beter studies in the future of Southeast Asia. Estimation of the probability of presence/absence of fish species has been obtained so far using different approaches. Although conventional statistical tools (e.g. logistic regression) provided interesting results, the application of artificial neural networks (ANNs) has recently outperformed those techniques. ANNs are especially effective in reproducing the complex, non-linear relationships that link environmental variables to fish species presence and/or abundance. In this study some new developments in ANN training procedures will be presented, which are specifically aimed at solving ecological problems related to the way the errors are computed in species composition models. The resulting improvements in species prediction involve not only the accuracy of the models, but also their ecological consistency. A case history about fish assemblages in the rivers of the Ping-Wang River Basin is presented to demonstrate how the enhanced modelling strategy improved the accuracy of the predictions about fish assemblages. Highest and lowest diversity indexes were obtained in the lower Ping and Maeklang sub-basins, respectively. Six physicochemical parameters (i.e. dissolved oxygen, water temperature, pH, conductivity, phosphorus and alkalinity) and six geo-morphological parameters (i.e. altitude, distance from the sea, discharge, depth and width) showed statistically significant in their relationships to diversity parameters (P-value < 0.05). Results from the classification and regression trees showed that the geo-morphological parameters were more significant in controlling and predicting both species richness and Shannon diversity index than the physicochemical parameters, in which altitude was the most significant. Fifty-three dominant fish species from 220 samplings were patternized into 4 assemblage-patterns *viz.*, mountainous-, piedmont-, transitory- and lowland- species. Any environmental changes in the rhitral environment will seriously impact to the mountainous- and piedmont- species since their specific distributions.

Importance of geographical parameters i.e. altitude, distance from the sea, stream width, discharge, water depth, and watershed area and physicochemical parameters i.e. water temperature, dissolved oxygen, and conductivity as variable explaining variation in fish community structure along a river gradient in a large scale whole basin (Fig. 18). However, the contribution of the other variables, especially the physicochemical water quality parameters, should be considered in terms of point and non-point pollution sources over a small scale (Ibarra et al., 2005; Orrego et al., 2009). The delineation of fish assemblage patterns enhances the understanding fish zonation in this region. Knowing the representatives of each assemblage allows for the development of indicator species for assessing the integrity of each river course, in the force of human influences in particular.

Aquatic ecosystem is influenced by the landscapes through which they flow (Hynes, 1975; Vannote et al., 1980), a fundamental link recognised in many of the conceptual models describing the structure and functioning of natural river systems. The word ecology has attracted to its scientific diversity; a useful working definition is the scientific study of the interactions between organisms and their abiotic and biotic environmental that determine the distribution and abundance of the organisms. Also, in this thesis the relationship of the diversity parameters (DP) and environmental parameters (EP) may occupy by the lentic and lotic conditions. The lotic condition was divided into positive proportion a negative proportion, the positive proportion was increased of the EP (e.g. WT, WID, WSH, pH, etc.) to diversity parameters and the second group was a negative relationship *viz.*, DFS, ALT and DO. While, the lentic condition (manmade reservoir) was shown the positive proportion i.e. pH, DEP, and CON and the negative proportion i.e. DO, WID, and AMM.

The fish communities in highland tropical streams connected to a reservoir were dominated by cyprinids. Three communities of fish were found in this study i.e. the reservoir community (RC), the stream community (SC) and the intermediate community (IC). Water depth had the main impact on the change in the communities. The *Henicorhynchus siamensis* a riverine species has shown that it can establish population in the lentic system. Also, *H. siamensis* could invade the tributaries during a certain period in rainy season as shown in the IC and SC. Meanwhile, the species in the SC could be found in the IC but they were not found in the reservoir area. Nevertheless, the small reservoir environment is similar to a river floodplain, which is suitable to enable fish of river origin to adapt to the new environment. Moreover, the *r*-strategist reproductive traits of *H. siamensis* such as early maturity, high fecundity, single broods and rapid egg and larval development would help them be successful in unfavorable environments.

Threats to fish communities were deforestation and collection for aquarium fish, especially the exotic Poeciliid fish in the upper reach, which is of the major concern. Meanwhile distribution of aquaculture escapees should be concerned in terms of genetic hybridization. Further studies on the function of individual species in each community are recommended. Moreover, an examination of the fish larvae and juveniles in the system should be also being considered since they also move and distribute in the reservoir. This would also provide information on species interaction and recruitment to the reservoir system.

Upper Chao Phraya river basin has a rich aquatic fauna. These report 201 fish species had been confirmed to inhabit in Ping-Wang River basin, which is the largest tributaries of Chao Phraya river basin. Historically, fishes were very abundant in the basin, and since there were few humans and the fishing gear used local made, fish harvesting had little impact on fish stocks, even through fishes constituted the important protein source for local people. In contrast, the anthropological treat to aquatic environment, instead to loss the stream habitat in the upper reach and lower reach of the river basin. In recent decades, fish populations have apparently declined. Especially, *O. siamensis* was a vulnerable and endemic species to the Chao Phraya river basin.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further study should be conducted in the areas from the mountainous high land to the sea in whole Chao Phraya river basin and main Southeast Asia rivers and/or marine area. The data set should be studied to achieve long term data (ecological parameters and diversity parameters) to predict the fish assemblages in Thailand and SEA. The study of biology and life history should encourage to study in various species e.g. treatened species, native species, commercial species, and invasive species etc. There should be a modern method to study the biology and life history e.g. hormone, cytology, and DNA. Encouragement on using modern methods to predict the changes of aquatic resources for commercial and conservation purpose should be done. The polution should be concerned on the relationships between diversity parameters and ecological parameters. And the study should be added to the prediction of climate change with the change of biological parameters and diversity parameters and aquaculture.

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Part 2: Publications

P1

Fish diversity in the upper Chao Phraya river basin, Southeast Asia

Suvarnaraksha, A., S. Lek-Ang, S. Lek, and T. Jutagate. (2011)

Ichthyological Exploration of Freshwaters.

(Submitted)

Fish diversity in the Upper Chao Phraya River Basin, Southeast Asia

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ABSTRACT

The lack of reliable data causes a dispute over fish diversity in the Indo-Burma hotspot (Southeast Asia). This study presents information on fish diversity and distribution in a unique high altitude mountain to lowland areas in the upper part of the Chao Phraya river basin, Thailand. Fourteen years of field dataset in the basin was used, covering 272 surveys of 10 sub-river basins to produce species richness and diversity indices. Similarities among sub-basins were examined by Ward‗s agglomerative method. Rarefaction was employed to extrapolate species richness and optimum numbers of the surveys. Two hundred and one species in 104 genera and 34 families were collected, including 16 exotic species. Fish of Family Cyprinidae dominated, followed by Balitoridae and Cobitidae, implying the characteristic of high altitude area. The overall endemism in the areas was found to be about 10%. Five IUCN-list fish *viz.*, *Oreoglanis siamensis*, *Himantura signifier*, *H. chaophraya*, *Pangasianodon gigas* and *Pangasius sanitwongsei* were found. Ward‗s method showed distinct differences between the upper- and lowland sub-basins. The rarefaction curve of each sub-basin reached the asymptote indicating the actual numbers of species were close to the species collected in this study. In conclusion, the fish community is especially characterized by rhithronic habitants, including some species that are not yet taxonomically described. Threats to fish communities were deforestation, collection for aquarium fish, and the distribution of the exotic Poeciliid fish in the upper reaches. Meanwhile, distribution of aquaculture escapees should be concerned in terms of genetic hybridization.

INTRODUCTION

The Indo-Burma region is considered the third largest global biodiversity hotspot after the Tropical Andes and Mesoamerica (Myers et al., 2000). Within this region, the number of freshwater fish has been documented at more than 1,260 species, compared to 2,345 fish species in the Oriental region (Lévêque et al., 2008) and more than 560 of these species are endemic (Conservation International, 2010). However, it is generally accepted that data and information on fish is very poor compared to other vertebrate groups (Myers et al., 2000), especially in this region (Sodhi et al., 2004) and this has led to a dispute about their distribution and conservation (e.g. De Silva et al., 2007; Darwall et al., 2008). Moreover, freshwater ecosystems, in general, have received much less focus in terms of conservation prioritization exercises (Taylor, 2010).

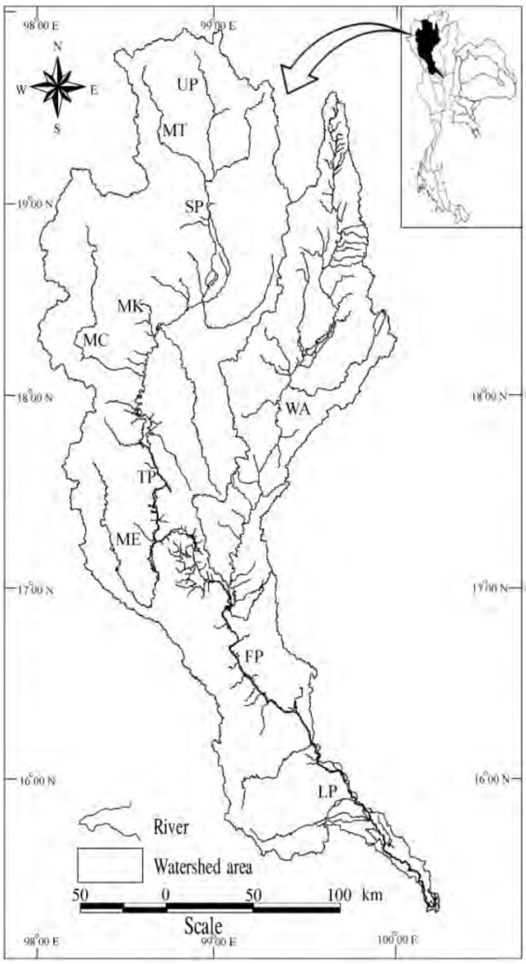

Figure 1 Location and map of the Ping-Wang River Basin and its sub-basins

In the Indo-Burma region, Thailand ranked among the top in the diversity of freshwater fish species (i.e. 690 species, Kottelat & Whitten, 1996; Vidthayanon et al., 1997; Nguyen & De Silva, 2006), which are supported by an extensive inland water area of about 4.5 million ha in seven major river basins *viz.*, Chao Phraya, Mekong, Eastern, Southern, Salween, Mekhlong and Tenasserim (Jutagate, 2010). All these basins, except for the Mekong, the studies on fish diversity are very few and less than desirable (Coates et al., 2003; Nguyen & De Silva, 2006). This is also the case in the Chao Phraya river basin, which is one of the 21 major river basins in East, South and Southeast Asian nations, and the fish diversity in this basin is recorded at about 222 species (Dudgeon, 2000), of which 34 species are endemic (De Silva et al., 2007). This basin covers about 30 percent of Thailand's land area, and is a home to about 40 percent of the country's total population. Therefore, it is clear that there is no sign, until now, of deceleration in anthropogenic stresses like other developed countries (Costanza et al., 2007). In recent years, there have been changes in the land uses on the river bank and within the watershed from agricultural uses to industrial and urban use (Mahujchariyawong & Ikeda, 2001), in which effluents cause polluted water (Meksumpun & Meksumpun 2008) and directly impact the fish community as well as the fisheries.

In order to create an approach for the appropriate conservation of fish, basic information on the diversity and distribution of individual species in the basin is needed. This is exclusively in Southeast Asia, where research and knowledge about the ecological and taxonomic aspects of many fauna are relatively rare and they may face extinction before we even know of their existence (Bickford et al., 2010). Therefore, in this study, we presented the baseline information on fish diversity distributed within the Upper Chao Phraya River Basin (also called "the Ping-Wang River Basin"), which contains more than three fourths of the freshwater fish species known from Chao Phraya river basin (Vidthayanon et al., 1997) and exclusively characterized as a high altitude area (i.e. comprised of 1st and 2nd order streams). The data cover 14 years consecutive surveys within 10 sub-river basins. This information could help correct the meager data on spatial diversity and distribution of fish species in the region.

MATERIAL AND METHODS

Study area

The Ping and the Wang rivers are the main rivers of northern Thailand and merge with Nan River in the Central part to form the Chao Phraya river. The Ping river is 740 km long, with a catchment area of about 33,896 km^2.The Wang river is 440 km long and has a catchment area of 10,791 km^2 (Takeuchi et al., 2005). The Wang river flows southwestward to join the lowland leg of Ping river in Tak Province to form a large watershed area between 15°42’ and 19°48’ North and 98°04’ and 100°08’ East.

The sampling area was divided into 10 sub-basins with various numbers of sampling stations (Fig. 1 and Table 1) *viz.*, the upper Ping river (UP), Maetang (MT), the second part of the Ping river (SP), Maeklang (MK), Maecheam (MC), the third part the Ping river (TP), Maeteon (ME), the Wang river (WA), the fourth part of the Ping river (FP) and the lower Ping river (LP). The first 8 sub-basins lie in a relatively high altitude mountainous area, and the latter 2 stations are in the lowland area. Geo-morphometric characteristics of each sub-basin are also shown in Table 1

Fish samplings

Two hundred and seventy two samplings were conducted spatially over the whole basin during January 1996 to April 2009 (Table 1). The sampling sites were chosen on the basis of accessibility, similarity and diversity of habitat types in streams and rivers (pools, cascade, falls, riffles, and stagnant water). Collection of fish samples were taken at every habitat type in every selected site, in which each site was approximately 35 or 40 mean stream width in length. Samplings were done by various methods i.e. beach seine net, cast net, multi-mesh gillnets as well as the electro-fishing with an AC shocker (Honda EM 650, DC 220 V 550BA 450VA, 1.5–2 A, 50 Hz), which was placed on the riverbank together with block nets and scoop nets. Each sampling site was sampled at least twice to represent dry and wet seasons.

Live fish were roughly identified in the field, measured for total length (mm), counted, and then returned back to the water. Only a few samples of individual species were anaesthetized in dilute solution of benzocaine (50 mg/l) and kept separately according to species level. Specimens were fixed in 10% formalin for a

Table 1 Descriptions of the sub-basins in the Ping-Wang River Basin and sampling protocols

Sub-basin	Geographic Coordinate	Bottom types	Elevation (m ASL)	Distance from the sea (km)	Water depth (m)	Stream width (m)	Forest (%)	Agricultures (%)	Urban (%)	Collecting period	Collecting techniques	No. of station
Upping Ping (UP)	19°07'-19°48' N 98°47'-99°17' E	G, P, R, S	684 ± 228.3	1,026 ± 24.1	0.4 ± 0.2	7 ± 0.5	76.5	23.3	0.1	2008	E	6
Maetang (MT)	19°10'-19°45' N 98°27'-98°55' E	G, P, R, S	756 ± 166.2	1,067 ± 36.0	0.6 ± 0.4	13 ± 11.2	72.1	25.4	0.3	2000-2001 2003-2004	E	48
The second Ping (SP)	18°31'-19°33' N 98°24'-99°22' E	G, P, R, S	553 ± 160.2	982 ± 41.0	1.9 ± 6.0	74 ± 230.5	75.0	24.9	0.1	1996, 2003-2004, 2008	E, N, T, C	98
Maeklang (MK)	18°24'-18°35' N 98°28'-98°41' E	G, P, R, S	1,070 ± 213.4	877 ± 4.6	0.3 ± 0	11 ± 5.4	88.4	11.5	0.1	2008	E	6
Maecheam (MC)	17°57'-19°09' N 98°04'-98°37' E	G, P, R, S	627 ± 207.3	927 ± 53.9	0.7 ± 0.4	21 ± 17.4	74.7	24.4	0.9	2007-2008	E, N	44
The third Ping (TP)	17°48'-18°43' N 98°14'-98°44' E	G, S, M	261 ± 11.5	704 ± 43.8	2.8 ± 1.2	424 ± 224.6	88.2	11.6	0.1	2005-2006, 2009	E, N	18
Maeteon (ME)	17°13'-18°02' N 98°14'-98°34' E	G, P, R, S	804 ± 229.2	847 ± 43.0	0.5 ± 0.2	8 ± 3.8	85.0	11.5	0.2	2008	E	24
The forth Ping (FP)	15°50'-17°49' N 98°39'-100°02' E	G, S, M	120 ± 33.5	580 ± 68.4	2.7 ± 0.5	359±77.5	67.7	29.6	2.8	2009	B, N, T	6
Lower Ping (LP)	15°42'-16°10' N 99°27'-100°08' E	G, S, M	48 ± 8.0	425 ± 16.0	3.2 ± 1.3	258 ± 27.7	72.6	22.0	5.4	2009	B, N, T	4
Wang river (WA)	17°07'-19°24' N 99°00'-100°06' E	G, S, M	408 ± 123.8	833 ± 225.2	0.9 ± 0.9	28 ± 48.2	76.5	23.3	0.1	2009	E	18

Note (i) Bottom types: R = Rocky, G = Gravel, P = Pebble, S = Sandy, M = Muddy; (ii) Collecting techniques: E = Electro fishing, N= Gill net, T = Trap, C = Cast net, B=Beach seine net month and changed to ethanol 30%, 50% and finally preserved in 70% ethanol. Specimens were re-checked and taxonomically identified into species at the Maejo Aquatic Resources Natural Museum (MARNM).

Data analyses

Ranks of individual species were presented as the percentages of relative abundance (%RA) and occurrence frequency (%OF). The diversity indices (Magurran 2004) *viz.*, Shannon diversity index (*H'*) and evenness (*J'*) were calculated for each sub-basin. Hierarchical agglomerative clustering by Ward's method was used to classify sets of dissimilarities of the fish assemblages in sub-basins and was analyzed by using Program R (R Development Core Team 2009). Kruskal-Wallis test was used to test significance of species richness. Under the assumption that species richness increases with the sample size, we rarefied species richness to the same number of individuals and a rarefaction curve was used to estimate species richness in each sub-basin. Rarefaction (R) was based on the equation (Hulbert, 1971)

$$R = \sum_{i=1}^{S}\left[1-\left(\frac{N-m_i}{n}\right)/\left(\frac{N}{n}\right)\right]$$

where, N is the total number of individuals, S is the total number of species, m_i is the number of individuals of species i, and n is the number of individuals in sub-sample, i.e. sub-basin. The rarefaction values were computed by using EstimateS v. 8.2.0 (Colwell, 2006).

RESULTS

A total of 32,080 fishes were collected representing 34 families, 104 genera and 201 species (Table 2). Fish in Order Cypriniformes were the most dominant, both in terms of the number of individuals (77.7 %) and the number of species (56.9 %), followed by order Siluriformes (8.6 % and 20.8 %) and Perciformes (7.7 % and 10.9 %) (Fig. 2). In terms of Family, Cyprinidae dominated with 40.3 % (81 species), followed by Balitoridae and Cobitidae with 10.0 % and 6.5 % (20 and 13 species), respectively (Table. 2). Among the genera, *Schistura* in Family Balitoridae was the

Table 2 Species composition of fish in the Ping-Wang River Basin and their occurrence in each sub-basin

Species	Family	N	%RA	%OF	TL (mm)	Guilds	M	Sub-basins									
								UP	**MT**	**SP**	**MK**	**MC**	**ME**	**TP**	**WA**	**FP**	**LP**
Garra cambodgiensis (Tirant, 1883)	CYP	3354	10.46	40.44	21-120	HER	Y	X	X	X		X	X		X		
Schistura breviceps (Smith, 1945)	BAL	2766	8.62	39.34	30-86	INV	N	X	X	X	X	X	X	X	X		
Mystacoleucus marginatus (Valenciennes, 1842)	CYP	1529	4.77	23.16	10-160	INV	Y		X	X		X		X	X	X	X
Schistura poculi (Smith, 1945)	BAL	1439	4.49	18.75	23-73	INV	N	X	X	X	X	X					
Henicorhynchus siamensis (Sauvage, 1881)	CYP	1330	4.15	11.40	51-185	HER	Y			X		X		X	X	X	X
Barilius pulchellus (Smith, 1931)	CYP	1126	3.51	34.93	22-109	INV	Y	X	X	X		X	X	X	X		X
Gambusia affinis (Baird & Girard, 1853) (e)	POE	831	2.59	17.28	12-52	INV	N		X	X		X	X				
Rasbora paviana Tirant, 1885	CYP	825	2.57	29.41	21-97	INV	?		X	X		X	X	X	X	X	X
Scaphiodonichthys burmanicus Vinciguerra, 1890	CYP	749	2.33	19.49	30-95	HER	Y	X	X	X	X	X	X				
Channa gachua (Hamilton, 1822)	CHA	735	2.29	47.06	12-200	PIS	Y		X	X	X	X	X	X	X		
Puntioplites proctozysron (Bleeker, 1865)	CYP	696	2.17	11.03	82-280	HER	Y			X		X		X	X	X	X
Poropuntius deauratus (Valenciennes, 1842)	CYP	690	2.15	19.85	20-213	HER	Y	X	X	X	X	X	X				
Puntius stoliczkanus (Day, 1871)	CYP	654	2.04	23.16	45-124	INV	N		X	X	X	X			X		
Oreoglanis siamensis Smith, 1933 (a, d)	SIS	645	2.01	13.97	25-144	INV	N	X	X		X	X	X				
Paralaubuca riveroi (Fowler, 1935)	CYP	626	1.95	3.68	48-440	INV	Y							X	X	X	X
Parambassis siamensis (Fowler, 1937)	AMB	619	1.93	8.46	21-58	INV	Y			X				X	X	X	X
Schistura spilota (Fowler, 1934)	BAL	606	1.89	15.07	48-61	INV	N	X	X	X	X	X	X		X		
Schistura geisleri (Kottelat 1990)	BAL	548	1.71	13.97	36-124	INV	N	X	X	X		X	X	X	X		
Schistura obeini Kottelat, 1998	BAL	526	1.64	5.88	15-65	INV	N	X	X	X		X					
Schistura menanensis (Smith, 1945)	BAL	479	1.49	5.88	25-105	INV	N	X	X				X	X	X		
Exostoma vincegerrae Regan, 1905	SIS	476	1.48	9.19	38-101	INV	N					X	X				
Puntius orphoides (Valenciennes, 1842)	CYP	468	1.46	23.16	21-34	INV	Y		X	X	X	X		X	X	X	X
Hampala macrolepidota Kuhl & Van Hasselt, 1823	CYP	446	1.39	12.87	33-370	PIS	Y			X		X		X	X	X	X
Pristolepis fasciatus (Bleeker, 1851)	NAN	387	1.21	9.19	30-220	INV	N			X				X	X	X	X
Discherodontus schroederi (Smith, 1945)	CYP	360	1.12	11.76	23-113	INV	Y		X	X					X		
Notopterus notopterus (Pallas, 1769)	OST	305	0.95	7.72	70-290	PIS	Y			X				X	X	X	X
Schistura waltoni (Fowler, 1937)	BAL	287	0.89	8.09	36-42	INV	N	X	X	X		X	X				
Barbonymus gonionotus (Bleeker, 1850)	CYP	285	0.89	9.93	73-245	HER	Y			X		X		X	X	X	X
Devario maetangensis (Fang, 1997) (d)	CYP	274	0.85	5.15	21-85	INV	?		X								
Hemibagrus nemurus (Valenciennes, 1840)	BAG	271	0.84	14.71	23-480	PIS	Y			X		X		X	X	X	X
Cyclocheilichthys armatus (Valenciennes, 1842)	CYP	267	0.83	8.82	58-231	HER	Y			X		X		X	X	X	X
Mastacembelus armatus (Lacepède, 1800)	MAS	245	0.76	16.18	95-480	INV	?		X	X			X	X	X	X	X
Oxyeleotris marmorata (Bleeker, 1852)	ELE	237	0.74	9.93	20-286	PIS	N			X		X		X	X	X	X
Schistura sexcauda (Fowler, 1937)	BAL	216	0.67	2.94	15-87	INV	N		X	X							
Barilius koratensis (Smith, 1931)	CYP	201	0.63	5.51	42-91	INV	Y			X			X		X		
Devario regina (Fowler, 1934)	CYP	198	0.62	9.93	20-85	INV	?			X		X		X			
Labiobarbus lineatus (Sauvage, 1878)	CYP	186	0.58	3.68	115-155	HER	Y			X					X		X
Homaloptera smithi Hora, 1932	BAL	175	0.55	9.56	19-67	INV	N	X	X	X		X	X				
Mystus mysticetus Roberts, 1992	BAG	172	0.54	4.78	143-152	PIS	Y			X		X	X		X	X	X

Table 2 (cont.) Species composition of fish in the Ping-Wang River Basin and their occurrence in each sub-basin

Species	Family	N	%RA	%OF	TL (mm)	Guilds	M	Sub-basins									
								UP	MT	SP	MK	MC	ME	TP	WA	FP	LP
Trichogaster trichopterus (Pallas, 1770)	OSP	160	0.50	8.46	23-54	INV	N		X	X			X		X	X	X
Acantopsis choirorhynchos (Bleeker, 1854)	COB	159	0.50	8.09	30-120	INV	?			X		X	X		X	X	X
Rasbora myseri Brittan, 1954	CYP	156	0.49	1.84	15-83	INV	?						X				
Esomus metallicus Ahl, 1923	CYP	149	0.46	9.19	18-58	INV	N		X	X		X			X	X	X
Mystus singaringan (Bleeker, 1846)	BAG	145	0.45	6.99	120-178	PIS	Y			X		X	X		X	X	X
Cyclocheilichthys repasson (Bleeker, 1853)	BAG	133	0.41	1.84	50-119	HER	Y						X		X		
Oreochromis niloticus (Linnaeus, 1758) (e)	CIC	129	0.40	9.93	27-256	HER	N			X			X		X	X	X
Crossocheilus reticulatus (Fowler, 1934)	CYP	123	0.38	2.21	29-130	HER	Y						X				
Yasuhikotakia modesta (Bleeker, 1864)	COB	122	0.38	5.15	45-56	INV	Y						X		X	X	X
Puntius brevis (Bleeker, 1850)	CYP	108	0.34	9.93	26-195	INV	Y		X	X		X	X	X		X	X
Pangasius pleurotaenia Sauvage, 1878	PAN	106	0.33	2.21	61-223	HER	Y						X			X	X
Schistura bucculentus (Smith, 1945)	BAL	106	0.33	2.94	31-77	INV	N		X	X		X					
Monopterus albus (Zuiew, 1793)	SYN	105	0.33	9.93	167-620	INV	?		X	X	X	X	X		X	X	X
Rasbora dusonensis (Bleeker, 1851)	CYP	105	0.33	2.94	31-101	INV	?						X		X	X	X
Schistura magnifluvis Kottelat, 1990	BAL	103	0.32	2.21	22-53	INV	N		X					X			
Lobocheilos quadrilineatus (Fowler, 1935)	CYP	101	0.31	0.74	60-135	HER	Y					X					
Channa striata (Bloch, 1793)	CHA	97	0.30	15.44	13-2880	PIS	N		X	X		X	X		X	X	X
Trichopsis vittata (Cuvier, 1831)	OSP	95	0.30	6.25	650-712	INV	N		X	X			X		X	X	X
Homaloptera zollingeri Bleeker, 1853	BAL	95	0.30	6.25	27-54	INV	N		X	X		X	X				
Macrognathus siamensis (Günther, 1861)	MAS	90	0.28	5.15	105-162	INV	?			X		X			X	X	X
Osteochilus hasseltii (Valenciennes, 1842)	CYP	90	0.28	6.25	35-246	HER	Y			X		X	X		X	X	X
Sikukia stejnegeri Smith, 1931	CYP	90	0.28	3.31	38-64	INV	Y			X							
Garra fuliginosa Fowler, 1934	CYP	89	0.28	3.31	82-160	HER	Y		X	X		X	X		X		
Dermogenys pusilla Kuhl & van Hasselt, 1823	HEM	85	0.26	7.72	18-67	INV	?			X		X	X		X	X	X
Homaloptera leonardi Hora, 1941	BAL	85	0.26	6.99	40-102	INV	N		X	X		X		X			
Balitora brucei Gray, 1830	BAL	84	0.26	4.04	32-80	INV	N		X	X		X					
Rhinogobius chiengmaiensis Fowler, 1934 (d)	GOB	83	0.26	2.57	13-163	INV	N		X	X			X				
Xenentodon cancila (Hamilton, 1822)	BEL	83	0.26	8.09	32-40	INV	?			X			X		X	X	X
Syncrossus helodes (Sauvage, 1876)	COB	78	0.24	5.88	56-91	INV	Y					X	X		X	X	X
Lepidocephalichthys hasselti (Valenciennes, 1846)	COB	77	0.24	9.19	17-93	INV	N		X	X				X			
Lepidocephalichthys berdmorei (Blyth, 1860)	COB	75	0.23	4.41	39-40	INV	N		X	X					X	X	X
Schistura mahnerti Kottelat, 1990	BAL	73	0.23	5.15	25-105	INV	N	X	X	X							
Labiobarbus leptocheila (Valenciennes, 1842)	CYP	70	0.22	4.41	82-182	HER	Y			X		X	X		X	X	X
Anabas testudineus (Bloch, 1795)	ANA	68	0.21	9.56	59-127	PIS	Y		X	X		X	X		X	X	X
Pseudomystus siamensis (Regan, 1913)	BAG	67	0.21	4.41	32-168	PIS	Y			X			X		X	X	X
Schistura pridii Vidthayanon, 2003 (d)	BAL	67	0.21	5.88	23-43	INV	N		X			X					
Cyclocheilichthys apogon (Valenciennes, 1842)	CYP	65	0.20	2.21	80-195	HER	Y						X			X	X
Kryptopterus cryptopterus (Bleeker, 1851)	SIL	64	0.20	3.68	124-173	PIS	Y					X	X			X	X
Glyptothorax lampris Fowler, 1934	SIS	58	0.18	6.62	31-77	PIS	?		X	X		X					
Raiamas guttatus (Day, 1870)	CYP	58	0.18	6.62	50-108	PIS	Y			X			X	X	X	X	X
Glyptothorax trilineatus Blyth, 1860	SIS	57	0.18	8.82	67-168	PIS	?	X	X	X		X		X			

Table 2 (cont.) Species composition of fish in the Ping-Wang River Basin and their occurrence in each sub-basin

Species	Family	N	%RA	%OF	TL (mm)	Guilds	M	Sub-basins									
								UP	MT	SP	MK	MC	ME	TP	WA	FP	LP
Neolissochilus stracheyi (Day, 1871)	CYP	56	0.17	5.88	31-252	HER	Y		X	X		X	X		X		
Rasbora atridorsalis Kottelat & Chu, 1987	CYP	55	0.17	1.47	20-55	INV	?								X		
Barbonymus altus (Günther, 1868)	CYP	54	0.17	6.25	67-145	HER	Y			X		X	X	X	X	X	X
Phalacronotus bleekeri (Günther, 1864)	SIL	54	0.17	4.04	115-410	PIS	Y					X	X		X	X	X
Paralaubuca typus Bleeker, 1865	CYP	50	0.16	4.78	67-221	INV	Y					X	X			X	X
Hypsibarbus wetmorei (Smith, 1931)	CYP	49	0.15	2.21	98-218	HER	Y			X			X			X	
Osteochilus lini Fowler, 1935	CYP	56	0.17	2.94	65-121	HER	Y			X		X					X
Acanthocobitis botia (Hamilton, 1822)	BAL	46	0.14	2.94	40-68	INV	?							X	X		
Toxotes chatareus (Hamilton, 1822)	TOX	45	0.14	3.31	98-165	INV	N					X	X			X	
Cirrhinus cirrhosus (Bloch, 1795) (e)	CYP	44	0.14	2.94	165-235	HER	Y			X					X	X	X
Tor tambroides (Bleeker, 1854)	CYP	43	0.13	1.10	101-312	HER	Y		X			X					
Pangasianodon hypophthalmus (Sauvage, 1878)	PAN	42	0.13	4.41	390-753	HER	Y			X			X		X	X	X
Pangasius macronema Bleeker, 1851	PAN	42	0.13	2.57	198-251	INV	Y					X	X			X	
Onychostoma gerlachi (Peters, 1881)	CYP	41	0.13	2.21	25-100	HER	Y		X					X			
Clupeoides borneensis Bleeker, 1851	CLU	40	0.12	4.41	31-52	INV	Y	X	X								
Labeo chrysophekadion (Bleeker, 1850)	CYP	37	0.12	5.88	94-705	HER	Y			X		X	X		X	X	
Nemacheilus binotatus Smith, 1933	BAL	37	0.12	3.68	27-42	INV	N			X			X				
Tetraodon leiurus Bleeker, 1851	TET	35	0.11	3.31	87-132	PIS	N			X			X			X	X
Barbonymus schwanenfeldii (Bleeker, 1853)	CYP	34	0.11	2.94	43-215	HER	Y					X	X				
Rasbora daniconius (Hamilton, 1822)	CYP	34	0.11	0.37	40-84	INV	?									X	
Schistura desmotes (Fowler, 1934)	BAL	34	0.11	1.47	20-49	INV	N							X			
Brachirus siamensis (Sauvage, 1878)	SOL	31	0.10	3.68	98-122	INV	?								X	X	X
Puntius partipentazona (Fowler, 1934)	CYP	26	0.08	2.21	20-61	INV	?			X			X		X		X
Hemibagrus wyckii (Bleeker, 1858)	BAG	25	0.08	3.68	154-320	PIS	Y						X			X	X
Osphronemus goramy Lacepède, 1801	OSP	25	0.08	4.04	97-365	HER	N			X			X			X	X
Pangio anguillaris (Vaillant, 1902)	COB	25	0.08	2.21	36-37	INV	?		X	X							X
Clarias batrachus (Linnaeus, 1758)	CLA	24	0.07	4.41	90-132	PIS	Y		X	X		X	X		X	X	X
Oreochromis hybrid (e)	CIC	24	0.07	2.21	40-144	HER	N			X							X
Mastacembelus cf. tinwini Britz, 2007	MAS	24	0.07	4.78	55-375	INV	?		X	X		X					
Osteochilus melanopleurus (Bleeker, 1852)	CYP	23	0.07	2.21	189-275	HER	Y						X			X	X
Osteochilus microcephalus (Valenciennes, 1842)	CYP	23	0.07	1.84	82-93	HER	Y						X			X	X
Yasuhikotakia morleti (Tirant, 1885)	COB	23	0.07	2.57	37-170	INV	Y			X			X				X
Devario aequipinnata (McClelland, 1839)	CYP	21	0.07	1.47	22-66	INV	?							X			
Acantopsis thiemmedhi Sontirat, 1999	COB	20	0.06	2.57	145-183	INV	?			X					X		
Rasbora borapetensis Smith, 1934	CYP	20	0.06	1.10	32-108	INV	?								X		X
Paralaubuca harmandi Sauvage, 1883	CYP	20	0.06	1.47	102-134	INV	Y									X	X
Acanthocobitis zonalternans (Blyth, 1860)	COB	19	0.06	0.37	20-78	INV	?							X			
Micronema hexapterus (Bleeker, 1851)	SIL	19	0.06	1.84	121-235	PIS	Y						X				X
Osteochilus waandersii (Bleeker, 1852)	CYP	19	0.06	1.84	75-89	HER	Y					X				X	X
Channa micropeltes (Cuvier, 1831)	CHA	18	0.06	2.21	390-475	PIS	Y			X					X	X	X
Chitala ornata (Gray, 1831)	NOT	18	0.06	3.31	305-415	PIS	Y						X		X	X	X

Table 2 (cont.) Species composition of fish in the Ping-Wang River Basin and their occurrence in each sub-basin

Species	Family	N	%RA	%OF	TL (mm)	Guilds	M	Sub-basins									
								UP	MT	SP	MK	MC	ME	TP	WA	FP	LP
Clarias hybrid (*C. macrocephalus* X *C. gariepinus*) (e)	CLA	18	0.06	2.94	154-200	PIS	Y			X						X	X
Danio albolineatus (Blyth, 1860)	CYP	18	0.06	1.84	21-48	INV	?			X				X			
Devario malabaricus (Jerdon, 1849)	CYP	18	0.06	1.47	59-73	INV	Y								X		
Mystus albolineatus Roberts, 1994	BAG	18	0.06	1.10	129-143	PIS	Y									X	X
Syncrossus beauforti (Smith, 1931)	COB	17	0.05	2.21	128-200	INV	Y			X			X				
Luciosoma bleekeri Steindachner, 1878	CYP	16	0.05	1.10	125-158	INV	Y		X								
Ompok bimaculatus (Bloch, 1794)	SIL	16	0.05	2.21	78-147	PIS	?								X	X	X
Poropuntius bantamensis (Rendahl, 1920)	CYP	16	0.05	0.74	97-179	HER	Y								X		
Acanthopsoides delphax Siebert, 1991	COB	15	0.05	2.21	32-45	INV	?		X	X			X				
Mystus multiradiatus Roberts, 1992	BAG	15	0.05	1.10	126-139	PIS	Y										X
Barbichthys laevis (Valenciennes, 1842)	CYP	14	0.04	0.74	86-155	HER	Y										X
Clarias macrocephalus Günther, 1864	CLA	14	0.04	2.57	64-277	PIS	Y			X			X			X	X
Kryptopterus cheveyi Durand, 1940	SIL	14	0.04	1.10	133-167	PIS	Y									X	X
Parambassis wolffii (Bleeker, 1851)	AMB	14	0.04	1.84	46-53	INV	Y									X	X
Labeo rohita (Hamilton, 1822) (e)	CYP	14	0.04	2.94	396-537	HER	Y			X			X		X	X	X
Trichogaster pectoralis (Regan, 1910)	OSP	13	0.04	1.47	26-105	INV	N						X			X	X
Mystacoleucus greenwayi Pellegrin & Fang, 1940	CYP	12	0.04	1.47	35-48	INV	Y			X							X
Sikukia gudgeri (Smith, 1934)	CYP	12	0.04	1.10	36-98	INV	Y								X		X
Wallago attu (Bloch & Schneider, 1801)	SIL	11	0.03	3.31	320-430	PIS	Y					X	X			X	X
Belodontichthys truncatus Kottelat & Ng, 1999	SIL	10	0.03	1.47	350-423	PIS	Y									X	X
Cyclocheilichthys enoplos (Bleeker, 1851)	CYP	9	0.03	2.21	231-435	HER	Y		X				X			X	X
Leptobarbus hoevenii (Bleeker, 1851)	CYP	9	0.03	1.10	257-463	HER	Y										X
Pangasius larnaudii Bocourt, 1866	PAN	9	0.03	1.84	541-563	HER	Y						X			X	X
Amblyrhynchichthys truncatus (Bleeker, 1851)	CYP	8	0.02	0.74	79-162	HER	Y						X				
Bagarius bagarius (Hamilton, 1822)	SIS	8	0.02	1.10	198-465	PIS	Y						X			X	X
Bagrichthys macracanthus (Bleeker, 1854)	BAG	8	0.02	0.37	176-211	PIS	Y										X
Cyprinus carpio Linnaeus, 1758 (e)	CYP	8	0.02	2.21	321-389	HER	Y			X					X	X	X
Himantura signifer Compagno & Roberts, 1982 (b)	DAS	8	0.02	1.47	398-410	INV	Y										X
Hypophthalmichthys molitrix (Valenciennes, 1844) (e)	CYP	8	0.02	1.47	450-752	HER	Y									X	X
Glyptothorax fuscus Fowler, 1934	SIS	7	0.02	0.74	46-75	PIS	?					X					
Mastacembelus favus Hora, 1924	MAS	7	0.02	1.10	75-126	INV	?										X
Barbichthys nitidus Sauvage, 1878	CYP	6	0.02	0.74	157-185	HER	Y										X
Cosmochilus harmandi Sauvage, 1878	CYP	6	0.02	0.74	312-323	HER	Y										X
Cynoglossus microlepis (Bleeker, 1851)	CYN	6	0.02	0.37	154-213	INV	?										X
Hemibagrus wyckioides (Fang & Chaux, 1949)	BAG	6	0.02	1.10	220-435	PIS	Y										X
Phalacronotus apogon (Bleeker, 1851)	SIL	6	0.02	0.74	278-432	PIS	Y										X
Acanthopsoides gracilentus (Smith, 1945)	COB	5	0.02	0.37	59-77	INV	?		X								
Bagrichthys macropterus (Bleeker, 1853)	BAG	5	0.02	0.37	154-187	PIS	Y										X
Channa lucius (Cuvier, 1831)	CHA	5	0.02	1.47	210-315	PIS	Y						X			X	X
Pterygoplichthys disjunctivus (Weber, 1991) (e)	LOR	5	0.02	1.84	87-206	HER	?			X					X		

Table 2 (cont.) Species composition of fish in the Ping-Wang River Basin and their occurrence in each sub-basin

Species	Family	N	%RA	%OF	TL (mm)	Guilds	M	Sub-basins UP	MT	SP	MK	MC	ME	TP	WA	FP	LP
Trichogaster microlepis (Günther, 1861)	OSP	5	0.02	0.37	32-34	INV	N						X				
Boesemania microlepis (Bleeker, 1858)	SCI	4	0.01	0.74	254-302	PIS	Y										X
Clarias gariepinus (Burchell, 1822) (e)	CLA	4	0.01	1.10	210-271	PIS	Y									X	X
Cynoglossus feldmanni (Bleeker, 1853)	CYN	4	0.01	0.74	65-97	INV	?										X
Hypsibarbus vernayi (Norman, 1925)	CYP	4	0.01	1.10	33-66	HER	Y			X					X		
Puntius leiacanthus Bleeker, 1860	CYP	4	0.01	0.74	23-64	INV	Y			X							
*Schistura vinciguerrae (*Hora, 1935)	BAL	4	0.01	0.37	15-91	INV	N			X							
Tuberoschistura baenzigeri (Kottelat, 1983)	BAL	4	0.01	0.74	21-24	INV	N			X							
Amblyceps foratum Ng & Kottelat, 2000	AML	3	0.01	0.74	90-93	INV	N			X							
Amblyceps mucronatum Ng & Kottelat, 2000	AML	3	0.01	0.74	45-102	INV	N		X	X							
Bagarius yarrelli (Sykes, 1839)	SIS	3	0.01	1.10	87-260	PIS	Y					X					X
Gyrinocheilus aymonieri Tirant, 1883	GYR	3	0.01	1.10	136-173	HER	Y			X			X		X		
Pangasianodon gigas Chevey, 1931 (c, e)	PAN	3	0.01	1.10	1550-1774	HER	Y			X							X
Pangasius conchophilus Roberts & Vidthayanon, 1991	PAN	3	0.01	0.37	675-634	INV	Y										X
Xiphophorus helleri Heckel, 1848 (e)	PEO	3	0.01	1.10	60-190	INV	N				X						
*Bangana sinkleri (*Fowler, 1934)	CYP	2	0.01	0.74	71-192	INV	Y		X								
Brachirus aenea (Smith, 1931)	SOL	2	0.01	0.37	120-143	INV	?						X				
Betta splendens Regan, 1910	OSP	3	0.01	0.37	34-55	INV	N								X		
Cirrhinus molitorella (Valenciennes, 1844)	CYP	2	0.01	0.37	158-287	HER	Y										X
Helicophagus leptorhynchus Ng & Kottelat, 2000	PAN	2	0.01	0.37	305-312	INV	Y										X
Helostoma temminckii Cuvier & Valenciennes, 1831	HEL	2	0.01	0.74	131-147	INV	Y										X
Pangasius bocourti Sauvage, 1880	PAN	2	0.01	0.37	564-632	INV	Y										X
Parachela oxygastroides (Bleeker, 1852)	CYP	2	0.01	0.37	59-120	INV	Y						X				
Albulichthys albuloides (Bleeker, 1855)	CYP	1	<0.01	0.37	124	HER	Y			X							
Brachirus harmandi (Sauvage, 1878)	SOL	1	<0.01	0.37	120	INV	?										X
Crossocheilus cobitis (Bleeker, 1853)	CYP	1	<0.01	0.37	90	HER	Y							X			
Ctenopharyngodon idellus (Valenciennes, 1844) (e)	CYP	1	<0.01	0.37	364	HER	Y										X
Himantura chaphraya Monkolprasit & Roberts, 1990 (a)	DAS	1	<0.01	0.37	681	INV	Y										X
Hypophthalmichthys nobilis (Richardson, 1845) (e)	CYP	1	<0.01	0.37	480	HER	Y										X
Labiobarbus siamensis (Sauvage, 1881)	CYP	1	<0.01	0.37	98	HER	Y						X				
Lates calcarifer (Bloch, 1790) (e)	CEN	1	<0.01	0.37	458	PIS	Y								X		
Lobocheilos melanotaenia (Fowler, 1935)	CYP	1	<0.01	0.37	76	HER	Y								X		
Pangasius sanitwongsei Smith, 1931 (c)	PAN	1	<0.01	0.37	1270	HER	Y										X
Poecilia reticularis Peters, 1859 (e)	PEO	1	<0.01	0.37	37	INV	N			X							
Puntius binotatus (Valenciennes, 1842)	CYP	1	<0.01	0.37	25	INV	Y						X				
Rasbora argyrotaenia (Bleeker, 1850)	CYP	1	<0.01	0.37	34	INV	?						X				
Solea ovata Richardson, 1846	SOL	1	<0.01	0.37	87	INV	?								X		
Thynnichthys thynnoides (Bleeker, 1852)	CYP	1	<0.01	0.37	187	HER	Y								X		
Tor douronensis (Valenciennes, 1842)	CYP	1	<0.01	0.37	167	HER	Y						X				
Wallago leerii Bleeker, 1851	SIL	1	<0.01	0.37	565	PIS	Y										X

Note

i. X indicate that the species was found

ii. UCN Red-list (as shown after scientific name): (a) vulnerable species, (b) endangered species and (d) critical endangered species and (e) exotic species

iii. Family: DAS=Dasyatidae; NOT=Notopteridae; CLU=Clupeidae; BAL=Balitoridae, CYP=Cyprinidae, COB=Cobitidae, GYR=Gyrinocheilidae; AML=Amblycipitidae, BAG=Bagridae, CLA=Clariidae, LOR=Loricariidae, SIL=Siluridae, SIS=Sisoridae, PAN=Pangasiidae; HEM=Hemiramphidae, BEL=Belonidae; MAS=Mastacembelidae, SYN-Synbranchidae; POE=Poecillidae; AMB=Ambassidae, ANA=Anabantidae, CHA=Channidae, CEN=Centropomidae, ELE=Eleotridae, GOB=Gobiidae, HEL=Helostomidae, NAN=Nandidae, OSP=Osphronemidae, SCI=Sciaenidae, TOX=Toxotidae; SOL=Soleidae, CYN=Cynoglossidae; TET=Tetraodontidae.

iv. %RA= Percentage of relative abundance; %OF = Percentage of occurrence frequency

v. Guilds: INV= invertivorous, HER = herbivorous, PIS = piscivorous

vi. M=Migratory species (Y = yes, N=no, ? = not clear)

Table 3 Aspects of diversity in fish in the Ping-Wang River Basin.

Aspects	**Sub-basins**										**Summary**
	UP	**MT**	**SP**	**MK**	**MC**	**TP**	**ME**	**WA**	**FP**	**LP**	
Species richness	16	56	100	11	66	30	90	79	78	112	201
Number of individuals	545	5,607	11,953	474	4,425	1,755	2,639	2,541	1,060	1,081	32,080
Diversity index (H’)	2.06	2.82	3.42	1.46	2.93	2.67	3.51	3.40	3.94	4.45	4.02
Species evenness (J’)	0.74	0.70	0.74	0.61	0.70	0.79	0.78	0.78	0.90	0.94	0.62
Endemic species (%)	6.25	5.36	1	9.09	3.03	3.33	1.11	0	0	0	3.03
Vulnerable species (%)	0	1.79	1	0	1.52	3.33	0	0	0	0.89	1.52
Endangered species (%)	0	1.79	1	0	0	0	1.11	0	0	0.89	0.00
Critical endangered species (%)	0	0	1	0	0	0	0	0	0	1.79	0.00
Species Restricted to Ping-Wang River (%)	6.25	5.36	1	9.09	1.52	3.33	1.11	0	0	0	1.52
Species Restricted to Chao Phraya river (%)	0.45	1.80	0.45	0.45	0.90	0.45	0.45	0.00	0.00	0.00	0.90
Exotic species (%)	0	1.79	10.0	9.09	1.52	3.33	2.22	7.60	8.97	9.82	5.08

most diverse with 14 species, followed by *Rasbora* (Cyprinidae), *Pangasius* (Pangasiidae) and *Puntius* (Cyprinidae) with 7, 6, and 6 species, respectively. The number of genera and number of species ratio was found to be 1: 1.93.

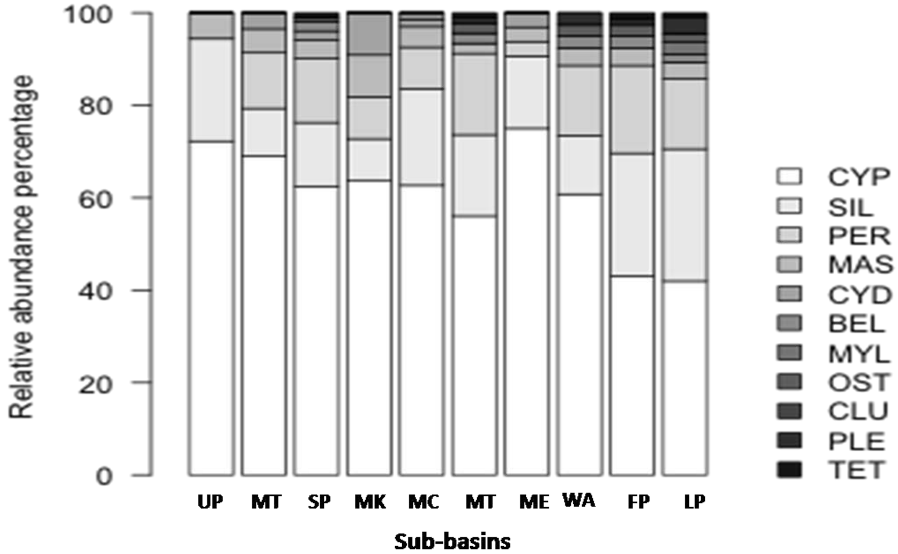

Figure 2. Relative abundances of major taxonomic groups in each sub-basins of the Ping-Wang River Basin.

Results of %RA and %OF showed that only a few species had values beyond 4 % and 10 %, respectively, which implied a typical left skew of species abundance. The five most abundant species accounted for 32.4 %RA of total fish collected. The highest %OF was found in *Channa gachua* (47.1 %) and only 8 species showed %OF higher than 20 % (Table 2), in which 6 of them belong to the family Cyprinidae, i.e. *Garra cambodgiensis*, *Mystacoleucus marginatus*, *Barilius pulchellus*, *Rasbora paviana*, *Puntius stoliczkanus* and *Puntius orphoides* and the other fish was *Schistura breviceps* (Balitoridae). The species that were high in number (≥ 200 individuals) but low %OF (≤ 6 %) implied the restricted distribution. These fishes were two cyprinids *Paralaubuca riveroi* and *Devario maetangensis* and three balitorids *Schistura obeini, Schistura menanensis* and *Schistura sexcauda*. On the other hand, *Channa striata* and *Anabas testudineus* showed a wide distribution (%OF ≥ 10 %), though the samples of each species were less than 100. *Pangasianodon gigas*, from the samples, was expected from stocking, whereas *Lates calcarifer* and *Clarias* hybrid were the escapees from culture practices.

Large sub-basins showed high *H’*, i.e. L (4.5), F (3.9) and P (3.5) and the abundance of individual species were in similar proportions, i.e. *J’* > 0.75 (Table 3). Although lower in *H’* in the upper sub-basins (i.e. U, T and K), these sub-basins were characterized by the endemic species and the rate of species that are restricted to the Basin was up to 10 % (Table 3). These endemic species were *D. maetangensis*, *Schistura pridii*, *Oreoglanis siamensis*, and *Rhinogobius chiengmaiensis*. Five IUCN fish species were also collected, i.e. *O. siamensis*, *Himantura signifier*, *H. Chao Phraya*, *P. gigas* and *Pangasius sanitwongsei*. Sixteen exotic species were found in all sub-basins, except the upper reach of the Ping River (UP). Among them, *Gambusia affinis* was the highest %OF at 17.3 % (Table 2) followed by *Oreochromis niloticus* (≈ 9 %OF).

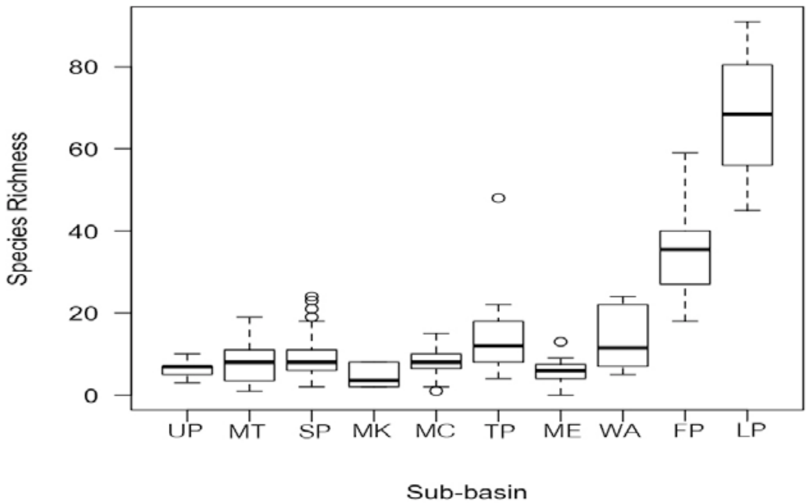

Figure 3. Species richness in each sub-basins of the Ping-Wang river basin.

Species richness gradually increased from the upper part (UP) to the lowland area (LP: Fig. 3) and were significantly different (Kruskal-Wallis test; $P < 0.001$). Results of hierarchical clustering showed that each sub-basin had its own characteristic of fish species composition (Fig. 4). The lowland sub-basins (FP and LP) were the least similar to those sub-basins in the upper part of the Basin. Meanwhile within the upper part, the most upstream sub-basins (UP and WA) were

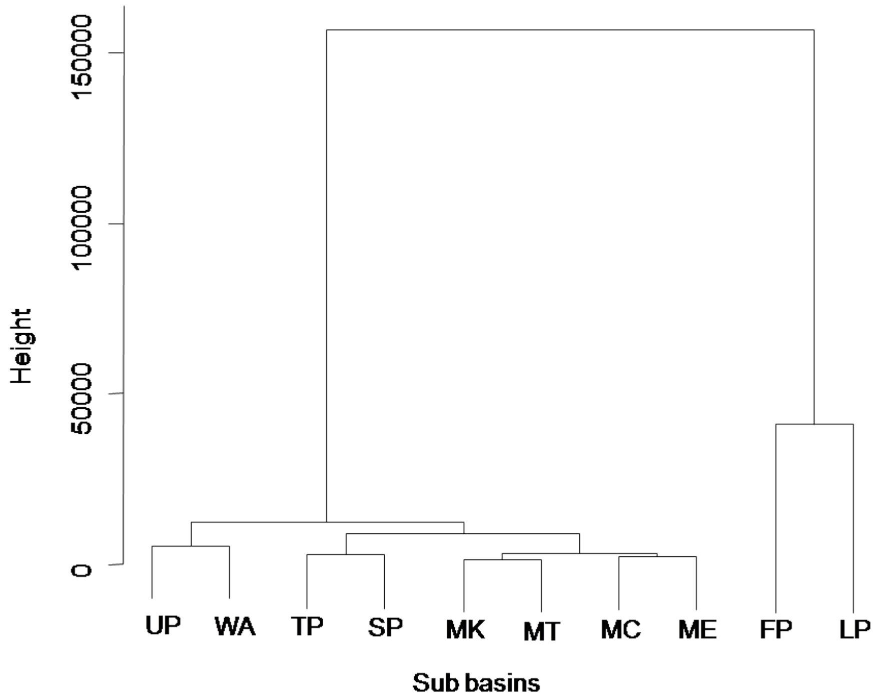

Figure 4. Dendrogram of the cluster analysis results corresponding to the sub-basins of the Ping-Wang river basin.

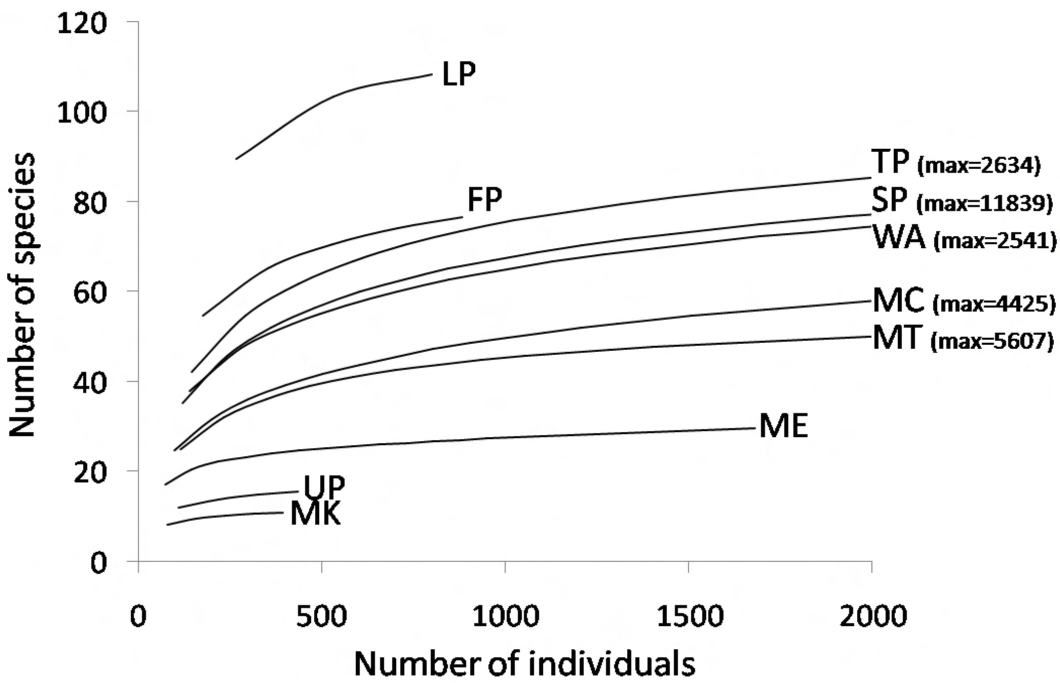

Figure 5. Rarefaction curves plot by sub-basins for the species richness of the Ping-Wang river basin.

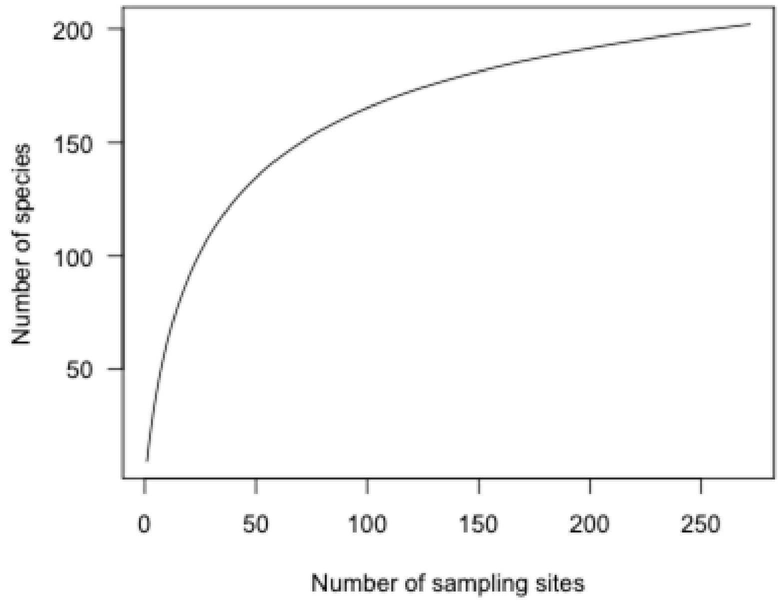

Figure 6. Rarefaction curves plot by number of species with number of sampling sites Ping-Wang river basin.

most similar. Numbers of expected species within the Basin was justified by the rarefaction curve because of the differences in numbers and kinds of habitats in each sub-basin. All the ten rarefaction curves for the sub-basins (Fig. 5) showed signs of reaching asymptotic levels. Adequacy of sampling was assessed also by the rarefaction curve and the asymptote was reach at about 250 (Fig. 6), confirming that the number of sampling sites in this study (272) was satisfactory.

DISCUSSIONS

The Ping-Wang river basin contained 201 fish species and the rarefaction curves showed that it was close to the maximum number of species occurring in the Basin. All the rarefaction curves reached asymptote implies that the species, which found in this study, covered almost all, if not all, taxonomically described species in the Basin. Thus, it is shown that the Chao Phrya River system is very high in fish species richness. Even in the upper part of the basin, as observed in this study, the accumulated species number was higher than most of the river basins in South, East and Southeast Asia, except the Mekong (1,200 species), the Yangtze (China, 320 species), the Cauvery river (India and Nepal, 265 species) and the Kapus (Indonesia, 250 species) (Nguyen & De Silva, 2006).

Dominance by fish in family Cyprinidae is common in the Asian freshwater bodies (Kottelat & Whitten, 1996), where they may contribute 40% or more of the species in a watershed (Taki 1978; Beamish et al., 2006). They have evolved partially through highly adapted body forms and mouth structures so that they occupy virtually all habitats throughout their distribution (Ward-Campbell et al., 2005; Beamish et al., 2006), but prevalence of the rhithronic species such as *O. siamensis*, *Exostoma vinciguerrae*, *Schistura* spp. and *Homaloptera* spp. (Vidthayanon, 2003; Vidthayanon et al., 2009; Hu & Zhang, 2010) is an exclusive characteristic of the mountainous area of Upper Chao Phraya River Basin. This is also included the 3 species of the sisorid species (Ng, 2010) *viz.*, *Glyptothorax lampris*, *G. trilineatus* and *G. fuscus*.

The species richness increased from the upper (UP) to the lower part (LP) of the basin. Low species richness in the high altitude reflects the low variability of food supplies because of the fast turnover time of available food from the terrestrial inputs (Tongnunui & Beamish, 2009). Also the findings showed that the species richness was related to sub-basin size, i.e. the larger the sub-basin, the higher the species richness. However, on a large scale, Nguyen & De Silva (2006) reported that species richness did not necessarily correlate to river basin size since rivers with small basins show high diversity. The *H'* index generally lies between 1.5 and 3.5 (Magurran, 2004), and the high value of 4.5 in the lower Ping river (LP) was because of the richness of nutrients, which increased natural food sources, as well as flood pulse effect in the lowland (Junk & Wantzen, 2004), which all supported high populations. Moreover, deep water, wider rivers and more discharges downstream are factors to increase diversity parameters (Horwitz, 1978).

Altitude and distance from the sea are found to be among of the most key factors that govern the species richness and fish community structures in riverine ecosystem (Oberdorff et al., 1995). The sub-basins, at an altitude > 250 m, were grouped together and regarded as rhithronic community (Welcomme et al., 2006). Residents in this area are always generally small in size and equipped with suckers or adhesive apparatuses (Bhatt & Pande, 1991), and may also have streamlined or flattened forms such as *G. cambodgiensis*, *O. siamensis* and *Schistura* spp., which were the dominated in this study and none of them were found in the lowland sub-basins (i.e. FP and LP).

Although only 5- ICUN fish species have been found so far in the Ping-Wang river basin, the uniqueness of the area, characterized by high mountains, and a high rate of endemism of fish should be of concern. There are also numbers of rhithronic species in this basin, and at least 3 species have not yet been taxonomically classified (A. Suvarnarhaksha, *personal collection*), in which the new taxonomically described, *Schistura pridii* was also from this basin (Vidthayanon, 2003). The threats for fish in the basin are becoming higher. As a consequent of urbanization in the lowland area, polluted water could be expected, and this could be harmful to many fish, even the generalist such as most of cyprinids, which are ubiquitous in the area. Deforestation for horticultures, i.e. cabbage, corn, and tomato, in the upper basin and indiscriminate fish collection for aquarium fish are among other major threats for the rhithronic habitants. Both issues not only affect the fish population *per se* but also the ecosystem, such as erosion from agricultural fields and habitat destruction by searching for aquarium target species. Although most of the rhithronic species have medium to high resilience and their minimum population doubling times are on average at 2 years (Froese & Pauly 2010), this would not be possible if their habitats were altered. Moreover, since most of the rhithronic members are mostly insectivorous (Tongnunui & Beamish, 2009), habitat degradation in the rhitral area, could lead to a decline in exogenous food sources including insects as well as their larvae (Raghavan et al., 2008).

Most of exotic species found in this basin were introduced for food enhancement purposes such as Nile tilapia, Chinese and Indian major carps and no impacts are reported so far. The presence of the Poeciliid fish as *G. affinis*, *Xiphophorus helleri* and *Poecilia reticulata* in the upstream part must be of concern since they prey on many aquatic larvae and often with devastating consequences (Mills *et al*., 2004; Vitule *et al.*, 2009), not only to fish but also to amphibians, which have high endemism in the area (Bickford *et al.*, 2010). Escapees from aquaculture, such as *Clarias gariepinus* and hybrid walking catfishes, were found in the studied area and should also be of concern. Senanan *et al.* (2004) observed the introgression of *C. gariepinus* genes into native catfish, *C. macrocephalus* in wild populations caused by the release/escape of hybrid catfish (*C. macrocephalus* x *C. gariepinus*). Na-Nakorn *et al.* (2004) mentioned that *C. macrocephalus* and *C. batrachus* in the wild may be directly replaced with the hybrid catfish, which have a higher growth rate.

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P2

Life history of the riverine cyprinid *Henicorhynchus siamensis* (Sauvage, 1881) in a small reservoir

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Life history of the riverine cyprinid *Henicorhynchus siamensis* (Sauvage, 1881) in a small reservoir

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Summary

The riverine species, *Henicorhynchus siamensis* (Sauvage 1881), is an important source of protein and an economical fish for the rural population of inland Indochina. Investigated in the present study were the reproductive feeding aspects and growth of *H. siamensis* living in a lake system. The gonadosomatic index peaked in August, which was delayed compared to river fish, and individuals took 1.5 years to attain the length of 50% maturity (about 200 mm). Stomach contents were dominated by phytoplankton and showed considerable seasonal variation. Asymptotic length of *H. siamensis* was 264.2 mm, with a 0.75 year^{-1} growth coefficient and slower growth during the winter. The role of the flood pulse as a major influence on the life history of the fish is also discussed.

Introduction

Fish of the genus *Henicorhynchus* are small migratory cyprinids and one of the most important groups in the Lower Mekong Basin and Chaophraya River basin fisheries, especially the Siamese mud carp *Henicorhynchus siamensis* (Sauvage, 1881). This fish is a common catch whereby in the basin area four sub-populations were recently identified (Adamson et al., 2009). *H. siamensis* is also the main fish catch produced by the commercial bag-net fisheries in Tonle Sap, Cambodia, where it constitutes more than 60% of the catch and accounts for almost 10% of the total value generated (Deap et al., 1998). Moreover, *H. siamensis* is ranked as the top species commonly consumed by Cambodians. These advantages play a crucial role as the most important animal food for the poor (Kent, 1997) and also fulfill a role as a dietary source of vitamins and minerals (Roos et al., 2007). The importance of this fish is also acknowledged in the Cambodian currency, the '*riel*', which is named after the Cambodian common name for *H. siamensis* of '*trey riel*' (Volbo-Jørgensen and Poulsen, 2000).

H. siamensis is known as an *r*-strategist with a medium to high resilience, whereby the minimum population doubling time is between 1.4 and 4.4 years (Froese and Pauly, 2009). *H. siamensis* is also well known for its migratory habit of lateral migration into the floodplains during the flood season and then returning to the rivers when the flood waters begin to recede (Rainboth, 1996). But it is also known not to prosper in impoundments (Lamberts, 2001; Chheng et al., 2004), as its life cycle depends on the river/flood regime. However, *H. siamensis* can successfully inhabit man-made lakes in Thailand as well as in the Lao PDR, and is among the candidates for a fish stock enhancement program to increase fish production in inland water bodies in the region (Jutagate, 2009).

Knowledge of the life cycles of many important Southeast Asia freshwater fish species is still very fragmentary, especially when they inhabit an uncommon environment (Volbo-Jørgensen and Poulsen, 2000). Given the importance of *H. siamensis* to fisheries in many parts of major Southeast Asian rivers, this study aimed to investigate the key facets of the *H. siamensis* life history (Froese et al., 2000), i.e. reproduction, feeding and growth. A goal was to see whether this small cyprinid could flourish and support a small-scale artisanal fishery in a reservoir and to evaluate its potential as a source of protein and micronutrients as well as income for the local people in the vicinity of the reservoir.

Materials and methods

Description of study area

The Mae-ngad Dam is located in Chiangmai Province, Northern Thailand (19°15.18N, 099°03.35E to 19°15.25N, 099°17.43E). It was dammed across a first order stream, the Mae-ngad, for multiple purposes such as hydroelectric power and irrigation. Its elevation ranges from 412 to 425 m ASL with a catchment area of 1309 km^2 and a water surface of 16 km^2. The mean water depth of the reservoir area is 30 m with a mixed clay and silt bottom. It is also noteworthy to mention that the *H. siamensis* in this study originated in the wild, since there has been no stocking of *H. siamensis* in this reservoir.

Fish sampling and on-site measurements

Data was obtained from twelve fishermen using gill nets as fishing gear in the lake. The gill net assemblies were composed of five 30-m^2 nets (10 m long × 3 m deep) with stretched mesh sizes of 10–30 mm. The nets were surface-set at twelve sites, which were equally distributed over the coastal area of the reservoir, and using one gill net assembly per sampling site. All nets were set overnight between 16.00 and 18.00 hours and lifted between 06.00 and 08.00 hours. At least 120 *H. siamensis* were randomly sampled monthly from July 2003 to June 2004 (1364 fish in total). Individuals were measured for total length (L, to the nearest 1 mm) and weighed (W, to the nearest 0.1 g). Data were used to establish the length–weight relationship $W = aL^b$, where a and b are specific constant values. The size of each individual was classified for length frequency distribution

(LFD) and the distributions determined at 1.0 cm length intervals. After measurement, the specimens were preserved in 10% formalin and taken to the laboratory for detailed analysis.

Reproductive aspects

Twenty-five mature gonads (i.e. 10 testes and 15 ovaries) per month were used for histological studies. They were fixed in 10% formalin / acetic acid / calcium chloride (FAACC) for 1 month before being embedded in paraffin and stained with haematoxylin-eosin. The samples were then cut into sections (7 μm) and observed under a light microscope. Ovary (n = 553) maturity was graded into five stages, I–V (Bagenal and Braum, 1978), where fish showing stage III and higher were considered to be mature. The gonads of the specimens were weighed (GW, to the nearest 0.1 g) to calculate the Gonadosomatic index: $GSI = 100 \times GW / W$. Eggs were counted gravimetrically (Bagenal and Braum, 1978). For each sex, ten fish per length class were collected during the peak GSI period to investigate the mature fish percentages, P, at each length interval (Chen and Paloheimo, 1994).

$$P = \frac{1}{1 + e^{(a - bL)}} \quad (1)$$

where a and b are constants and when calculated, the percentage at 50% maturity was replaced in the equation (1) to obtain the length at 50% maturity.

Stomach contents

Stomachs were examined individually, dissected, opened longitudinally, and the digestive tracts fixed in 10% formalin. The stomach contents were squeezed out and diluted to 1 ml. The suspended matter was then placed in a Sedgewick rafter counting cell and examined under light microscopy. Food items were identified to the lowest possible taxonomic unit. For diet analyses the percentage of frequency of occurrence ($O\%$), number (N%) and index of relative importance (IRI%) (Hyslop, 1980) were calculated for each dietary item (i) and used in dietary comparisons.

$$\mathrm{IRI}_i = \mathrm{N}\% \times O\% \quad (2)$$

and

$$\mathrm{IRI}\% = \left(\frac{\mathrm{IRI}_i}{\sum_{i=1}^{n} \mathrm{IRI}_i}\right) \times 100 \quad (3)$$

Dietary components from the stomach contents between seasons were subjected to Factorial Correspondence Analysis (FCA) implemented in R software by using library 'ade4' (R Development Core Team, 2008) to show any significant differences in the seasonal variation and to identify some particular food items.

Growth

Length frequency distribution (LFD) data was used for growth estimation. Fish growth was assumed to follow the von Bertalanffy growth function (VBGF), which was modified by Somers (1988) as:

$$L_t = L_\infty \left[1 - e^{-(K(t-t_0) - CK/2\pi)(\sin 2\pi(t-t_0) - \sin 2\pi(t-t_0))}\right] \quad (4)$$

where L_t is length at time t, L_∞ is the asymptotic length, K is the growth coefficient and t_0 is the theoretical age at length zero. Analyses were carried out using the ELEFAN routine in FiSAT-II software (Gayanilo et al., 2002), which can be applied to both fish and shellfish (Nurul Amin et al., 2008). The steps to be analyzed by reconstructing the LFD from the initial estimates of L_∞ and K have already been described (Amarasinghe and De Silva, 1992). Theoretical age at length zero (t_0) was derived from the equation proposed by Pauly (1979):

$$\log_{10}(-t_0) = -0.392 - 0.275\log_{10} L_\infty - 1.038\log_{10} K \quad (5)$$

Two more parameters were incorporated into the VBGF, when seasonality was taken into account: C, which is between 0 and 1 indicates the magnitude of the seasonal growth pattern; and t_s, the time from birth to the start of growth oscillations, which can be calculated as:

$$t_s = \mathrm{WP} - 0.5 \quad (6)$$

whereWP is the time of the year during which the growth rate is minimal, i.e. winter point (Gayanilo et al., 2002). The best-fitted growth curve was chosen on the basis of non-parametric scoring from the goodness of fit index (i.e. Rn value).

Results

Length–weight relationship

Ranging from 140–290 mm, 1364 samples were used in the analysis. The relationships were derived from unsexed samples since there is no external sexual dimorphism and no clear-cut sex differentiation between females and males. The equation derived was $W = 0.01L^{3.08}$ ($r = 0.82$) and the exponential value of 3.08 indicated that the growth of *H. siamensis* was isometric, i.e. the weight increased proportionally with length (Froese, 2006).

Reproductive aspects

The histology of the gonads (Fig. 1) confirmed that *H. siamensis* has a synchronous ovary (i.e. single spawned). The temporal changes in the gonadosomatic index (GSI) clearly showed a single peak in both sexes, which tended to increase in June, was highest in August (i.e. 18.60 ± 0.81 and 3.15 ± 9.74) for females and males, respectively, then regressed from September (Fig. 2).

The logistic curve, which describes the maturity size, is shown in Fig. 3. The lengths at 50% maturity of female and male *H. siamensis* were 197.6 and 201.6 mm. Fecundity of *H. siamensis* ranged widely from 20 300 to 455 680 eggs, with an average of 105 782 ± 59 930 eggs. Relative fecundity was 1034 ± 116 eggs per g of body weight; the relationship between length and fecundity (F_e) can be described by an empirical power equation: $F_e = 21141L^{3.087}$ ($r = 0.762$, n = 171).

Stomach contents

General composition of the diet was obtained by analyzing contents of 108 *H. siamensis* stomachs from 160 to 274 mm in size; 71 dietary items (67 phytoplankton species, four zooplankton species) and plant material were identified. The *Cyclotella* sp., *Melosira varians* and *Navicula* sp. (IRI% = 21.55, 18.20 and 12.58, respectively) were found to be the main dietary components along with a few zooplankton, e.g. copepods (IRI% = 5.15) (Table 1). Among

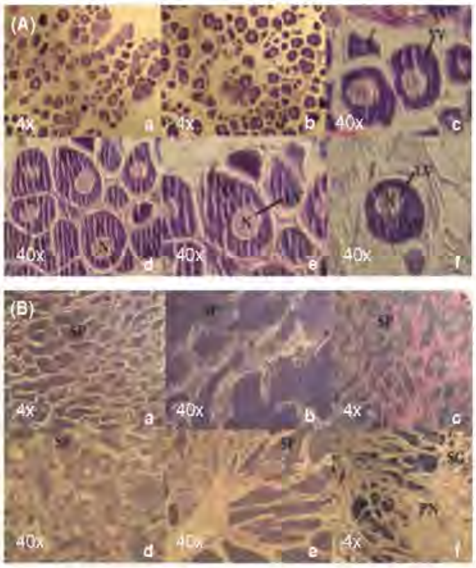

Fig. 1. (A) Histological appearance of ovary maturation, *H. siamensis* (n = 15 individuals per month). (a) Immature ovary; (b) mature or rebuilding ovary; (c) mature ovary; (d) fully mature or ripe ovary; (e) mature ovary; (f) spent ovary: LV, lipid vesicle; N, nucleus; YV, yolk vesicle. (B) Histological appearance of testis maturation, *H. siamensis* (n = 10 individuals per month). (a) Immature testis; (b) mature or rebuilding testis; (c) mature testis; (d) fully mature or ripe testis; (e) mature testis; (f) spent or resting testis: SP, spermatozoa; SG, spermatogonia; PN, pycnotic nets of degenerating cells

the phytoplankton, the Chrysophyta family showed the highest index of relative importance (IRI%) (63.75%) followed by Chlorophyta (12.83%) and Pyrrophyta (7.79%).

The factorial analysis of the temporal variation in the diet based on each month's sampling could be clearly divided into three main groups (Fig. 4). The first group (group I) was during the beginning of the rainy season (June and July), dominated by Chlorophyta e.g. *Crucigenia crucifera* (Cruc), *Crucigenia irregularis* (Crui), *Gloecapsa* sp. (Gloe) and *Kirchneriella lunaris* (Kirl), Cyanophyta, i.e. *Anabaena* sp. (Anab), *Aphanocapsa* sp. (Apha) and *Lyngbya* sp. (Lyng) and Chrysophyta i.e. *Dinobryon* sp. (Dino). Group II was during the winter (December), characterized by few dietary items and low species diversity, dominated by Cryptophyta, i.e. *Chilomonas* sp. (Chil) and *Cryptomonas* sp. (Cryp) and Pyrrophyta i.e.

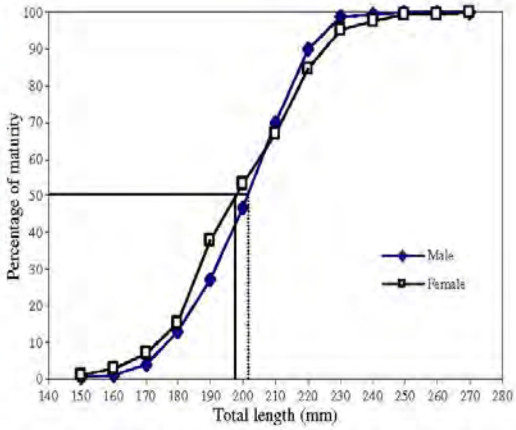

Fig. 3. Length at 50% maturity, female (vertical solid line) and male (vertical dash line) *H. siamensis*, Mae-ngad Reservoir, as indicated by percentage of sample maturing in each length class (10 mm interval)

Peridinium sp. (Peri). The other months were in group III, which was very complex and contained many phytoplankton species but was dominated by *Staurastrum* sp. (Stau), *Cyclotella* sp. (Cycl) *Melosira varians* (Melv) and *Navicula* sp. (Navi) (Fig. 4).

Population dynamics

The growth curve that gave the highest goodness of fit index (Rn = 0.114) was selected. The VBGF was then expressed as

$$L_t = 264.2\left[1 - e^{-(0.75(t-(0.22))-(0.08)/2\pi)(\sin 2\pi(t-0.45)-\sin 2\pi(t_0-0.45))}\right] \quad (7)$$

A clear seasonally oscillating growth pattern implies that the species is sensitive to seasonal variation and that recruitment started in July (Fig. 5). The winter point (*WP*) was 0.95, which signifies that growth slowed during December. The growth performance (Ø) index was 4.72. From the derived growth parameters, *H. siamensis* attains at least 50% of the asymptotic length (L_∞) at about 1.5 years, length at 50% maturity at ca 2 years and approaches L_∞ at about 3.5 years of age. The potential longevity, $3/K$ (Pauly and Munro, 1984), of *H. siamensis* was estimated at 4 years.

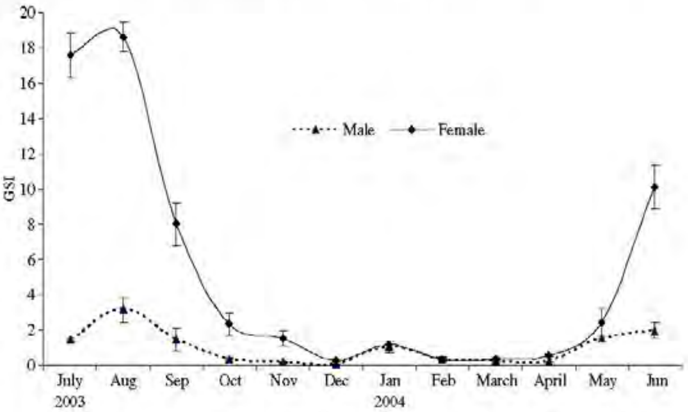

Fig. 2. Seasonal variation in gonado-somatic index (GSI ± SE), *H. siamensis* from Mae-ngad Reservoir, July 2003 – June 2004 presented separately for each sex. Numbers of samples in each month also shown

Table 1
Species, abbreviations (Abb.), total number (N), percentages of frequency of occurrence (*O*%), number (N%) and index of relative importance (IRI%) of dietary items in digestive tract of *H. siamensis* from Mae-ngad Reservoir, July 2003 to June 2004

Food items	Abb.	N	N%	O%	IRI%	Food items	Abb.	N	N%	O%	IRI%
Chlorophyta		4 447 200	18.68	28.67	12.83	Chrysophyta (Cont,)					
Actinastrum sp.	Acti	4825	0.02	0.20	0.00	*Melosira granulata*	Melg	1 117 628	4.69	4.25	5.48
Ankistrodesmus sp.	Anki	151 001	0.63	1.90	0.33	*Melosira varians*	Melv	2 978 703	12.51	5.30	18.20
Arthrodesmus convergens	Arth	4825	0.02	0.20	0.00	*Navicula* sp.	Navi	2 059 789	8.65	5.30	12.58
Closterium sp.	Clos	137 975	0.58	1.77	0.28	*Neidium* sp.	Neid	56 442	0.24	1.24	0.08
Coelastrum sp.	Coel	520 379	2.19	2.75	1.65	*Nephrocytium* sp.	Neph	1966	0.01	0.13	0.00
Cosmarium sp.	Cosm	102 509	0.43	1.31	0.15	*Nitzschia* sp.	Nitz	206 563	0.87	2.75	0.65
Crucigenia sp.	Crus	40 029	0.17	0.52	0.02	*Pinnularia* sp.	Pinn	130 584	0.55	2.09	0.32
Crucigenia crucifera	Cruc	3217	0.01	0.13	0.00	*Pleurosigma* sp.	Pleu	536	0.00	0.07	0.00
Crucigenia irregularis	Crui	1608	0.01	0.07	0.00	*Rhizosolenia* sp.	Rhiz	1608	0.01	0.13	0.00
Crucigenia quadrata	Cruq	61 920	0.26	0.79	0.06	*Rhopalodia* sp.	Rhop	18 379	0.08	0.46	0.01
Crucigenia rectangularis	Crur	28 949	0.12	0.46	0.02	*Surirella* sp.	Suri	74 596	0.31	0.79	0.07
Crucigenia tetrapedia	Crut	4825	0.02	0.13	0.00	*Synedra* sp.	Syne	184 045	0.77	1.64	0.35
Dictyosphaerium sp.	Dict	650 787	2.73	2.55	1.91	Cryptophyta		14 117	0.06	0.26	0.00
Eudorina sp.	Eudo	278 678	1.17	0.92	0.29	*Chilomonas* sp.	Chil	11 973	0.05	0.13	0.00
Elakatothrix sp.	Elak	49 589	0.21	0.72	0.04	*Cryptomonas* sp.	Cryp	2144	0.01	0.13	0.00
Gloecapsa sp.	Gloe	4825	0.02	0.13	0.00	Cyanophyta		2 593 129	10.89	10.73	6.71
Kirchneriella sp.	Kirs	8578	0.04	0.13	0.00	*Anabaena* sp.	Anab	2681	0.01	0.07	0.00
Kirchneriella lunaris	Kirl	3753	0.02	0.20	0.00	*Aphanocapsa* sp.	Apha	97 057	0.41	1.05	0.12
Kirchneriella subsolitaria	Kiru	536	0.00	0.07	0.00	*Cylindospermopsis* sp.	Cyli	5920	0.02	0.07	0.00
Oocystis sp.	Oocy	242 309	1.02	2.23	0.62	*Chroococcus* sp.	Chro	28 771	0.12	0.65	0.02
Pandorina sp.	Pand	139 657	0.57	1.18	0.19	*Lyngbya* sp.	Lyng	1 369 706	5.75	1.96	3.10
Pediastrum sp.	Peds	135 991	0.57	1.05	0.16	*Merismopedia* sp.	Meri	60 712	0.26	0.85	0.06
Pediastrum biradiatum	Pedb	33 073	0.14	0.33	0.01	*Microcystis* sp.	Micr	484 247	2.03	3.34	1.86
Pediastrum duplex	Pedd	332 826	1.40	0.39	0.15	*Osillatoria* sp.	Osil	540 283	2.27	2.49	1.55
Pediastrum simplex	Peds	3217	0.01	0.13	0.00	*Spirogyra* sp.	Spir	3753	0.02	0.26	0.00
Pediastrum tetrastrum	Pedt	4289	0.02	0.07	0.00	Euglenophyta		994 218	4.18	5.69	3.45
Scenedesmus sp.	Sces	187 004	0.79	2.29	0.49	*Euglena* sp.	Eugl	13 939	0.06	0.39	0.01
Scenedesmus bijugavaralternans	Sceb	15 011	0.06	0.52	0.01	*Phacus* sp.	Phac	254 052	1.07	1.83	0.54
Staurastrum sp.	Stau	1 179 756	4.96	4.65	6.32	*Trachelomonas* sp.	Trac	726 228	3.05	3.47	2.90
Tetraedron sp.	Tetr	112 045	0.47	0.79	0.10	Pyrrophyta		2 674 024	11.23	4.91	7.79
Tetrastrum komarekii	Tetk	3217	0.01	0.13	0.00	*Ceratium* sp.	Cera	1 002 464	4.21	2.16	2.49
Chrysophyta		11 541 859	48.48	43.26	63.75	*Peridinium* sp.	Peri	1 671 560	7.02	2.75	5.29
Amphora sp.	Amph	36 629	0.15	0.79	0.03	Other groups		1 541 126	6.47	6.48	5.48
Cyclotella sp.	Cycl	3 485 564	14.64	5.37	21.55	Arthropoda		1 343 561	5.64	5.37	5.36
Cymbella sp.	Cymb	396 071	1.66	3.21	1.46	Copepods	Cope	1 102 014	4.63	4.06	5.15
Dinobryon sp.	Dino	2681	0.01	0.07	0.00	Cladocerans	Clad	184 184	0.77	0.85	0.18
Eunotia sp.	Euno	30 860	0.13	0.72	0.03	*Bosmina* sp.	Bosm	57 363	0.24	0.46	0.03
Fragilaria sp.	Frag	312 063	1.31	4.12	1.48	Rotifera		27 621	0.12	0.59	0.02
Gomphanema sp.	Gomp	310 837	1.31	3.47	1.24	*Keratella* sp.	Kera	27 621	0.12	0.59	0.02
Gyrosigma sp.	Gyro	136 316	0.57	1.37	0.22	Plant material	Plan	169 944	0.71	0.52	0.10

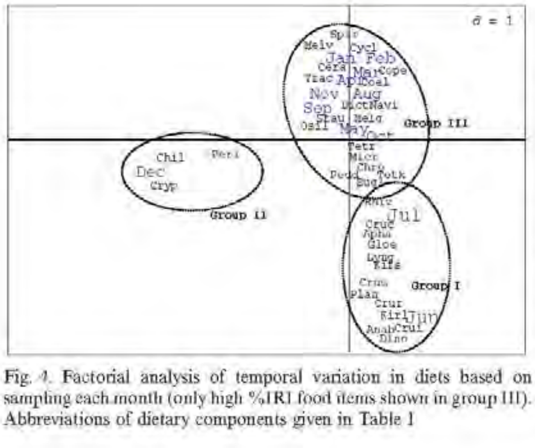

Fig. 4. Factorial analysis of temporal variation in diets based on sampling each month (only high %IRI food items shown in group III). Abbreviations of dietary components given in Table 1

Discussion

Türkmen et al. (2002) showed that fish transferred to a different location, especially from a river to a lake, showed variations in their spawning characteristics. It was also observed that spawning characteristics of fish of the same length and species, but living in locations with different ecological features, had some variations. van Zalinge et al. (2004) reported that *H. siamensis* in the mainstream Mekong mature and reproduce within the first year of life, but that this was longer when they lived in impounded conditions. In the current study, length at 50% maturity of *H. siamensis* (i.e. ca 190 mm) was attained after one and a half years, while length at 50% maturity in a large reservoir was about 160 mm, which is also greater than its first year length of around 145 mm (Moreau et al., 2008).

Most riverine cyprinids spawn during the early part of the rainy season (De Silva, 1983), although *H. siamensis* can develop their gonads as early as the late dry season around March to April and peak during May and June (Sokheng et al., 1999), but in this study the GSI began to develop at the beginning of the rainy season. Viravong (2006) reported that the *H. siamensis* population above the Great Khone Falls, possibly because of floods and rains arriving earlier there, spawns earlier than the population below the falls. The average GSI increased from low values in the dry season to a maximum of about 20% immediately before spawning (July to August)

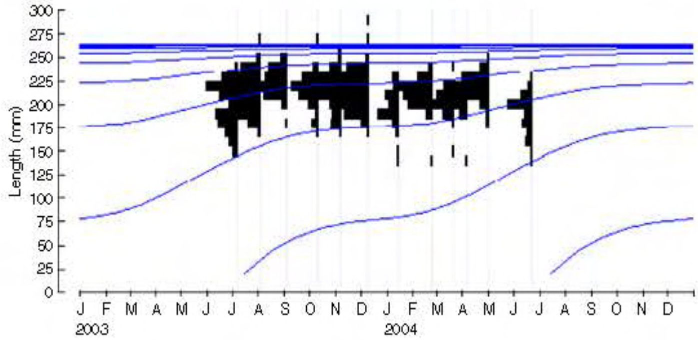

Fig. 5. Restructured length–frequency histogram, *H. siamensis*, Mae-ngad Reservoir for 2003–2004, with superimposed growth curves (L_∞ = 264.2 mm, K = 0.75 year^{-1}, C = 0.8, WP = 0.95, Rn = 0.114)

but the GSI was slightly higher for the river-dwelling *H. siamensis* (Viravong, 2006).

As a member of the littoral community, *H. siamensis* is known to be a mainly plant and detritus feeder, with the trophic level between 2.0 2.19. In a newly impounded condition, rich in nutrients and with a dominance of planktonic algae, *H. siamensis* was shown as restricted to being a phytoplankton feeder (i.e. trophic level range is 2.0: Thapanand et al., 2009). The presence of a few zooplankton in the stomach contents of *H. siamensis* in this study would put its trophic level slightly higher than 2.0. Feeding mostly on phytoplankton and plant materials, which have low energetic values, means that *H. siamensis* consumes a large quantity of food and has a long feeding period during the daytime (Amarasinghe et al., 2008). *H. siamensis* showed an exclusively herbivore pattern although there were temporal variations in the food components during the different seasons, similar to the population in the Mekong mainstream (Chheng et al., 2004), although most riverine cyprinids in the Mekong had flexible diets (i.e. omnivores: Warren et al., 1998).

The results on the growth of *H. siamensis* in this study, obtained from 1364 samples over a 12-month period, provided excellent data that could be used for simple length-based analysis (Hoenig et al., 1987). Moreover, the modal groups detectable from the raw data with the apparent shifts in the modal length over time (Fig. 4) make the results of the study reliable (Ama-Abasi et al., 2004). The growth performance index (Φ') is a species-specific parameter to indicate the unreliability in the accuracy of estimated growth parameters, which could be calculated as $\Phi' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro, 1984). The Φ' of the present study (4.19) was close to (chi-square test, P-value > 0.05) the value from a large reservoir (4.75: Moreau et al., 2008), which meant that the estimated growth parameters were authentic. The high amplitude of oscillation (C = 0.8) of *H. siamensis* indicated that growth does not cease completely but slows down during the unfavorable period (i.e. during December), which could be due to dietary items that were lowest in number and diversity, and lower than the average water temperature. Similar results were obtained from a large reservoir, where C = 0.6 and WP = 0.95 (Moreau et al., 2008). This situation is also likely to occur in the Mekong mainstream where there is a drastic decline in temperature from November to January (Prathumratana et al., 2008).

In conclusion, although *H. siamensis* has shown that it can establish populations in a lentic system, the piscimetric values of its biological traits (i.e. GSI, length at 50% maturity, L_∞ and K) were lower than those in the lotic system. This phenomenon would relate to differences in the flood pulse between the two systems. Lamberts (2001) reported that the well-being index (i.e. condition factor) of *H. siamensis*, in Tonle Sap, was remarkably increased during the flood season. There is also evidence that the growth and yield of the cyprinids were highly correlated with flooding (De Graaf, 2003). Periodic inundations and drought (i.e. flood pulse) are the driving force responsible for the existence, productivity and interactions of the major biota in river-floodplain systems (Junk and Wantzen, 2004). Meanwhile there is less variation in the flood pulse in the regulated lake (Wantzen et al., 2008), where the hydrological regimes are almost entirely dependent on the rainfall in the catchment areas and the demand is for water for primary uses (Nissanka et al., 2000).

Nevertheless, Mattson and Kaunda (1997) mentioned that the small reservoir environment is similar to a river floodplain, with large fluctuations in temperature, oxygen concentration, turbidity and water level, which are suitable to enable fish of river origin to adapt to the new environment. Moreover, the *r*-strategy reproductive traits of *H. siamensis* such as early maturity, high fecundity, single broods and rapid egg and larval development would help them to be successful in unfavorable environments (Viravong, 2006). Being an *r*-strategist with foraging behavior also makes *H. siamensis* a good candidate for maintaining the population in higher trophic levels in the lake similar to the case of the Thai river sprat (*Clupeichthys aesarnensis* Wongratana, 1983) in a number of reservoirs in the lower Mekong basin (Jutagate et al., 2003).

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P3

Reproductive biology and conservation approaches of a vulnerable species Siamese Freshwater batfish (*Oreoglanis siamensis*) from foothill Himalayan, Thailand

Suvarnaraksha, A., Lek, S., Lek-Ang, S. and Jutagate, T. (2011),

(in preparation)

Reproductive biology and conservation approaches of a vulnerable species Siamese Freshwater batfish (*Oreoglanis siamensis*) from foothill Himalayan, Thailand

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ABSTRACT

A vulnerable and an endemic Freshwater batfish (*Oreoglanis siamensis*) was studied in 2006-2007 in a high mountain stream in northern Thailand (18° 06' - 19°10' N and 98°04' - 98°34' E). This species was examined for reproductive biology preferences. Spawning in freshwater batfish occurred in late dry-cool season to early dry-hot season (January to April) in the upper tributaries of Maechaem river basin; at least 87.1-95.7% of female were in ripe or spawning condition in this season, while the sperm of male was mature and ripe through the year. Size at first maturity was 47 mm for males, and 53 for females. L_{50} estimates were 68.9±1.765 mm (males) and 82.4 ±1.369 mm (females). Maximum fecundity was 47 oocytes. Fecundity (F) varied from 18-47 (31.41 ± 7.67) for ripe females of 53-113 mm, respectively, correlation between TL and F and W and F followed a linear relationship (F=7.14+0.38TL; r^2=0.424; or F= 20.41+2.3W; r^2=0.491; n=71). Ripe oocytes have mean diameter of 2.96±0.28 mm (range = 2.5-4.2 mm; n=30).

INTRODUCTION

The Siamese bat catfish (*Oreoglanis siamensis* Smith, 1933) is a red list vulnerable benthic species (Kottelat, 1996) inhabiting endemic to Inthanon mountain in Chiangmai province of northern Thailand. Then, it is the important for understanding the biology, life history and conservation propose. The Maechaem watershed is located in the West of Inthanon mountain composes a large tributaries of the Ping river basin. It is located 117 km south-western of Chiangmai city. The Maechaem sub-basin is bounded by coordinates 18° 06' - 19°10' N and 98°04' - 98°34' E, and it covers a total area of 3,853 km^2. The climate of this mountainous basin is defined by large variations in seasonal and annual rainfall that are influenced by Pacific-born typhoons, superimposed on the south-west monsoon (Walker, 2002). There are freshwater resources utilizing for urban and agricultural purposes. This resulted in increased concern for the future of the vulnerable freshwater stream species. Thus, the *O. siamensis* is particularly sensitive to any anthropogenic perturbations which disrupt stream flows for extended period.

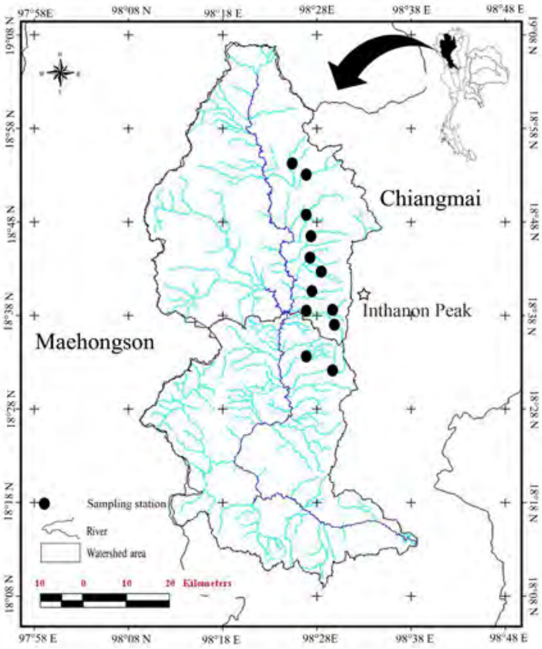

Figure 1. Map of Maechaem watershed.

The studies concerning with the reproduction of tropical freshwater fishes revealed a diversity of life-history and its relationship to discharge regime. Many lowland species reproduce during the wet season, when the inundation of lateral floodplains ensures an expanded habitat and a greater array and abundance of food (Fernandes, 1997). As a consequence many species of tropical and sub-tropical stream-dwelling fishes spawn during the dry season (Milton & Arthington 1983; Wooton 1990). Most of those studies have been carried out in stream tropical waters, with only a few at limit of biological data of tropical stream species, especially this species is seriously lacking of biological information. Studies of the ecology of Southeast Asia tropical freshwater fishes are limited and none have examined the reproductive biology of tropical stream-dwelling fishes. Studies of temperate stream fishes also emphasized on the importance of localized productivity and the acquisition of energy in determining the timing of reproduction (Encino & Granado-Lorencio 1997), and these factors may be of importance in tropical stream fishes aswell (Roberts 1989).

The members of the genus *Oreoglanis* are distributed from the upper part of the Salween river basin (Vidthayanon et al., 2009), Chao Phraya river basin (Suvarnaraksha, 2003), and Mekong river (Rainboth, 1996). *O. siamensis*, however, was reported to occur only in Inthanon mountain range (Smith, 1945). Because of this torrent stream species was occurs in montane brooks and small high-gradient streams (Rainboth, 1996). Inhabits cold swift mountain streams and high altitude 500-1,200 m asl (Suvarnaraksha, 2003). Attaches itself to rock surfaces facing the current (Smith, 1945) and feeds on crustaceans and insect larvae (Vidthayanon, 2005). However, some of the hill tribe residents used it as a protein sources, land use change, and fragmentation of streams by human being along the habitat of this fish has driven it to the edge of extinction. It has a vulnerable red list species in Thailand (Kottelat, 1996). Despite being a vulnerable species, *O. siamensis* was little studied on biology e.g. growth, reproduction, and fecundity. However, it has a few numbers of eggs (*per se* A. Suvarnaraksha). The life-history characteristics and restrict to habitat make them be sensitive to the intense exploitation. The conservation of natural population and exploitation of sustainable resources of *O. siamensis* have been become increasingly matters of concerns. Unfortunately, to the best knowledge no work has been done on the biology and the life of *O. siamensis*. Then, the first study program of *O. siamensis* was initiated with the aim to understand the reproduction biology and length weight relationship of this vulnerable fish.

MATERIALS AND METHODS

Study Area

The Maechaem river watershed is located in Chiang Mai province of northern Thailand (Fig. 1). It is a major upper tributary sub-basin of the Ping river, which in turn, is the largest tributary of central Thailand's Chao Phraya river, it is located 117 km southwestern of Chiangmai city. A large part of Maecheam river drainage was covered by mountains and forests (74.73%). The Maechaem sub-basin is bounded by coordinates 18° 06' - 19°10' N and 98°04' - 98°34' E, and covers a total area of 3,853 km^2, west of Inthanon highest spot of Thailand (2,565 m a.s.l.). The depth of the sampling sites ranges between 0.25-2.0 m. with various bottom types (i.e. rock, gravel, sand, silk and mud). There are some small hill tribe villages in the area. Temperatures from mid-November to January average between 13°C and 28°C; the hills are even colder. Temperatures in Chiang Mai begin to rise in February and in the hot season (March-May) ranges between 17°C and 36°C. In the rainy season (June-mid November) (Fig. 2A). The average annual temperature ranges from 20 to 34°C and the rainy season is from May to October. The climate of this mountainous basin is defined by large variations in seasonal and annual rainfall that are influenced by Pacific-born typhoons, superimposed on the south-west monsoon (Walker, 2002) (Fig. 2B). The orographic effect induces an altitudinal increase of spatial rainfall distribution (Dairaku et al., 2000; Kuraji et al., 2001).

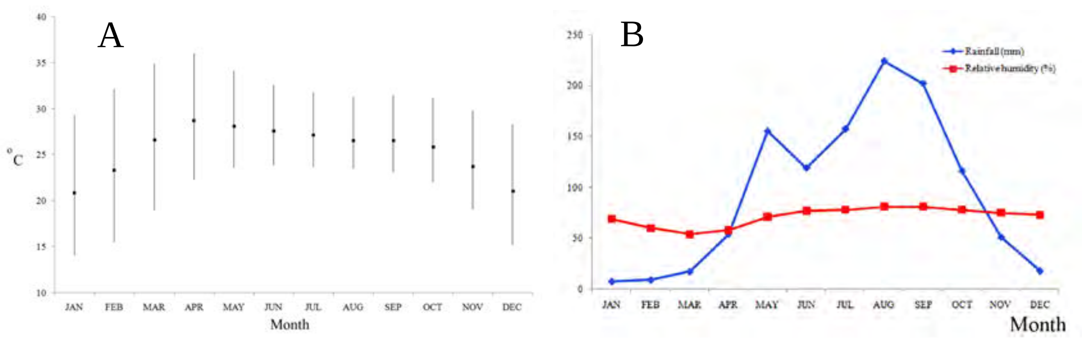

Figure. 2 A: Average of temperature; B: average of rainfall and hubidity in Maechaem watershed (1988-2009).

Sample collection

Fishes were electrofished (Honda EM 650, DC 220 V 550BA 450VA,1.5–2 A, 50 Hz) in the upper Maechaem river system, between November 2007 and October 2008, through monthly sampling. Each tributaries sampling site was done at 45 to 60 minutes intervals or the area covering about 100 m^2, The datas were collected with various microhabitat, substrate type i.e. rocky, sandy, and gravel, and habitat type (riffle, pool, and run) to cover all species distributions. The skin diving was carried out to observe the abundance and behavior of the fish. Fish captured in each part was kept separate after selected *O. siamensis* and fixed in 10% formalin and the life specimens was released to the their habitat after measurement and weight. Then, *O. siamensis* was identified and separated from the other species, sacrificed in a lethal solution of anesthetic, and conditioned in ice for transportation. The processe in evening at the rest room and the following data obtained: (i) total length (TL) to the nearest 0.1 mm (ii) total weight (WT) to the nearest 0.01 g (iii) sex (iv) gonad weight (GW) to the nearest 0.01 g. Gonads were removed from the visceral cavity, Prior to the preservation of the ovaries/testis were classified in a macroscopic scale of gonadal development, for both sexes; for females size and colour of oocytes was also registered and, for males sperm liberation when pressing the abdomen. According to these characteristics the following classification was considered: females – 2nd stage, immature, mature, and ripe; and males – 2nd stage, immature, mature, and ripe. Thereafter, ovaries were fixed in Bouin solution for oocytes measurements and counts. The specimens were fixed in 10% formalin. After one month, we were series of ethanol from 30%, 50% and preserved in 70% ethanol. Specimens were deposited at the Maejo Aquatic Resources Natural Museum.

Ovaries preserved in Gilson’s fluid were stored for two weeks and shaken periodically to promote oocyte release. Oocytes were then cleaned by subsequent alcohol change and removal of the ovarian walls, and stored in a 70° GL alcohol solution. Fecundity (Bagenal & Braum, 1971) was determined after counting all vitellogenic oocytes from ripe ovaries and correlated to TL and WT. Spawning type was evaluated according to the distribution of oocytes diameter (measured on subsamples of 10ml under a compound microscope -x4) from dissociated ovaries in different maturation stages (mature, and ripe).

The reproductive patterns of the *O. siamensis* were assessed by two methods: gonadosomatic index (GSI) and histology. GSI was calculated for each fish for both sexes to determine the spawning seasons using the equation: GSI = [testis/ovary weight/body weight] x 100). For histological examination of gonads, a subsample of gonadal tissue was removed from each fish. These gonad samples were weighed (±0.01g), placed in tissue cassettes, dehydrated and impregnated with wax. Histological sections were cut at 8 µm from each block using a tissue microtome, mounted on glass microscope slides and stained with Harris's haematoxylin and eosin counter stain. Each histological section was scored by estimating the percentage that each of the gonad maturity stages occupied within the total area of the section. Female gonads were classified into maturity stages: stage II (previtellogenic oocytes); immature (yolk precursor or non staining (primary) yolk); mature (red-staining (secondary) yolk); and spent; and for males: stages I, (primary germ cells and spermatogonia); immature (spermatocytes and spermatids); mature (spermatozoa); and spent. As no observable difference in scoring was detected between replicate blocks from the same fish, only one subsample was taken from the mid-position on a randomly selected gonad lobe for the remaining *O. siamensis* samples.

Size at first sexual maturity (LMAT) was determined from the minimum total length of fish with developed vitellogenic eggs (maturity stages IV or V) for females and spermatids (maturity stages V or VI) for males. Gonads were classed as ripe when the majority of the gonad was in maturity stages IV and V for females and stages V and VI for males. Fish were in spawning condition when the greatest proportion of their gonad was in stage V (females) and stage VI (males). To estimate the size of fish in the population where 50% of fish in a length class were mature (L_{50}). Fish were grouped into 10 mm total length classes to increase sample sizes. The logistic function was defined as;

$$P = \frac{1}{1 + e^{(a - bL)}} \text{ ------------------ } (1)$$

where *a* and *b* are constants and when calculated, the percentage at 50% maturity was replaced in upper equation to obtain the length at 50% maturity.

The condition factor (k) of the experimental fish was estimated from the relationship (Williams, 2000):

$$K = \frac{100W}{L^3} \text{----------------------- (2)}$$

where K=condition factor, W= weight of fish (g), and L= length of fish (mm). Fecundity (Bagenal & Braum, 1971) was determined after counting all vitellogenic oocytes from ripe ovaries and correlated to TL and TW in equation (3).

$$F=aTL^b\text{, and } F=aTW^b \text{ -------- (3)}$$

The relationship between the length (TL) and weight (W) of fish was expressed by equation (Pauly, 1983):

$$\mathrm{W=aL^b} \text{ --------------------------- (4)}$$

where W=Weight of fish in (g), L=Total length (TL) of fish in (mm), a Constant (intercept), and b=The length exponent (slope). The *a* and *b* values were obtained from a linear regression of the length and weight of fish. The correlation (r^2), which is the degree of association between the length and weight, was computed from linear regression analysis: $R=r^2$.

RESULTS

Environmental conditions

The fish tended to stay in areas with clear, slightly alkaline water with high level of dissolved oxygen, water temperature was less than 20 °C and moderate fast flow (Table 1). Monthly water flow at riffles was in the dry season (dry-cool and dry-hot season), then increased in rainy season. Flows in pools and runs were slower than at slope high slope. Bottom substrates at the stations were stone, rocks and gravel and surrounded by large rock. The stream canopy was cover by large three and high humidity, moss and fern were growing along the stream bank. Many of them were inhabits at the creeks of the stream, they were lied on the rocky or stone bottom by flat ventral of body for feeding and against the water flow. The dorsal part of *O. siamensis* coloration was mimic to the rock color shelter. While, in the spawning season were found the sinking eggs in the pool with lower flow.

Table 1. Environmental parameters at the sampling sites where *O. siamensis* were observed.

Environmental parameters	
pH	7.74-8.20
Dissolved Oxygen	5.5-8.4 mg/l
Temp	15.93-19.93 °C
Alkalinity	50-76 ppm.
Hardness	93.3-128.6 ppm.
Total Dissolve Solid	40-160 ppm.
Conductivity	50.7-160.0 µS/cm.
Flow	19-100 cm/sec^{-1}
Stream Depth	17-60 m.
Stream Width	2-8 m.
Nitrite	0.002-0.003 ppm.
Ammonia	0.001-0.004 ppm.

Reproductive conditions

Siamese bat catfish could not clearly express the secondary sexual characteristic, it was difficult to distinguishable except during the spawning season. Female, the belly is enlarged, swelled and flat from top view, and large yellow egg can be seen. Genital papilla was enlarged and urogenital pore is magnified, round tip and reddish. Male, has a protrude genital papillae and urogenital pore is enlarged and smaller size than female. Of the total of 249 *Oreoglanis siamensis* studied, 170 (48%) were males, 179 (52%) were females. The sex ratio was 1:1 (χ^2-test, p<0.05). The size at 50% maturity was 68.9 mm TL (SD 1.765) in males, and 82.4 mm TL (SD 1.369) in males (Fig. 6). Smaller females were first mature 53 mm TL, and the smallest mature male was 47 mm TL.

In *O. siamensis* gonadal maturation followed a similar annual pattern (Fig. 4). Between late of dry-hot season to beginning of rainy season (May to August), the majority of the collected fish were in stage II (post-spawning) and immature stage (early preparatory periods). In the late of that rainy to early dry-cool season, the mature individuals (mature stage) were more abundant in September to December (pre-spawning period). During January to March or/and April, high percentage of fish specimens collected were in the ripe stage (Fig. 4).

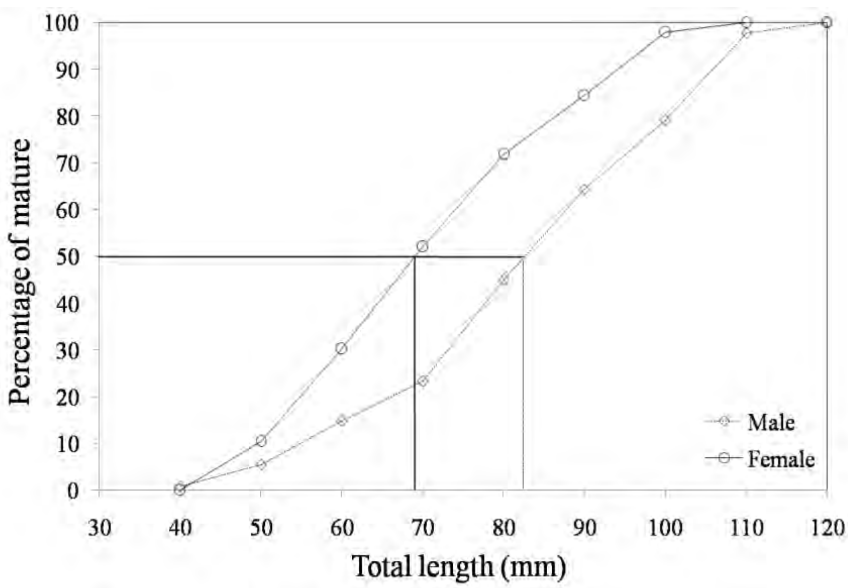

Figure 3. Length at 50% maturity, female (circle) and male (diamond) *O. siamensis*, Maechaem watershed, as indicated by percentage of sample maturing in each length class (10 mm interval).

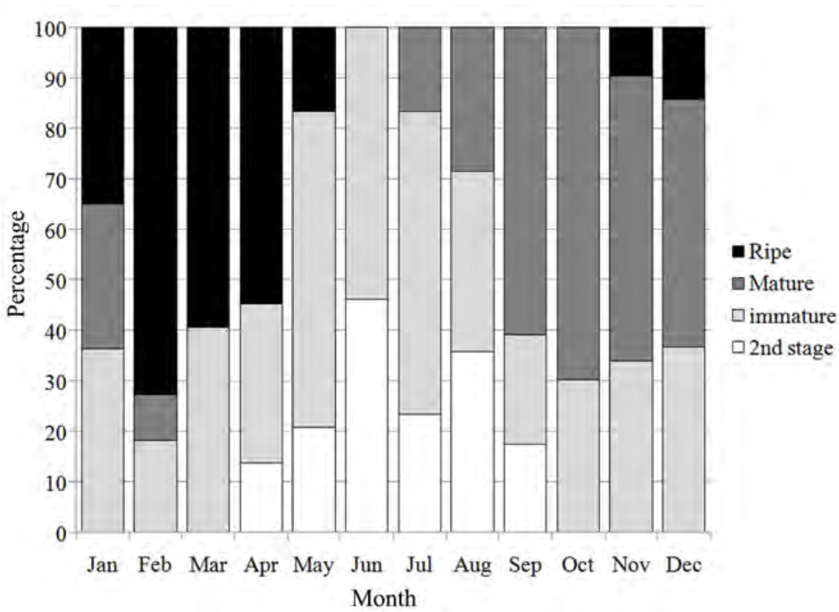

Figure 4. Percent frequency of maturity stage of *O. siamensis*.

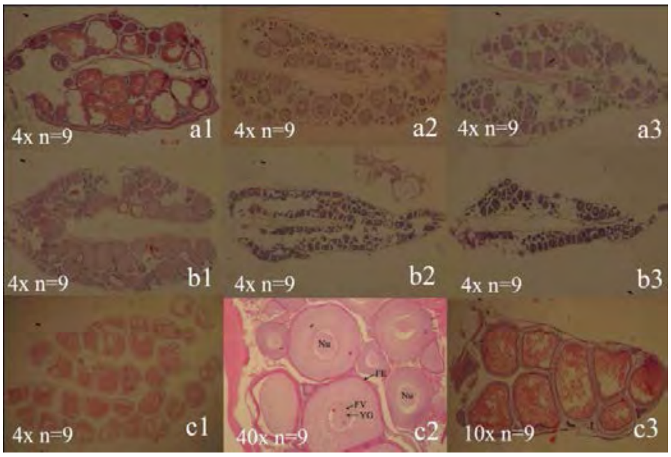

Figure 5. Histological appearance of ovary maturation of *O. siamensis* (n=9 per month). Abbreviation: Nu=nucleus, FE=follicle epithelial, YG=Yolk vesicle; **Note** a) ripe and spent stage (dry-hot season), a1) late ripe stage, a2) spent stage, a3) spent stage, b) late spent, primary stage and immature stage (rainy season), b1) late spent stage, b2-3) primary stage and immature stage, and c) mature and ripe stage (dry-cool season), c1-2) mature stage, c3 ripe stage.

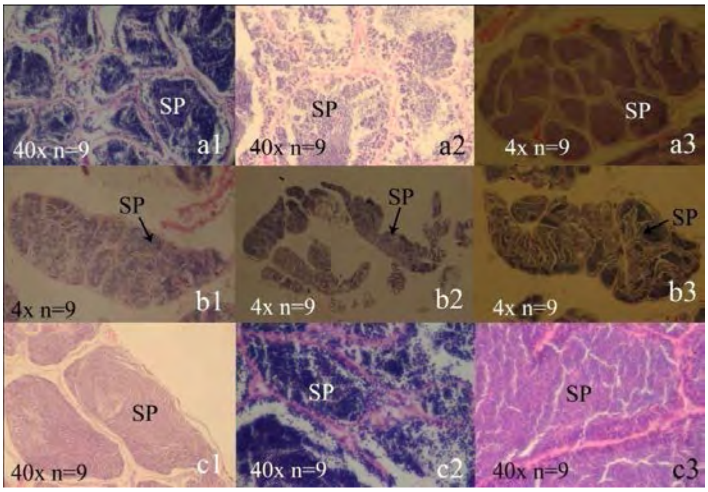

Figure 6. Histological appearance of testis maturation of *O. siamensis* (n=9 per month). Abbreviation: SP=spermatozoa, **Note** a) ripe and spent stage (dry-hot season), a1) mature stage, a2) mature stage, a3) mature stage, b) late mature, primary stage and immature stage (rainy season), b1) late mature stage, b2-3) primary stage and immature stage, and c) mature stage (dry-cool season), c1-3) mature stage, c3 ripe stage.

Microscopic study revealed similar characteristics in the gonadal tissue for the species. In Fig. 3, gonadal maturity stage in female are presented. Spent stage (after spawning) observed during April to June (dry-hot season) and July (starting to rainy season) (Fig. 5a1, 5a2, and 5a3). The ovaries in second stage and immature stage were observed during August to October (Rainy season) (Fig. 5b1, 5b2 and 5b3). While, they were started to mature stage in November to December (early dry-cool season) and ripe stage in January to February (late dry-cool season) (Fig. 5c1, 5c2 and 5c3). Also, some of specimens were ripe in March to early April.

The late of the dry-cool season testis was in stage V (Fig. 6a1, 6a2 and 6a3). The testis in stage II and III (Fig. 6b1, 6b2 and 6b3) presented seminiferous tubules with cells at different stages of development. In mature stage V (Fig. 6c1, 6c2 and 6c3), testes showed the lumen of seminiferous tubules filled with spermatozoa (s). The spermatogonia and the seminiferous tubules were observed along the entire testis.

Table 2. The condition factor (K) in *O. siamensis*.

Month	Condition factor	Month	Condition factor
Jan	1.01±0.39	Jul	0.95±0.26
Feb	0.82±0.17	Aug	0.96±0.30
Mar	0.93±0.20	Sep	0.92±0.17
Apr	0.86±0.19	Oct	0.89±0.19
May	0.85±0.22	Nov	0.89±0.19
Jun	0.87±0.33	Dec	1.18±0.39

Of the total of 179 adult females sampled, only 96 ovaries were found to be suitable for an estimate of fecundity. The females studied ranged from 53 to 113 mm TL, and were captured along year round cycle. The condition factor ranged from 0.82 to 1.18±0.09 during the period studied, which maximum valued in dry-cool season (December to January) (Table 2). Fecundity (F) varied from 18-47 (31.41 ± 7.67) for ripe females of 53-113 mm, respectively, correlation between TL and F and W and F followed a linear relationship ($F=7.14+0.38TL$; $r^2=0.424$; or $F= 20.41+2.3W$; $r^2=0.491$; n=71). Egg character of Siamese bat catfish is rounded-shape, ripened egg is pale-yellowish color, transparent and glossy. The egg type is demersal but not sticky. Ripe oocytes have mean diameter of 2.96±0.28 µm (range = 2.5-4.2 µm; n=30). Considering that the mean number of oocytes per gram weight is independent of fish size the mean number of oocytes per grams of body weight as 7 oocytes.

A total of 532 specimens were analyzed, being the value obtained for the length-weight relationship showed that the *O. siamensis* was allometric in its growth. Ranging from 20-117 mm, 532 samples were used in the analysis. The relationship was derived from unsexed samples since there is no external sexual dimorphism. The equation derived was W=0.00005$L^{2.738}$ (r^2=0.947) (Fig. 7).

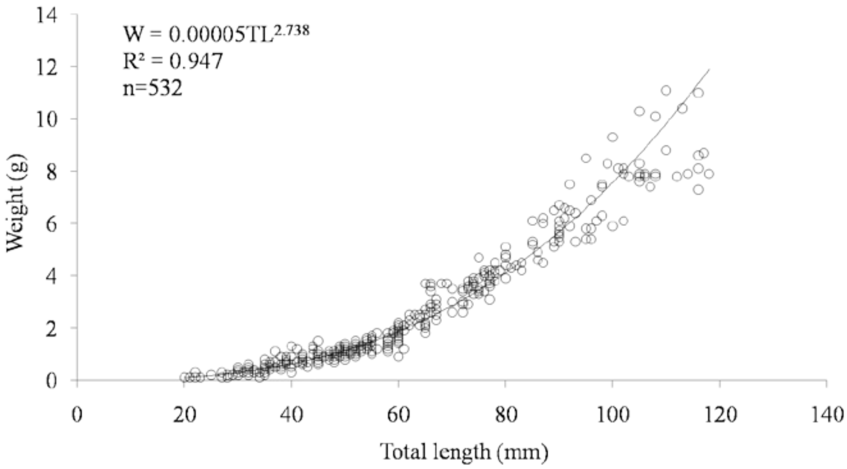

Figure 7. Length-weight relationships of *O. siamensis*.

DISCUSSIONS

The streams in northern Thailand, like in many other tropical streams, are characterized by a steep topography, fast flow, rocky bottom, canopy cover, and high level of dissolved oxygen. Nevertheless, the fish still have to well adapted to the special habitat e.g. *Homaloptera* spp., *Balitora* spp., and *Glyptothorax* spp. (Kottelat, 2001). Also, *O. siamensis* was well adapted by flatten belly, adhesive maxillary barbel and pair fins, stream line body shape, and aerodynamic dorsal part. These characteristics were suitable for feeding on the small invertebrate and aquatic insect larvae on the rocks (Vidthayanon, 2005). It could tolerate a low water temperature in high altitude which might limit the growth of the *O. siamensis* food items (Han et. al., 2000). The environmental condition of *O. siamensis* was abundant along the habitats in Maechaem Stream showed that *O. siamensis* inhabited the waters between 500 to 1200 m altitudes.

The early stages such as eggs and larvae stages are of great important for fishes, then the reproductive tactics in teleostean fish involving the allocation of a size-dependent reproductive effort between fecundity and egg size. The demersal species tend to produce large and few eggs, the larger eggs and the larvae hatching from them are more likely to survive than smaller ones, but Duarte & Alcaraz, 1989 reported no evidence of evolutionary trends towards greater eggs. They were reduce the variance in growing conditions, should be more dependent on the survival of the individual larvae, which increases as egg size increases. Also, *O. siamensis* is a demersal steam species, it produces large oocytes and few numbers like some of parental care species (Paugy, 2002) e.g. *Xynobagrus nigri* (Olurin & Odeyemi, 2010) and *Notopterus notopterus* (*per se* A. Suvarnaraksha) or rainbow trout, Sea back trout, and brook trout (Serezli *et al.,* 2010). While, their fecundities were very small number of eggs compare with the other glyptothorine species e.g. *Glyptothorax madraspatanum* (18 to 47 vs. 1640 to 6830) (Dobriyal & Singh, 1993) and a little bit fewer number of eggs than parental care species (Paugy, 2002). The fecundity and egg size was related, egg size is one of the important determinants of eggs and larval quantity as it is positively correlated with both survival of egg and larval and also of the growth of the larvae (Gall, 1975). But, Elger (1990) reported the product of clutch size and egg volume is not correlated with either clutch size or egg volume after removing the effects of body size. Furthermore, as larger eggs sizes often take longer to hatch than smaller eggs, they are at risk from predation or adverse abiotic conditions for longer periods of time (Miller et al., 1988); it was related to the report of Unsrisong et al., 2005. The adults and juvenile were found in the same habitats, it is possible a non-migratory species.

The *O. siamensis* was spawn in the late dry-cool to dry-hot season (January to April) of Thailand, this conformed to a study of Unsrisong et al., 2005, but a liitle bit early. Meanwhile, it was difference with lowland tropical stream species reproduction according to rainfalls regiems (Alkins-Koo, 2000; Chellappa et al., 2009). In the dry season, reduced stream flow and a reduced spate frequency ensure a more benign physical environment than during the wet season, and food may also be more abundant at this time as well. Moreover, the wet-season primary production may be reduced because of a combination of increased cloud cover associated with the monsoonal wet season and high suspended sediment loads during the period of elevated discharge, both of which limit light availability for primary producers (Pusey et al., 2001). The main habitats were in the high elevation and canopy cover. The spawning season sufficient data on seasonal freshwater fish egg variations are not available, but the time of spawning does appear to be linked with the availability of food for the larvae in both lake and stream species (Bagenal, 1971). Then, the few numbers of eggs restrict to the habitat of *O. siamensis* led to endanger or extinct in the near future.

CONCLUTIONS

The first report showed the dry-cool to dry-hot spawning season of mountainous vulnerable species in northern of Thailand and tropical Southeast Asia. The situation of low fecundity, restrict to the specific habitat, and anthropology disturbs were one of the chance to be extinct in the near future. Then, this vulnerable species should prevent aggression from human activities and more study of their life history and strategies for management.

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Fish diversity and assemblage patterns along the longitudinal gradient of tropical river in the Indo-Burma hotspot region (the Ping-Wang river basin, Thailand)

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Running title: Fish assemblages in a rhitral environment in Thailand

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ABSTRACT

Fish diversity and assemblage patterns along the longitudinal gradient of the Ping-Wang river basin were investigated. Diversity study was based on data from 272 samplings, collected between January 1996 and April 2009. Sixteen physicochemical water quality- and geo-morphological- parameters were also examined at each sampling as well as area and the percentage of 3 types of land-uses of each sub-basin. One hundred and ninety two fish species were collected and the most diverse family was Cyprinidae (76 species) followed by Balitoridae (20 species) and Cobitidae (13 species). The highest and lowest diversity values were obtained in the "Maeklang" and "lower Ping" sub-basins, respectively. Six physicochemical parameters (i.e. DO, water temperature, pH, conductivity, phosphorus and alkalinity) and six geo-morphological parameters (i.e. altitude, distance from the sea, discharge, depth and width) were statistically significant in their relationships to diversity parameters (P-value < 0.05). Results from the classification and regression trees showed that the geo-morphological parameters were more significant in controlling and predicting both species richness and Shannon diversity index than the physicochemical parameters, in which altitude was the most significant. Fifty-three fish species from 220 samplings were patternized into 4 assemblage patterns *viz.*, mountainous, piedmont, transitory and lowland species. Any environmental changes in the rhitral environment will seriously impact to the distribution of species in the mountainous and piedmont assemblages.

Keywords Fish diversity, Environmental variables, Prediction, Assemblage patterns, CCA, Indo-Burma Hotspot, Thailand

INTRODUCTION

Variations in geomorphology characteristics of the river as well as environmental variables, both biotic and abiotic, are the major factors that govern riverine fish communities both in terms of species richness and distribution of individual species (Orrego et al., 2009; Alexandre et al., 2010; Kimmel and Argent, 2010). Knowledge on this issue has been widely reported both on regional and local scales but is still very poor for the Indo-Burma, the third largest global biodiversity hotspot (Myers et al., 2000), particularly on the species living exclusively in the headwater section (i.e. rhithral environment), where are difficult to access. So far, more than 1,260 freshwater fish species in the region (i.e. about 10 % of global freshwater fishes) have been reported and more than 560 of this species are endemic (Conservation International, 2010).

The longitudinal gradient of river course can be divided into upper (i.e. rhithron), middle and lower (i.e. potamon) sectors, in which each area has its own characteristics of species assemblages, though overlapping to some degree (Schmutz et al., 2000). To evaluate the status and any changes of assemblages in each section over time, diversity indices are commonly used and the commonest indicator is the number of species found, i.e. species richness (Oberdorff et al., 2002; de Thoisy et al., 2008; He et al., 2010). This indicator is an integrative descriptor of the animal community, influenced by a large number of natural environmental factors as well as anthropogenic disturbances, including the geological history of the area, environmental stability, ecosystem productivity and heterogeneity (Lenat, 1988; Céréghino et al., 2003; He et al., 2010). It is suggested that if the physical aspects of the stream are relatively stable, they are responsible for the consistent pattern in biological community structure (Orrego et al., 2009) even though some other factors may have an influence, such as competition, predation, point and non-point pollution sources (Ibarra et al., 2005; Orrego et al., 2009) as well as hydraulic stress (Welcomme et al., 2006).

The occupancy by species of particular sections throughout the length of a river depends on the extent that specific needs are supplied by the locally available resources, especially food and shelter (Tomanova et al., 2007; de Oliveira & Eterovick, 2009). The species that is exclusively present in a particular section, incorporated with the studies on habitat disturbance gradient, could be the bio-indicator to evaluate ecological integrity of that zone (Lasne et al., 2007). Many classifications of running waters, notably fish-based classifications, have been proposed since the end of the 19th century (e.g. Huet, 1959) and are becoming more important since the last decade, especially when the anthropogenic impacts are accelerated (e.g. Schmutz et al., 2000; Welcomme et al., 2006) because the deviation between the observed assemblage type and the one expected in undisturbed conditions provides an assessment of their ecological status (Lasne et al., 2007).

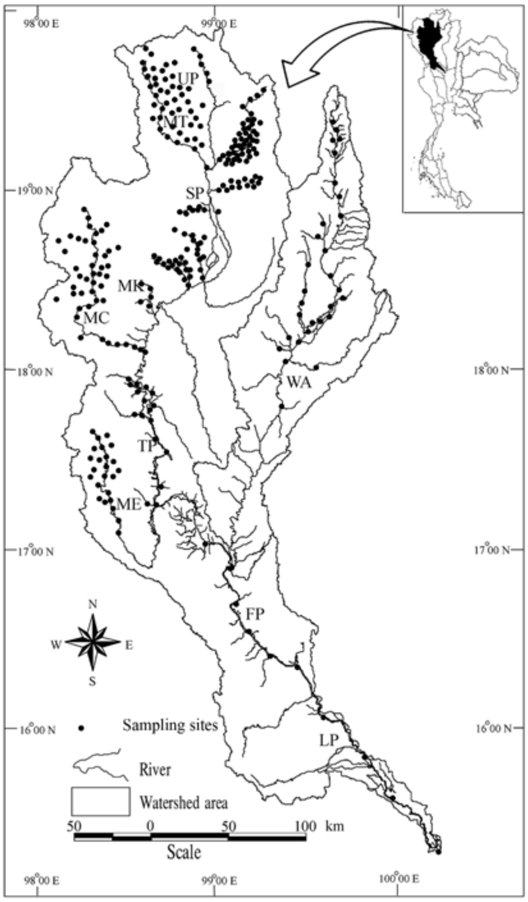

Figure 1. Location and map of the Ping-Wang river basin (showing also the locations of 10 sub-basins)

Due to the fact that most of the areas in this basin are almost intact and less disturbed by urbanization, fish community structure, in this study, reflected the longitudinal river gradient, which would closely related to the gradual change in habitat diversity (Ferreira & Petrere, 2009; He et al., 2010). In this study, we aimed to draw out the perspectives of (a) the relationship between biotic and abiotic variables as descriptors to predict their influences on the fish community in terms of species diversity and (b) identification of the fish species community structures along the longitudinal gradient in a rhithral environment of a large scale of river system located in the Indo-Burma hot spot, i.e. the Ping-Wang River Basin, where high concentrations of endemic fish species are evident and are undergoing immense habitat loss, especially urbanization and infrastructure developments (Sodhi et al., 2004; De Silva et al., 2007; Dugan et al., 2010).

Materials and methods

Study area

The Ping - Wang river-system is the major river-system of northern Thailand (Fig. 1) and located in the Chao Phraya river basin and a high altitude river basin in Indo-Burma. The Ping river is 740 km long with a catchment area of about 33,896 km^2. The Wang river is 440 km long and has a catchment area of 10,791 km^2 (Takeuchi et al., 2005). The Wang river flows southwest ward to join the lowland of Ping river at Tak province to form a large watershed area lying between $15^o42'$ and $19^o48'$ North and 98 $^o04'$ and $100^o08'$ East. The highest altitude of this river system is at 2,565 m ASL and connected to the lower Chao Phraya river basin at the altitude of 48 m ASL.

Fish data

The databases of fish samples were compiled during the ichthyological surveys in running water of the Ping-Wang River-system between January 1996 and April 2009 (A. Suvarnaraksha, *own collected data*) and no major changes in land-uses were observed during the sampling period. The total number of sampling sites was 272, which were selected to cover the main rivers and tributaries of the Ping-Wang river-system. The sampling sites were distributed among 10 sub-basins in the river-system (Fig. 1), where a Digital Elevation Model (DEM) was used to define and divide the geographical range of the Ping-Wang river-system into sub-basins by ArcView GIS 9.2, according to the catchment area and fish sample spots. Each sub-basin was visited to cover both in dry and wet seasons. The total number of sampling sites was 272.

Table 1 Descriptions of the sub-basins in the Ping-Wang River Basin, collection period and number of stations in each sub- basin

Sub-basin	Geographic Coordinate	Bottom	Categorical identities	Collection period	No. of Stations
Upping Ping (UP)	19°07'-19°48' N 98°47'-99°17' E	G, P, R, S	Fast flowing and clear water, rocky, gravel, pebble and sandy bottom, stream enclosed by forest canopy.	2008	6
Maetang (MT)	19°10'-19°45' N 98°27'-98°55' E	G, P, R, S	Fast flowing and clear water. Rocky, gravel, pebble and sandy bottom, covered by forest canopy.	2000-2001 2003-2004	48
The second Ping (SP)	18°31'-19°33' N 98°24'-99°22' E	G, P, R, S	Fast flowing and stagnant water. Clear or turbid water. Rocky, gravel, pebble, muddy and sandy bottom. Partially covered by forest canopy, agricultural area and urban.	1996, 2003-2004, 2008	98
Maeklang(MK)	18°24'-18°35' N 98°28'-98°41' E	G, P, R, S	Fast flowing and clear water, rocky, gravel, pebble and sandy bottom, stream enclosed by forest canopy.	2008	6
Maecheam (MC)	17°57'-19°09' N 98°04'-98°37' E	G, P, R, S	Fast flowing and clear water, rocky, gravel, pebble and sandy bottom, stream enclosed by forest canopy.	2007-2008	44
The third Ping (TP)	17°48'-18°43' N 98°14'-98°44' E	G, S, M	Slow flowing or stagnant water and turbid water. Gravel, muddy and sandy bottom. Partially covered by forest canopy, agricultural area and urban.	2005-2006, 2009	18
Maeteon (ME)	17°13'-18°02' N 98°14'-98°34' E	G, P, R, S	Fast flowing and clear water, rocky, gravel, pebble and sandy bottom, stream enclosed by forest canopy.	2008	24
The forth Ping (FP)	15°50'-17°49' N 98°39'-100°02' E	G, S, M	Slow flowing and turbid water. Gravel, muddy and sandy bottom. Partially covered by forest canopy, agricultural area and urban.	2009	6
Lower Ping (LP)	15°42'-16°10' N 99°27'-100°08' E	G, S, M	Slow flowing and turbid water. Gravel, muddy and sandy bottom. Partially covered by forest canopy, agricultural area and urban.	2009	4
Wang river (WA)	17°07'-19°24' N 99°00'-100°06' E	G, S, M	Fast flowing and clear water on upper reaches and slow flowing and turbid water in lower part of Wang river. Gravel, muddy and sandy bottom. Partially covered by forest canopy, agricultural area and urban.	2009	18

Note R = rocky, G = gravel, P = pebble, S = sandy and M = muddy

Each site was single visit and chosen on the basis of accessibility, similarity in habitat types, and to maximize the diversity of habitat types (pools, cascade, falls, riffles, and stagnant water) at each sub-basin (Table 1).

To gather all species within sampling site, fish samples were collected by using various fishing methods such as small and large seines, cast-nets, gillnets of various mesh sizes, and traps (Table 1). The electro-fishing did supplement sampling with an AC shocker (Honda EM 650, DC 220 V 550BA 450VA, 1.5–2 A, 50 Hz), which was placed on the riverbank together with block nets and scoop nets. Live fishes were identified in the field, measured for total length (mm), counted, and then returned back to the water. Only a few samples of individual species were anaesthetized in dilute solution of benzocaine (50 mg/l) and kept separately according to species level for further taxonomical reference. Specimens were preserved in formalin, identified in the lab by several related publications e.g. Smith 1945, Taki, 1974, Kottelat 1985, 1998, 2001, Roberts 1993, 1994, Rainboth 1996, Vidthayanon et al., 1997 and others. And then, specimens were deposited in the Maejo Aquatic Resources Natural Museum (MARNM). Fish data was presented in terms of diversity parameters as species richness, Simpson Dominance index, species evenness and Shannon diversity index (Shannon, 1948).

Environmental parameters

The physicochemical water quality parameters were measured at each sampling, including water temperature (WT; °C), conductivity (CON; μS/cm), total dissolved solids (TDS; mg/l), dissolved oxygen (DO; mg/l), and pH, and were detected *in situ* by using a YSI 556 (MPS) multi-probe system. Water was sampled for laboratory analyses of nitrite (NIT; mg/l), ammonia (AMM; mg/l), total phosphorus (PO_4^+; mg/l), alkalinity (ALK; mg/l) and hardness (HAR; mg/l) following APHA (1989) protocols.

The geo-morphological parameters were also obtained from each sampling. Water depth (DEP; m) and stream width (WID; m) were measured at the beginning, middle and end of the each sampling site. Velocity of the water flow was measured by flow-meter (G.O. Environmental model 1295, VEL; m/s) and measurement was conducted at least three times (i.e. at the middle of the stream and both the bank sides) and the mean values were used. Discharge (DIC; m^3/s) was calculated as Q = AV, where Q is discharge, A is the cross-sectional area of the channel and V is the average flow velocity. The altitude (ALT; m ASL) of the sampling site was provided by a GPS GarmineTrex VISTA. ArcView GIS 9.2 was used to estimate landscape position i.e. distance from the sea (DFS; km), watershed area (WSH; km^2), and the land cover (i.e., forest area (FOR; %), agricultural area (AGR; %) and urban area (URB; %)).

Statistical analyses

A matrix data of numbers of fish captured in each species at each site was made for further analyses. The linear regression model (Cade & Noon, 2003) was used to examine the relationships between individual environmental parameters and species richness and also Shannon diversity index (Gutiérrez-Estrada et al., 2008). The classification and regression tree (CART: Breiman et al., 1984) was optimized from a set of environmental parameters and aimed at predicting species richness and Shannon diversity index by site. The cost-complexity pruning was used to prune the regression tree (Breiman et al., 1984). For making CARTs, species richness was *log (x+1)* transformed to stabilize variances (He et al., 2010). The optimal tree size was determined by r^2-value and the complexity parameter.

The data of 192 fish species from 272 samplings was rearranged by eliminating the species that occurred less than 5 % of total samplings and the samplings that contained less than 5 % of total species. Then, after less than 5% eliminating, a matrix of 53 fish species, according to 220 samplings, was employed and the data were transformed into presence/absence data. Relationships between fish assemblages and environmental parameters were examined by Canonical Correspondence Analysis (CCA), an ordination technique designed for direct analysis of relationships between multivariate ecological data (Ter Braak, 1986). Statistical significance, for CCA, of the relationship between a set of environmental factors and fish species was taken using a Monte Carlo permutation test with 999 permutations and was accepted at P-value < 0.05. Ward's hierarchical agglomerative clustering was used to classify the group of fish species based on their similarity in occurrences (Ward, 1963). All statistical analyses were performed by using an R-statistical software (Ihaka & Gentleman, 1996) using packages “stats” (R Development Core Team, 2010), “rpart” (Therneau & Atkinson, 2010) and “ade4” (Chessel et al., 2004).

RESULTS

A total of 192 species within 11 orders, 33 families were collected. The most diverse family was Cyprinidae (76 species) and followed by Balitoridae (20 species), Cobitidae (13 species) and Bagridae (10 species) and the remaining families were contained less than 10 species (Table 2). The greatest species richness was found in the lower portion of the river-system “Lower Ping” Sub-basin (112 species) while the minimum species richness was obtain at the highest altitude “Maeklang” Sub-basin (11 species) and there were similar trends for Shannon diversity index, Simpson Dominance index, species evenness and species richness (Table 3). However, numbers of individuals per 100 m^2 and biomass (kg) per hectare were scattered among sub-basin (Table 3).

Relationships between the environmental and diversity parameters

Summary of values of the 20 environmental parameters in each sub-basin is presented in Table 4. Five geo-morphological parameters, i.e. altitude, distance to the sea, discharge, depth, and width, showed high statistical significance in their relationships to diversity parameters (P-value < 0.001, Fig. 2). The higher r^2 values (i.e. strong relationships) of geo-morphological parameters and diversity indices were found (Fig. 2), when compared to those physicochemical parameters (Fig. 3). Altitude and distance to the sea showed strongly negative relationships for both indices, implying that higher diversity was found in the lower altitude, which was close to the sea and then declines as the altitude increases. It was also observed that diversity indices in the low levels of the three remaining parameters fluctuated widely and they all showed positive trend, i.e. the higher the value, the higher the diversity indices.

The high altitude sub-basins (i.e. the Upper Ping, Maetang, Maeklang and Maeteon) showed the characteristics of low water temperature, high water current velocity and non-polluted area. Meanwhile, the high percentage of agricultural and urban area in the fourth Ping sub-basin would dedicate to the lower dissolved oxygen and higher in nitrite and ammonia compared to the other sub-basins. There were six

Table 2 Species list and its abbreviation (abbr.) of 198 fish species found during 1996-2009 in the Ping-Wang River Basin.

Scientific name	Abbr.	Scientific name	Abbr.	Scientific name	Abbr.
Myliobatiformes/Dasyatidae		*Hypsibarbus vernayi* (Norman, 1925)	Hver	*Gyrinocheilus aymonieri* Tirant, 1883	Gaym
Himantura chaophraya Monkolprasit and Roberts, 1990	Hcha	*Hypsibarbus wetmorei* (Smith, 1931)	Hwet	**Balitoridae**	
Himantura signifer Compagno & Roberts, 1982	Hsig	*Labeo chrysophekadion* (Bleeker, 1850)	Lchr	*Balitora brucei* Gray, 1830	Bbru
Osteoglossiformes/Notopteridae		*Labeo rohita* (Hamilton, 1822)	Lroh	*Homaloptera smithi* Hora, 1932	Hsmi
Chitala ornata (Gray, 1831)	Corn	*Labiobarbus leptocheila* (Valenciennes, 1842)	Llep	*Homaloptera zollingeri* Bleeker, 1853	Hzol
Notopterus notopterus(Pallas, 1769)	Nnot	*Labiobarbus lineatus* (Sauvage, 1878)	Llin	*Homaloptera leonardi* Hora, 1941	Hleo
Clupeiformes/Clupeidae		*Leptobarbus hoevenii* (Bleeker, 1851)	Lhoe	*Nemacheilus binotatus* Smith, 1933	Nbin
Clupeoides borneensis Bleeker, 1851	Cbor	*Lobocheilos melanotaenia* (Fowler, 1935)	Lmel	*Schistura breviceps* (Smith, 1945)	Sbre
Cypriniformes/Cyprinidae		*Lobocheilos quadrilineatus* (Fowler, 1935)	Lqua	*Schistura bucculentus* (Smith, 1945)	Sbuc
Albulichthys albuloides (Bleeker, 1855)	Aalb	*Luciosoma bleekeri* Steindachner, 1878	Lble	*Schistura desmotes* (Fowler, 1934)	Sdes
Amblyrhynchichthys truncatus (Bleeker, 1851)	Atru	*Mystacoleucus greenwayi* Pellegrin & Fang, 1940	Mgre	*Schistura geisleri* (Kottelat 1990)	Sgei
Bangana sinkleri (Fowler, 1934)	Bsin	*Mystacoleucus marginatus* (Valenciennes, 1842)	Mmar	*Schistura magnifluvis* Kottelat, 1990	Smag
Barbichthys laevis (Valenciennes, 1842)	Blae	*Neolissochilus stracheyi* (Day, 1871)	Nstr	*Schistura mahnerti* Kottelat, 1990	Smah
Barbichthys nitidus Sauvage, 1878	Bmic	*Onychostoma gerlachi* (Peters, 1881)	Oger	*Schistura menanensis* (Smith, 1945)	Smen
Barbonymus altus (Günther, 1868)	Balt	*Osteochilus hasseltii* (Valenciennes, 1842)	Ohas	*Schistura obeini* Kottelat, 1998	Sobe
Barbonymus gonionotus (Bleeker, 1850)	Bgon	*Osteochilus lini* Fowler, 1935	Olin	*Schistura poculi* (Smith, 1945)	Spoc
Barbonymus schwanenfeldii (Bleeker, 1853)	Bsch	*Osteochilus melanopleurus* (Bleeker, 1852)	Omel	*Schistura pridii* Vidthayanon, 2003	Spri
Barilius koratensis (Smith, 1931)	Bkor	*Osteochilus microcephalus* (Valenciennes, 1842)	Omic	*Schistura sexcauda* (Fowler, 1937)	Ssex
Barilius pulchellus (Smith, 1931)	Bpul	*Osteochilus waandersii* (Bleeker, 1852)	Owaa	*Schistura spilota* (Fowler, 1934)	Sspi
Cirrhinus cirrhosus (Bloch, 1795)*	Ccir	*Parachela oxygastroides* (Bleeker, 1852)	Poxy	*Schistura vinciguerrae* (Hora, 1935)	Svin
Cirrhinus molitorella (Valenciennes, 1844)	Cmol	*Paralaubuca harmandi* Sauvage, 1883	Phar	*Schistura waltoni* (Fowler, 1937)	Swal
Cosmochilus harmandi Sauvage, 1878	Char	*Paralaubuca riveroi* (Fowler, 1935)	Priv	*Tuberoschistura baenzigeri* (Kottelat, 1983)	Tbae
Crossocheilus cobitis (Bleeker, 1853)	Ccob	*Paralaubuca typus* Bleeker, 1865	Ptyp	**Cobitidae**	
Crossocheilus reticulatus (Fowler, 1934)	Cret	*Poropuntius bantamensis* (Rendahl, 1920)	Pban	*Acanthocobitis botia* (Hamilton, 1822)	Abot
Ctenopharyngodon idellus (Valenciennes, 1844)	Cide	*Poropuntius deauratus* (Valenciennes, 1842)	Pdea	*Acanthocobitis zonalternans* (Blyth, 1860)	Azon
Cyclocheilichthys apogon (Valenciennes, 1842)	Capo	*Puntioplites proctozysron* (Bleeker, 1865)	Ppro	*Acanthopsoides delphax* Siebert, 1991	Adel
Cyclocheilichthys armatus (Valenciennes, 1842)	Carm	*Puntius brevis* (Bleeker, 1850)	Pbre	*Acanthopsoides gracilentus* (Smith, 1945)	Agrl
*Cyclocheilichthys enoplos (*Bleeker, 1851)	Ceno	*Puntius orphoides* (Valenciennes, 1842)	Porp	*Acantopsis choirorhynchos* (Bleeker, 1854)	Acho
Cyclocheilichthys repasson (Bleeker, 1853)	Crep	*Puntius partipentazona* (Fowler, 1934)	Ppar	*Acantopsis thiemmedhi* Sontirat, 1999	Athi
Cyprinus carpio Linnaeus, 1758*	Ccar	*Puntius stoliczkanus* (Day, 1871)	Psto	*Lepidocephalichthys berdmorei* (Blyth, 1860)	Lber
Danio albolineatus (Blyth, 1860)	Dalb	*Raiamas guttatus* (Da3y, 1870)	Rgut	*Lepidocephalichthys hasselti* (Valenciennes, 1846)	Lhas
Devario aequipinnata (McClelland, 1839)	Dequ	*Rasbora atridorsalis* Kottelat & Chu, 1987	Ratr	*Pangio anguillaris* (Vaillant, 1902)	Pang
Devario maetangensis (Fang, 1997)	Dmae	*Rasbora borapetensis* Smith, 1934	Rbor	*Syncrossus beauforti* (Smith, 1931)	Sbea
Devario malabaricus (Jerdon, 1849)	Dmar	*Rasbora daniconius* (Hamilton, 1822)	Rdan	*Syncrossus helodes* (Sauvage, 1876)	Shel
Devario regina (Fowler, 1934)	Dreg	*Rasbora dusonensis* (Bleeker, 1851)	Rdus	*Yasuhikotakia modesta* (Bleeker, 1864)	Ymod
Discherodontus schroederi (Smith, 1945)	Dsch	*Rasbora myseri* Brittan, 1954	Rmys	*Yasuhikotakia morleti* (Tirant, 1885)	Ymor
Esomus metallicus Ahl, 1923	Emet	*Rasbora paviana* Tirant, 1885	Rpav	**Siluriformes/Amblycipitidae**	
Garra cambodgiensis (Tirant, 1883)	Gcam	*Scaphiodonichthys burmanicus* Vinciguerra, 1890	Sbur	*Amblyceps mucronatum*Ng & Kottelat, 2000	Amuc
Garra fuliginosa Fowler, 1934	Gful	*Sikukia gudgeri* (Smith, 1934)	Sgud	*Amblyceps foratum* Ng & Kottelat, 2000	Afor
Hampala macrolepidota Kuhl & Van Hasselt, 1823	Hmac	*Sikukia stejnegeri* Smith, 1931	Stej	**Bagridae**	
Henicorhynchus siamensis (Sauvage, 1881)	Hsia	*Thynnichthys thynnoides* (Bleeker, 1852)	Tthy	*Bagrichthys macracanthus* (Bleeker, 1854)	Bmac

Table 2 Species list and its abbreviation (abbr.) of 198 fish species found during 1996-2009 in the Ping-Wang River Basin (Cont.).

Scientific name	Abbr.	Scientific name	Abbr.	Scientific name	Abbr.
Hypophthalmichthys molitrix (Valenciennes, 1844)	Hmol	*Tor tambroides* (Bleeker, 1854)	Ttam	*Bagrichthys macropterus* (Bleeker, 1853)	Bmar
Hypophthalmichthys nobilis (Richardson, 1845)	Hnob	**Gyrinocheilidae**		*Hemibagrus nemurus* (Valenciennes, 1840)	Hnem
Hemibagrus wyckii (Bleeker, 1858)	Hwyc	*Wallago attu* (Bloch & Schneider, 1801)	Watt	*Channa lucius* (Cuvier, 1831)	Cluc
Hemibagrus wyckioides (Fang & Chaux, 1949)	Hwyk	*Wallago leerii* Bleeker, 1851	Wlee	*Channa micropeltes* (Cuvier, 1831)	Cmic
Mystus albolineatus Roberts, 1994	Malb	**Sisoridae**		*Channa striata* (Bloch, 1793)	Cstr
Mystus multiradiatus Roberts, 1992	Mmul	*Bagarius bagarius*(Hamilton, 1822)	Bbag	**Cichlidae**	
Mystus mysticetus Roberts, 1992	Mmys	*Bagarius yarrelli* (Sykes, 1839)	Byar	*Oreochromis niloticus* (Linnaeus, 1758)*	Onil
Mystus singaringan (Bleeker, 1846)	Msin	*Exostoma vincegerrae* Regan, 1905	Evin	*Oreochromis* hybrid*	Ohyb
Pseudomystus siamensis (Regan, 1913)	Psim	*Glyptothorax lampris* Fowler, 1934	Glam	**Eleotridae**	
Clariidae		*Glyptothorax fuscus*	Gfus	*Oxyeleotris marmorata* (Bleeker, 1852)	Omar
Clarias batrachus (Linnaeus, 1758)	Cbat	*Glyptothorax trilineatus* Blyth, 1860	Gtri	**Gobiidae**	
Clarias gariepinus (Burchell, 1822)	Cgar	*Oreoglanis siamensis* Smith, 1933	Osia	*Rhinogobius chiengmaiensis* Fowler, 1934	Rchi
Clarias hybrid(*C. macrocephalus* X *C. gariepinus*)	Chyb	**Cyprinodontiformes/Poeciliidae**		**Helostomidae**	
Clarias macrocephalus Günther, 1864	Cmac	*Gambusia affinis* (Baird & Girard, 1853)	Gaff	*Helostoma temminckii* Cuvier & Valenciennes, 1831	Htem
Loricariidae		*Poecilia reticularis* Peters, 1859	Pret	**Nandidae**	
Pterygoplichthys disjunctivus (Weber, 1991)	Pdis	*Xiphophorus helleri* Heckel, 1848	Xhal	*Pristolepis fasciatus* (Bleeker, 1851)	Pfas
Pangasiidae		**Synbranchiformes/Synbranchidae**		**Osphronemidae**	
Helicophagus leptorhynchus Ng and Kottelat, 2000	Help	*Monopterus albus* (Zuiew, 1793)	Malb	*Osphronemus goramy* Lacepède, 1801	Ogor
Pangasianodon gigas Chevey, 1931	PGIG	**Mastacembelidae**		*Trichogaster pectoralis* (Regan, 1910)	Tpec
Pangasianodon hypophthalmus (Sauvage, 1878)	Phyp	*Macrognathus siamensis* (Günther, 1861)	Msia	*Trichogaster trichopterus* (Pallas, 1770)	Ttri
Pangasius bocourti Sauvage, 1880	Pboc	*Mastacembelus armatus* (Lacepède, 1800)	Marm	*Trichopsis vittata* (Cuvier, 1831)	Tvit
Pangasius conchophilus Roberts & Vidthayanon, 1991	Pcon	*Mastacembelus favus* Hora, 1924	Mfav	**Sciaenidae**	
Pangasius larnaudii Bocourt, 1866	Plar	*Mastacembelus* cf. *tinwini*Britz, 2007	Mtin	*Boesemania microlepis* (Bleeker, 1858)	Bmic
Pangasius macronema Bleeker, 1851	Pmac	**Beloniformes/Belonidae**		**Toxotidae**	
Pangasius pleurotaenia Sauvage, 1878	Pple	*Xenentodon cancila* (Hamilton, 1822)	Xcan	*Toxotes chatareus* (Hamilton, 1822)	Tcha
Pangasius sanitwongsei Smith, 1931	Psni	**Hemiramphidae**		**Pleuronectiformes/Cynoglossidae**	
Siluridae		*Dermogenys pusilla* Kuhl & van Hasselt, 1823	Dpus	*Cynoglossus microlepis* (Bleeker, 1851)	Cmio
Belodontichthys truncatus Kottelat & Ng, 1999	Btru	**Perciformes/Ambassidae**		*Cynoglossus feldmanni* (Bleeker, 1853)	Cfel
Kryptopterus cheveyi Durand, 1940	Kche	*Parambassis siamensis* (Fowler, 1937)	Psia	**Soleidae**	
Kryptopterus cryptopterus (Bleeker, 1851)	Kcry	*Parambassis wolffii* (Bleeker, 1851)	Pwol	*Brachirus harmandi* (Sauvage, 1878)	Bhar
Micronema hexapterus (Bleeker, 1851)	Mhex	**Anabantidae**		*Brachirus siamensis* (Sauvage, 1878)	Bsia
Ompok bimaculatus (Bloch, 1794)	Obin	*Anabas testudineus* (Bloch, 1795)	Ates	*Solea ovata* Richardson, 1846	Sova
Phalacronotus apogon (Bleeker, 1851)	Papo	**Channidae**		**Tetraodontiformes/Tetraodontidae**	
Phalacronotus bleekeri (Günther, 1864)	Pble	*Channa gachua* (Hamilton, 1822)	Cgac	*Tetraodon leiurus* Bleeker, 1851	Tlei

Table 4 Average (± SD) of physicochemical parameters and geo-morphological parameters in each sub-basin of the Ping-Wang River basin

Parameters	**Sub-basins**									
	UP	**MT**	**SP**	**MK**	**MC**	**TP**	**ME**	**FP**	**LP**	**WA**
Water temperature (°C)	23.4±1.5	23.4±1.4	23.7±2.9	24.8±1.4	22.1±1.3	27.2±2.4	21.8±0.6	29.0±1.5	30.8±0.3	27.2±3.9
Conductivity (mg/l)	64.0±16.7	72.1±26.1	84.6±49.9	65.0±13.8	78.6±73.9	77.2±28.5	51.7±39.5	103.3±8.2	100.0±8.2	84.4±11.5
Total dissolved solids (mg/l)	126.0±107.4	79.6±34.6	93.8±58.7	66.7±17.5	90.9±66.9	148.9±85.5	95.4±43.5	81.7±7.5	80.0±8.2	98.9±16.0
Dissolved oxygen (mg/l)	6.06±1.0	6.25±0.8	7.08±1.3	5.52±0.4	6.18±0.7	5.09±0.9	5.93±0.5	4.17±1.1	4.90±0.5	4.72±2.0
Nitrite(mg/l)	0.01±0	0.01±0	0.03±0.03	0.08±0.02	0.010±0.54	0.0±0	0.02±0.01	0.08±0.02	0.08±0	0.03±0.01
Ammonia(mg/l)	0.03±0.01	0.03±0.02	0.03±0.2	0.02±0.03	0.012±0.70	0.01±0	0.01±0.01	0.33±0.11	0.035±0.07	0.02±0.01
Phosphorus (mg/l)	0.216±0.1	0.116±0.1	0.060±0.1	0.071±0	0.106±0.1	0.076±0	0.068±0	0.122±0	0.203±0.1	0.097±0.1
pH	7.3±0.4	7.2±0.4	7.5±0.6	7.0±0.3	8.0±0.2	7.1±0.5	6.6±0.4	8.4±0.2	8.5±0.3	7.6±0.9
Alkalinity (mg/l)	82.0±14.8	64.2±27.6	100.8±138.9	45.0±8.4	59.1±33.0	81.3±27.8	62.1±12.2	132.5±17.8	142.8±28.5	94.5±15.9
Hardness (mg/l)	92.0±22.8	103.3±23.6	84.3±50.3	51.7±7.5	105.2±27.2	101.8±25.8	53.8±7.1	80.2±20.3	103.5±28.5	60. 6±25.1
Current velocity (m/s)	0.804±0.4	0.519±0.5	0.389±0.2	0.330±0.1	0.795±0.1	0.443±0.2	0.341±0.2	0.535±0.3	0.592±0.2	0.430±0.5
Depth (m)	0.4±0.2	0.6±0.4	1.9±6.0	0.3±0	0.7±0.4	2.8±1.2	0.5±0.2	2.7±0.5	3.2±1.3	0.9±0.9
Width (m)	7±0.5	13±11.2	74±230.5	11±5.4	21±17.4	424±224.6	8±3.8	359±77.5	258±27.7	28±48.2
Discharge (m^3/s)	4.05±0.71	15.38±28.41	2.77±1.52	1.52±0.9	35.18±63.7	19.31±40.38	2.76±3.1	814.86±691.3	799.27±401.3	7.05±6.76
Altitude (m)	684±228.3	756±166.2	553±160.2	1,070±213.4	627±207.3	261±11.5	804±229.2	120±33.5	48±8.0	408±123.8
Distance from the sea (km)	1,026±24.1	1,067±36.0	982±41.0	877±4.6	927±53.9	704±43.8	847±43.0	580±68.4	425±16.0	833±225.2
Watershed area (km^2)	6,355	1,761	4,236	600	3,838	3,071	3,143	2,940	2,944	10,791
Forest area (%)	76.5	72.1	75	88.4	74.7	88.2	85	67.7	72.6	76.5
Agricultural area (%)	23.3	25.4	24.9	11.5	24.4	11.6	11.5	29.6	22	23.3
Urban area (%)	0.1	0.3	0.1	0.1	0.9	0.1	0.2	2.8	5.4	0.1

Note abbreviations of sub-basin as in **Table 1**

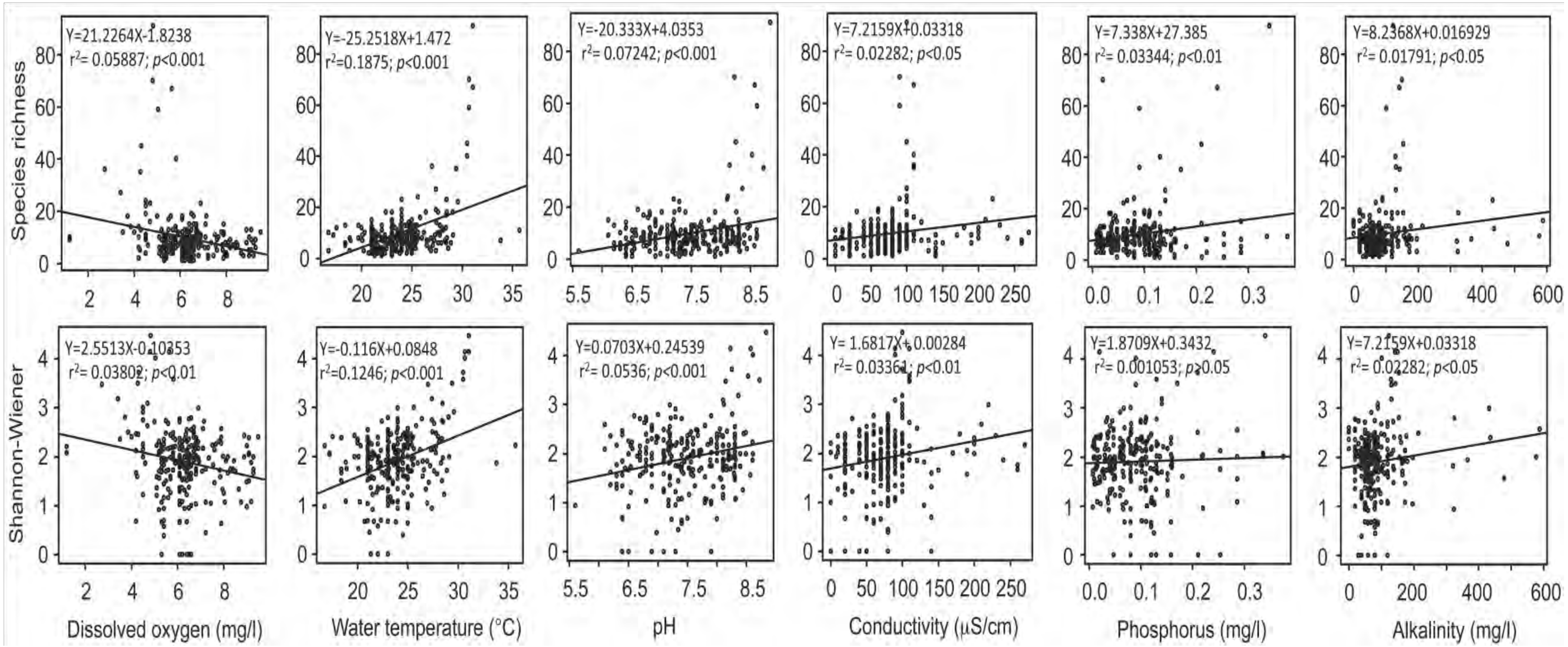

Figure 2. Scattered plots between physicochemical water quality parameters and diversity indices, and their linearity trends (selected only the statistically significant parameter, P < 0.05)

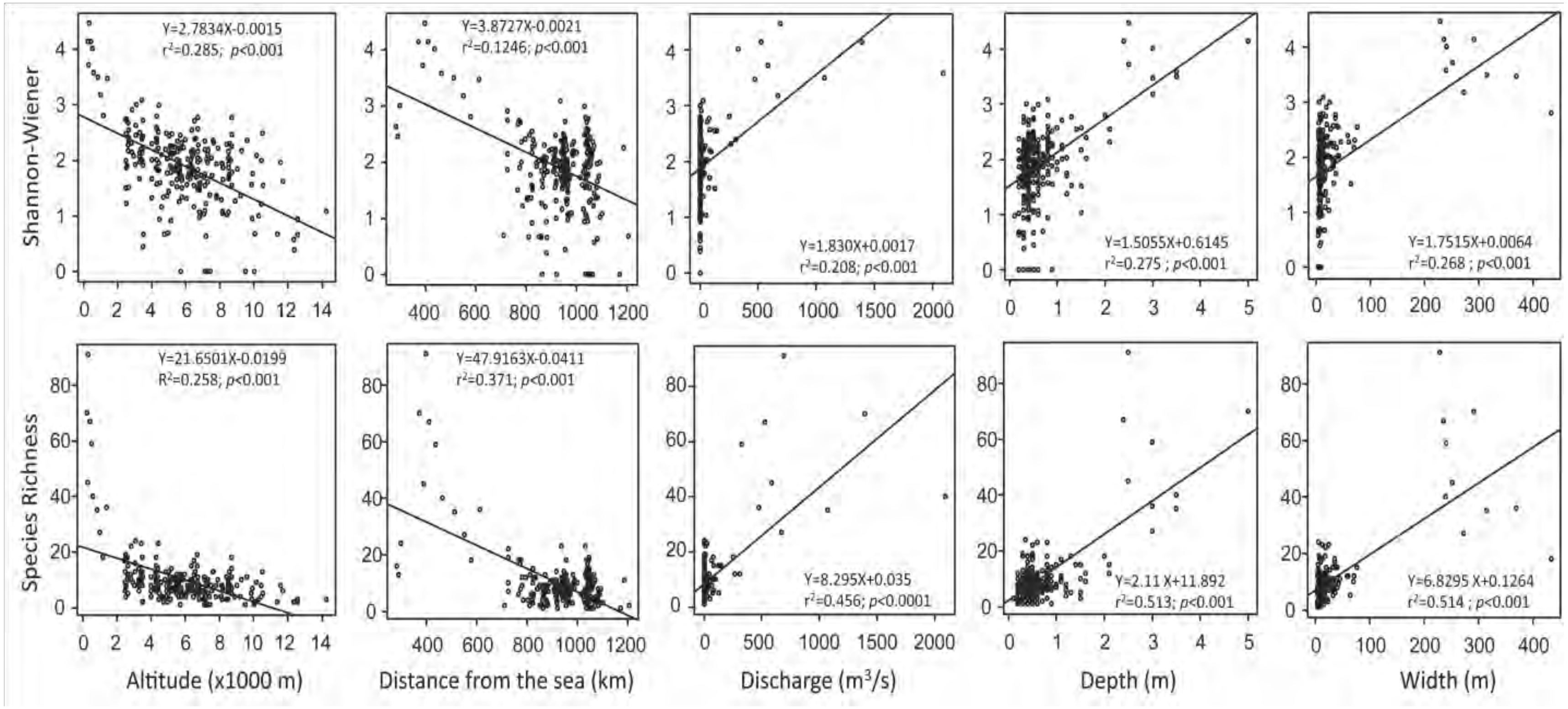

Figure 3. Scattered plots between geo-morphological parameters and diversity indices and their linearity trends (selected only the statistically significant parameter, $P < 0.05$)

physicochemical parameters, i.e. DO, water temperature, pH, conductivity, phosphorus and alkalinity, which showed statistical significance relationships to diversity parameters (P-value < 0.05, Fig. 3). Higher DO in the high altitude area (Table 4) made a negative relationship of this parameter to both species richness and Shannon diversity index but showed positive relationships to the other predictive parameters. However, due to extensive and high variation of the obtained data, all the linear models showed low power in prediction, i.e. r^2 was less than 0.5. Scattered plots of temperature to both response variables showed that from the low temperature to 30 ^oC, the relationships tended to be non-linear. But if temperature was beyond 30 ^oC, the diversity trended to decline. The pH ranged from 5.5 to 8.7 and the diversity parameters were obviously low in acidic water and the relationship to species richness tended to be as in power function. Average of conductivity was 75.23 ± 38.47 $\mu S.cm^{-1}$ and high fish diversity was observed around this range. Species richness and Shannon diversity index were slightly increased as alkalinity and phosphorus increased but non-statistical relationship was found between Shannon diversity index and phosphorus (P-value > 0.05).

Table 3 Summary of fish diversity indices from the samplings during 1996-2009 in the Ping-Wang river basin.

Sub-basins	Total individuals	Shannon Diversity index	Simpson Dominance index	Species evenness	Species richness
UP	545	2.0628	5.179	0.744	16
MT	5607	2.8194	6.168	0.7004	56
SP	10375	3.4195	6.745	0.7425	98
MK	474	1.4581	3.523	0.6081	11
MC	4425	2.9265	6.536	0.6985	66
TP	1789	3.5133	9.015	0.7808	84
ME	1755	2.6698	4.532	0.785	30
FP	1060	3.9366	30.42	0.9036	78
LP	1081	4.4506	60.094	0.9432	112
WA	2244	3.3971	9.697	0.7775	77

Predicting of diversity parameters

Species richness and Shannon diversity index of each individual sampling ranged from 11 to 112 species and 1.099 to 3.401, respectively. They were then log-transformed and fed to CART model as a response variable by using 20 environmental predictors. The geo-morphological parameters were the major factors in determining both diversity indices. For species richness, by the tree “pruning “process and optimal tree selection, 3 parameters were included in the CART model and altitude (ALT) was the major contributor in predicting species richness followed by width (WID) and distance from the sea (DFS) (Fig. 4). Altitude was used in both of the first and the second splits, meanwhile the other parameters were used in the third split. The coefficient of determination, r^2, of this model was 0.59 and showed that if the altitude was less than 93.5 m ASL, high species diversity was observed, i.e. about 60 species.

The r^2 of the model for Shannon diversity index was 0.76. Six parameters were accumulated and used as predictors *viz.*, width, altitude, discharge, pH, agricultural area and alkalinity (Fig. 5). Width was used in the first split and showed that the index would not beyond 3. Altitude was used in the second split and showed the trend that the higher the altitude, the lower the index. The remaining 4 parameters were combined with altitude to make further splits for prediction.

Relationships of fish assemblage and environmental parameters

Fifty-three fish species and twenty environmental variables were loaded in the CCA analysis. Total model inertia (sum of unconstrained eigen values) was 4.232, and the sum of all canonical eigen values was 5.531, in which the species-environment correlation coefficients for the first and second axes of CCA accounted for 55.9 % and 17.62 %, respectively. Monte-Carlo permutation attested that both axes were significant ($P < 0.001$). The length of vector of a given variable on the CCA plots indicates the importance of that variable. The first CCA environmental axis (CCA1) was described by altitude, distance from the sea, water depth, stream width and water temperature of the basin. The first two parameters were negatively correlated to CCA1 while the remaining parameters were positively. The most important variable for the second CCA environmental axis (CCA2) was watershed area, meanwhile the others were correlated less than 0.5 (Table 5 and Fig. 6a). Composition of individual fish species, which related to the environmental vectors loaded to CCA, was shown in Fig. 6b and the first five species having strong loading to CCA1 and CCA2, either positive or negative correlation, are presented in Table 5.

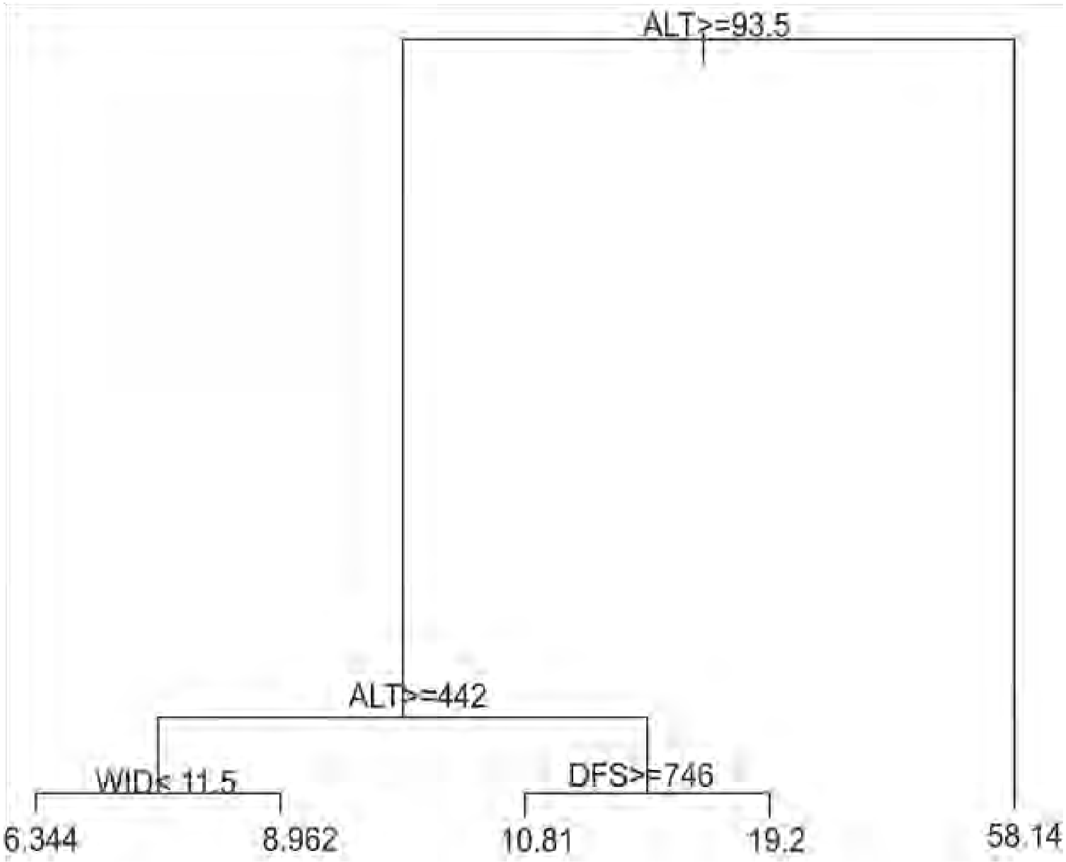

Figure 4. CART model to predict species richness in the Ping Wang River Basin.

Distribution of fish species along the CCA axes can be classified into 4 main assemblage patterns (Fig. 6b). The first assemblage (quadrant I) was negatively correlated to both CCA1 and CCA2, implying that they inhabited in the mountainous area of high altitude with relative low temperature and strong current velocity. The second assemblage was negatively correlated to CCA1 and positively to CCA2. The shorter distance from CCA1 (quadrant II) indicated that the fish in this assemblage occupied a lower altitude than those in the first assemblage. The remaining two assemblage patterns were positively correlated to CCA1 (quadrants III and IV) and implying that the fishes in these assemblages live in the lower portion of the river course, where the river width and depth were more than the previous two assemblages. The last assemblage (quadrant IV, negatively to CCA2) inhabited a larger watershed close to agricultural and urban areas, which have high phosphorus loading. Meanwhile, species that distributed in the around the center of the bi-plot

(Fig. 6B) had very little differentiation among each other e.g. *Discherodontus schoeroderi*, *Puntius brevis*, *Puntius orphoides*, and *Rasbora paviana.*

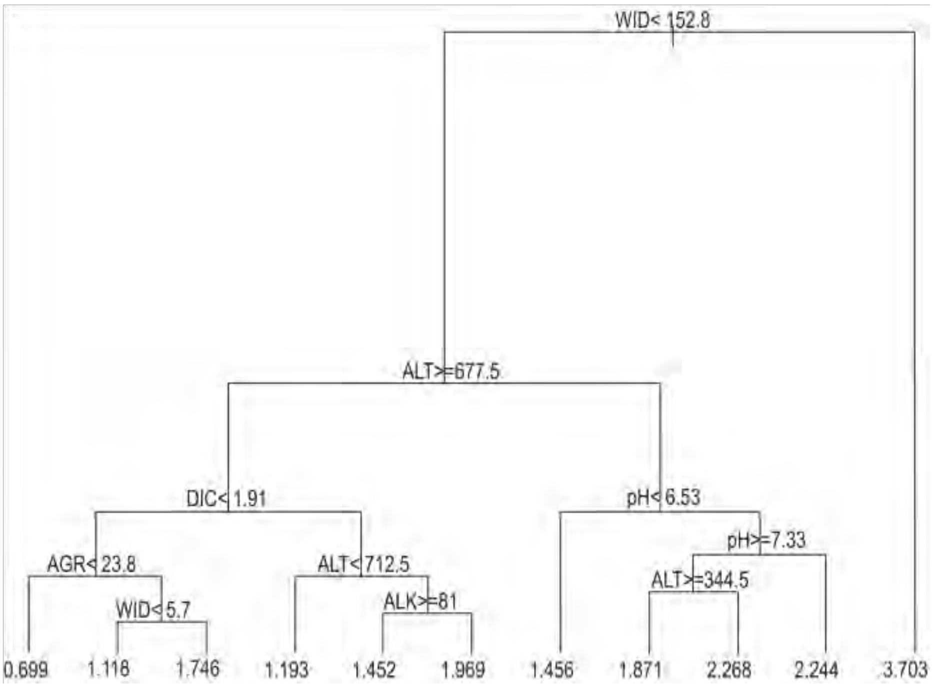

Figure 5. CART model to predict Shanon diversity index in the Ping Wang River Basin.

The result from Ward's analysis (Fig 6c) was used to refine the habitat preference of 53 individual species after the CCA analysis. Eight species in quadrant I, inhabiting the small streams in high altitude area with low temperature, were grouped together and defined as "mountainous" species They were *Oreoglanis siamensis* (Osia), *Devario regina* (Dreg), *Exostoma vinciguerrae* (Evin), *Schistura pridii* (Spri), *Schistura waltoni* (Swal), *Scaphiodonichthys burmanicus* (Sbur) *Glyptothorax trilineatus* (Gtri) and *Devario maetangensis* (Dmae). The remaining species in quadrant I, which located closely to CCA1 axis, and all species in quadrant II were grouped and defined as "piedmont" species (22 species). The examples in this group were *Lepidocephalichthys hasseltii* (Lhas), *Dermogenys pusilla* (Dpus), *Monopterus albus* (Malb), *Channa gachua* (Cgac) and *Homaloptera leonardi* (Hleo). Species positively correlated to CCA1, were divided into two groups. Firstly, the species located close to CCA1, were defined as "transitory" species, i.e. species that migrated between piedmont and lowland area, (8 species) such as *Puntius orphoides* (Porp),

Table 5 Statistics associated with the first two canonical axes from Canonical correspondences analysis (CCA) for 20 environmental variables and the first five fish species that showed strong loading to CCA

	Axis 1	**Axis 2**		**Axis 1**	**Axis 2**
Correlations of geo-morphological parameters loading with axis			Correlations of physicochemical parameters loading with axis		
Altitude (m)	-0.929	-0.142	Water temperature (°C)*	0.583	0.064
Distance from the sea (km)*	-0.703	0.196	Conductivity (µS/m)*	0.387	0.149
Current velocity (m/s)*	-0.224	-0.045	pH	0.238	0.150
Width (m)*	0.583	-0.284	Total Dissolved Solids (mg/l)*	0.219	0.024
Depth (m)*	0.591	-0.227	Phosphorus (mg/l)*	0.191	-0.428
Discharge (m^3/s)*	0.430	-0.242	Alkalinity (mg/l)*	0.202	0.388
Watershed area (km^2)*	0.153	-0.809	Hardness (mg/l)*	0.082	-0.052
Forest area (km^2)	-0.228	0.149	Dissolved Oxygen (mg/l)	-0.359	0.377
Agricultural area (km^2)*	0.105	-0.142	Nitrite (mg/l)*	0.105	0.167
Urban area (km^2)*	0.232	-0.406	Ammonia (mg/l)*	0.163	-0.056
Correlations of fish species with strong positive loadings on CCA1			Correlations of fish species with strong negative loadings on CCA1		
Pristolepis fasciatus	1.398	-0.364	*Oreoglanis siamensis*	-1.119	-0.889
Barbonymus altus	1.387	-0.398	*Devario regina*	-1.102	-0.517
Mystus singaringan	1.387	-0.528	*Exostoma vinciguerrae*	-1.090	-1.064
Notopterus notopterus	1.360	-0.489	*Schistura pridii*	-0.898	-0.742
Osteochilus hasselti	1.322	-0.331	*Devario maetangensis*	-0.890	-0.465
Correlations of fish species with strong positive loadings on CCA2			Correlations of fish species with strong negative loadings on CCA2		
Lepidocephalichthys hasselti	-0.546	1.344	*Exostoma vinciguerrae*	-1.090	-1.064
Dermogenys pusilla	-0.484	0.731	*Oreoglanis siamensis*	-1.119	-0.889
Monopterus albus	0.966	0.654	*Schistura pridii*	-0.898	-0.742
Channa gachua	0.038	0.592	*Scaphiodonichthys burmanicus*	-0.873	-0.735
Homaloptera leonardi	-0.405	0.559	*Glyptothorax trilineatus*	-0.854	-0.683

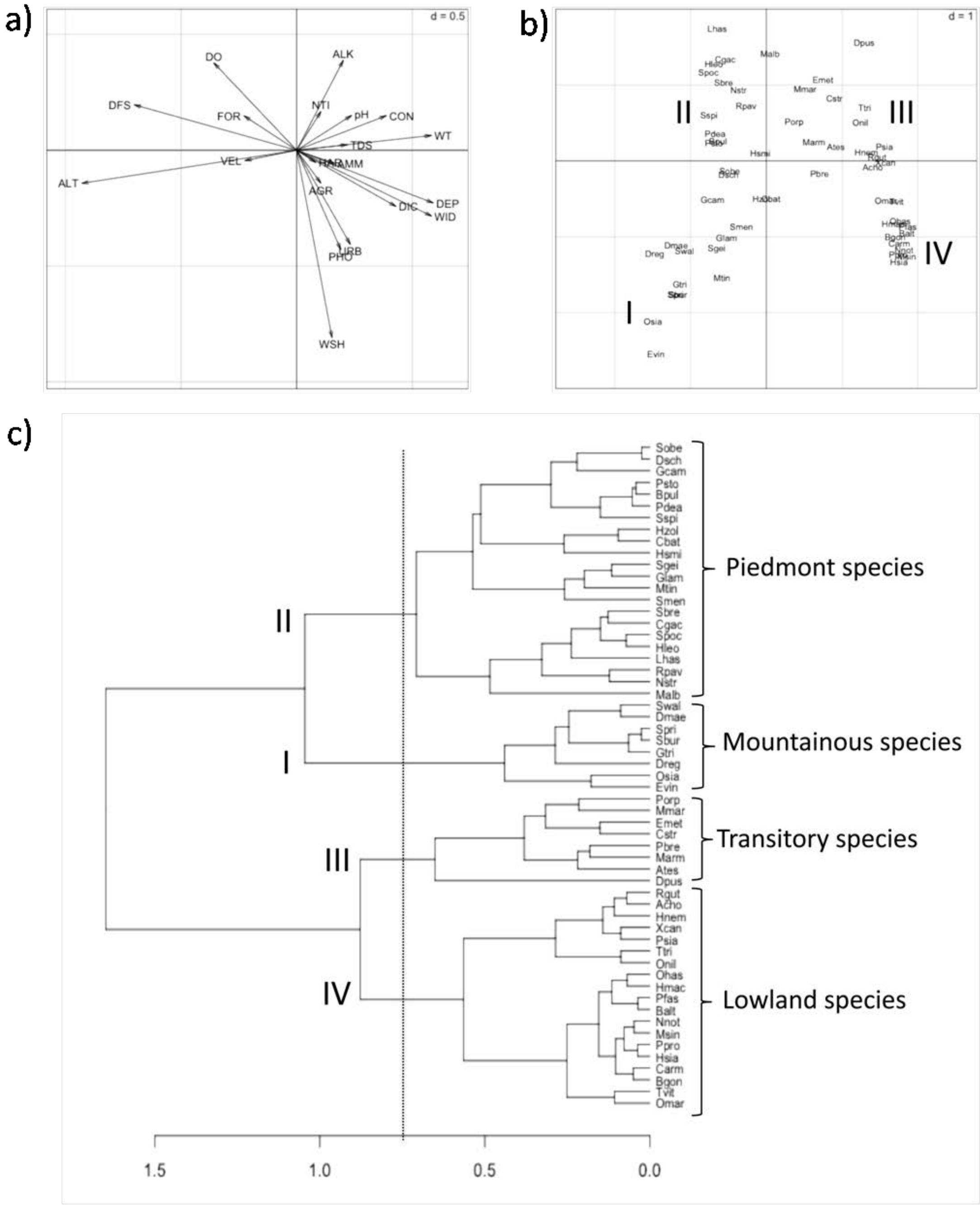

Figure 6. Biplots CCA ordination with the composition of fish species related to the environmental vectors in the Ping-Wang River basin. a) environmental variables loading to CCA axes and b) species assemblages and c) Dendrogram of fish assemblages in the Ping-Wang River Basin.

Note See text for abbreviation of environmental parameters and Table 2 for fish species.

Mastacembelus armatus (Marm), *Puntius brevis* (Pbre) and *Mystacoleucus marginatus* (Mmar), and secondly, the group of species that showed the highest positive loading to CCA1 were defined as "lowland" species. Examples of this group were *Pristolepis fasciatus* (Pfas), *Barbonymus altus* (Balt), *Mystus singaringan* (Msin), *Notopterus notopterus* (Nnot) and *Osteochilus hasselti* (Ohas).

DISCUSSION

Understanding the diversity, abundance and coexistence of diverse fish species assemblages in river ecosystems are among the central goals in tropical ecological research (Herder & Freyhof, 2006). Dominance by the multi-species and ecologically diverse Cyprinidae is common in Southeast Asia, where they may contribute 40% or more of the species in a watershed (Taki 1978; Beamish et al., 2006). This is because cyprinids have evolved partially through highly adapted body forms and mouth structures so they occupy virtually all habitats throughout their distributions (Ward-Campbell et al., 2005). The second most dominant family of Balitoridae indicates the characteristic of high altitude mountainous area of this study since the fish in this family are significantly related with high elevation (Beamish et al., 2008).

The complexity and non-linearity of the relations between the communities and their environment are very common (Gevrey et al., 2003) as shown in the results. Meanwhile, the low r^2 values from the linear correlations found in some environmental variables to the diversity indices showed the weak relationships. For prediction of fish diversity, it was found that geo-morphological and landscape parameters were the good predictors for species richness and Shannon diversity index compared to those physicochemical parameters. Changes in both diversity indices follow the general longitudinal pattern of river fish distribution as the lowest levels tend to be found at high altitudes, and the highest levels at mid to low altitudes (Gaston & Blackburn, 2000; He et al., 2010). High values of both diversity indices in the lower altitude with larger watershed also supports the species–area relationships pattern, which suggests larger areas of habitat generally contain more species than smaller areas (Angermeier & Schlosser 1989; Han et al., 2008). The large watershed is also associated with deep and wide area, which shows robust positive relationships to species richness (Connor & McCoy, 1979; Angermeier & Karr, 1983). High discharge implies a large volume of water for a number of fishes to occupy and increase in river flow results in more fish species richness because of greater heterogeneity of local fish habitats (Guégan et al., 1998; He et al., 2010).

The physicochemical parameters would be important to fish species richness and abundance in a relatively small spatial scale or single drainage system (Tongnunui & Beamish, 2009; Alexandre et al., 2010). Low rate of correlation between these parameters to species richness implies that they had weak relationships. Killgore & Hoover (2001) reported on a second degree polynomial relationship between DO and species richness, implying there is an optimum level of DO to fish diversity, which as seen in the result that peak of species richness and diversity index ranged between 4 and 6 $mg.l^{-1}$. Temperature reflects directly on metabolism and is recognized as a dominant factor in the control of species diversity (Oberdorff et al., 1995; Guégan et al., 1998), which the relationship as power function indicated the critical temperature at about 30 ^{o}C and few species can survive beyond this point. This kind of relationship is also the case for pH, which few species can inhabit the acidic condition and being optimized at range 7.5-8.5. Meanwhile the linear-trend positive relationships of the remaining three parameters, i.e. conductivity, phosphorus and alkalinity, to species diversity are widely reported (e.g. Johal et al., 2001; Shahnawaz et al., 2010). The effects of land uses on fish community structure have been widely investigated and proven to be the important determinants (e.g. Orrego et al., 2009; Alexandre et al., 2010).

Distinct patterns of fish assemblage along the longitudinal river gradient reflects the homogenous spatial units within the river basin (Welcomme et al., 2006; Ferreira & Petrere, 2009) and the results from ordination and classification showed four fish assemblage patterns from the headwater to lowland river reaches. Multiple mechanisms can explain partitioning of fish assemblages along longitudinal gradients of the river such as resource availability, quality of habitats and adaptation of individual species (Matthews, 1998). The assemblage of mountainous species showed their restricted occurrence in a high altitude area, with associated riffles, pools and rapids. All the fish in this assemblage shows their morphological adaptation to survive in the strong flow conditions (Casatti & Castro, 2006; Welcomme et al., 2006). The interplay between strong currents and rocky substrates usually generates the mountainous areas rich in food, such as patches of rapidly growing periphytic algae and the aquatic insect larvae that directly or indirectly fed by mountainous species (Casatti & Castro, 2006). Moreover, the cold water designation whole year round in the mountainous area also likely influence the fish community (Wanner et al., 2011). Any human activities that disturb the pool-riffle structure, such as changes to the flow regime, increases in sediment load and make and anoxic condition would affect this assemblage (Welcomme et al., 2006).

Various microhabitats in the piedmont, such as main channel, backwaters and side channel anabranches as well as various bottom types support the richness of both the fluvial specialist and habitat generalist fish species (Freeman & Marcinek, 2006). Yet, large debris from forest area in the piedmont, which is characterized by extreme flooding and bank erosion during the rainy season, shows a positive effect on fish densities and diversity (Angermeier & Karr, 1983; Wright & Flecker, 2004). Residences in this assemblage also require relatively high dissolved oxygen levels and as such they are sensitive to reductions conditions are sensitive to reductions in water quality (Welcomme et al., 2006). Meanwhile, differences in food resources and habitats use among the fish species within the assemblages results in complexity in this assemblage. For example, *Garra cambodgiensis*, an algae eater, and an insectivore *Schistura breviceps* occupy the rocky and pebble bottoms (Rainboth, 1996; Kottelat, 1998; Ward-Campbell et al., 2005). The fluvial specialists, *Barilius pulchellus* and *Homaloptera* spp. inhabit the main channel. Although both of them are insectivores, *B. pulchellus* feeds on odonatan larvae whereas *Homaloptera* spp. feed on benthic insects (Rainboth, 1996). Meanwhile, the inhabitants in the backwater include *Channa gachua*, *Clarias batrachus* and *Mastacembelus* spp., the first two species being predators and the latter an insectivore (Rainboth, 1996; Kottelat, 1998).

Complexity of fish community in the lowland river could be driven by a great amount of productive littoral zone due to the large watershed with deep and wide river channel (Angermeier & Karr, 1983; Han et al., 2008). Both rheophilous and limnophilous fishes were the common residents in the lowland river. However, some species were sub-divided to involve the transitory assemblage, in which rheophilous cyprinids always dominate (Allouche, 2002). Four rheophilous cyprinids (out of 8 species) were included in this assemblage viz., *Puntius orphoides*, *Puntius brevis*, *Mystacoleucus marginatus* and *Esomus metallicus*. The word "transitory" was used to describe this assemblage implying that, indeed, the fish could also occupy the lowland rivers (Rainboth 1996; Kottelat, 1998), where the lentic cyprinids and other limnophilic fishes dominated, i.e. lowland species (Allouche, 2002; Beamish et al., 2006). However, upstream movement of these lowland species is sometimes observed especially for reproduction (Silva & Davies, 1986; Ferreira & Petrere, 2009; Tongnunui & Beamish, 2009). This phenomenon supports the pattern of species addition for the shifting in species composition (Huet, 1959; Petry & Schulz, 2006). Meanwhile the pattern of species replacement is expected in mountainous regions, where abrupt transitions could be observed as well as physicochemical conditions being stressful and fewer fish species adapt to survive (Ferreira & Petrere, 2009; He et al., 2010). Damming of the river course upstream for irrigation purpose, which would likely to be taken place in the near future at the Ping-Wang River Basin, is inevitably affect the fish assemblages in the downstream river course. Damming alters the river flow, reduces nutrient loading from upstream and prevents fish migration (Welcomme et al., 2006), especially the transitory species.

In conclusion, this study confirms the importance of geo-morphological i.e. altitude, stream width, and distance from the sea as a variable explaining variation in fish community structure along a river gradient (Esselman et al., 2006; Sullivan et al., 2006; Grossman et al., 2010) in a large scale whole basin. However, the contribution of the other variables, especially some of the physicochemical water quality parameters, should be considered in terms of point and non-point pollution sources over a small scale (Ibarra et al., 2005; Orrego et al., 2009). The delineation of fish assemblage patterns enhances the understanding of fish zonation in this region. The patterns in fish assemblage structure of this large-scale Ping-Wang river basin seemed to be influenced by species-specific responses to dominant environmental gradients. Meanwhile, further study is needed to examine the role of individual species within each zone for better assessment of the impacts of human disturbances in each zone in the future.

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P5

Fish communities in highland tropical streams connected to a reservoir.

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(In preparation)

FISH COMMUNITIES IN HIGHLAND TROPICAL STREAMS CONNECTED TO A RESERVOIR

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Running title: Fish communities in a highland tropical reservoir

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ABSTRACT

Fish communities in the high altitude streams connected to the Mae-ngad reservoir (412 to 425 m ASL), Thailand, were investigated both in the streams (10 stations) and the reservoir (2 stations). The study was carried out from October 2002 to September 2003 with a total of 144 surveys. Fish belonging to 66 species and 21 families were captured and almost one-half (48%) of the species caught were insectivores. The dominant family was the Cyprinidae (23 species) followed by Balitoridae and Cobitidae (each containing 7 species), which both exclusively inhabit the strong current stream. A self-organizing map (SOM) was used to cluster the fish community, according to the similarities in fish composition in each survey. Three fish communities were obtained, namely reservoir-, stream- and intermediate-communities. The reservoir communities were characterized by "lentic-adapted" fish such as *Labiobarbus lineatus,* (Sauvage, 1878) and *Puntioplites proctozysron* (Bleeker, 1865), whereas rheophilic species, such as *Rasbora paviana* Tirant, 1885 and *Channa gachua* (Hamilton, 1822), were dominant in the stream community. The intermediate community, which contained a mixture of species from both the other communities, was found during the rainy season. A classification and regression tree was used to examine the contribution of environmental variables to the composition of the communities and to build predictive models. Six variables were selected as predictors, of which water depth was the major parameter to predict community types, followed by water chemistry. The overall percentage of successful prediction by the model was 66.0 %: the model was 100% accurate for the prediction of the reservoir community but very low for the stream community (40%).

Keywords: lentic-adapted species, rheophilic species, Self organizing map, environmental variables, Thailand

INTRODUCTION

River impoundment changes the water body from “rivers” to “reservoirs”, affecting not only the hydrology but also the physical, chemical, and biological characteristics. The result of these environmental alterations is a progressive decrease in the number of individuals and species of the native flora and fauna (Barrella and Petrere 2003). Impoundment also has an immediate impact on fish assemblages (Gao et al. 2010) and long- term changes on fish communities (Taylor et al. 2001). The impact of downstream damming on fish communities has been well documented in past decades and including recent studies of an upstream area, especially in connected tributaries. However there are still relatively few studies (e.g. Falke and Gido 2006; Penczak et al. 2009). The case is different if the damming is in the upper river course in a mountainous area connected to the first- and second- order streams. These have comparatively low fish species richness (Oberdoff et al. 1995; Welcomme et al. 2006), and most of the resident fish have the specific characteristics of living in a strong current with turbulent water flow and rocky substrates, i.e. rheophilic species (Casatti and Castro 2006).

Alterations in the river discharge patterns also affect the structure of the stream fish assemblages in the upper river course (Poff and Allan 1995). Fish assemblage structure varies with increasing distance from a reservoir and the abundance of reservoir fish in the upstream reaches declines with the distance from a reservoir (Falke and Gido 2006). Meanwhile, fish species that had successfully colonized the reservoir after impoundment could expand into the inflowing river (Hladík et al. 2008). For example, piscivorous fish can migrate into nearby streams and predate on the stream residents (Martinez et al. 1994, Matthews et al. 1994), while omnivorous fish could also move into the stream and compete for food sources with stream residents or alter the ecosystem in these streams (Gido and Matthews 2000).

Changes in fish communities in the reservoir, therefore, would be expected to be the communities of the species that could adapt to both lotic and lentic habitats and those, which migrate and inhabit exclusively the streams (McCartney 2009). Moreover, the composition of fish migrating from the reservoir into the inflowing river can be reflected in the changes in the fish assemblage in the inflowing river (Hladík et al. 2008). Variability in fish abundance and community structure is also governed by environmental factors along river courses (Lasne et al. 2007), which is also the case when the river is dammed and there is a change in environmental factors (Barrella and Petrere 2003). Therefore, to evaluate that if there were any differences in the fish community structures induced by damming the upper reach of a tropical region, the objective of this study was to examine the fish community patterns in the streams that connected to a reservoir as well as the contribution of environmental variables to the assemblages.

MATERIALS AND METHODS

Study area and its characteristics

The Mae-ngad reservoir is located in Chiangmai province, in northern Thailand (19º15.18 N, 099º 03.35 E to 19º 15.25 N, 099º 17.43 E, Fig. 1). It is multi-purpose and encompasses fisheries as an asset. Its elevation ranges from 412 to 425 m ASL with a catchment area of 1,309 km^2, a water surface of 16 km^2 and it can store up to 265 million m^3 of water. It was dammed across the Mae-ngad stream, one of the first order stream tributaries of the Ping River Basin. The maximum depth of the reservoir area is 30 m with a mixed clay and silt bottom. Meanwhile, the depth of the tributary streams, connected to the reservoir, ranges between 0.25-2.0 m and there are various bottom types (i.e. rock, gravel, sand, silt and mud) along the stream gradient. There is an area of forest cover around the reservoir without any agricultural activities or villages in the vicinity.

Field sampling

Fish were sampled monthly from October 2002 to September 2003 from 10 stations in the tributaries and 2 stations in the reservoir (Fig. 1). The sampling of the tributaries was done by using electro-fishing with a gasoline-powered electro shocker (Honda EM 650, DC 220 V 550BA 450VA, 1.5–2 A, 50 Hz). Electric shocking at each tributary sampling station was carried out for 45 to 60 minutes and the area covered was about 100 m^2, in various microhabitats, according to the bottom types. Sampling of the reservoir were done by gillnetting (mesh size 20, 40, 70, and 100 mm stretched mesh and each net's dimension was 25 x 1.2 m^2) from 0600 pm to 0600 am at the two sampling stations. Samples were identified in the field, sacrificed in a lethal

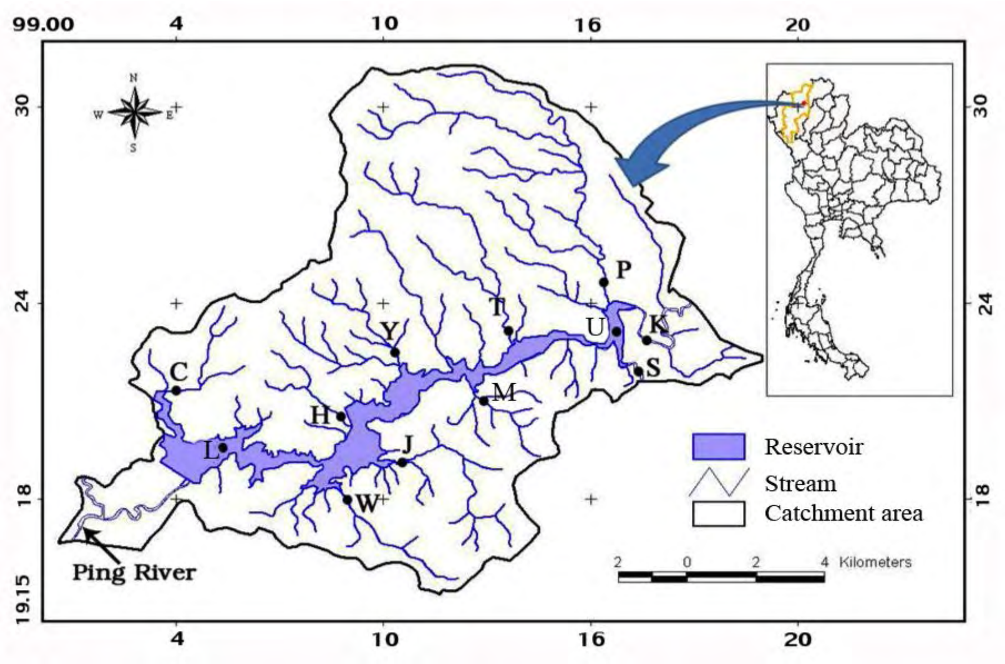

Figure 1. Map of the location of the sampling stations. Stream stations: S = Huay Mesoon,
K = Huay Mekhod, P = Huay Mepang, T = Huay Tontong, Y= Huay Tonyang, M =
Huay Mekua, H = Huay Phakub, J = Huay Mejog, W = Huay Panwa, C = Huay Chompoo and Reservoir stations: L = Lower part of the reservoir and U = Upper part of the reservoir

solution of anesthetic, counted, weighed (to the nearest 0.1 g), measured (to the nearest 0.1 mm), and fixed in 10% formalin. Unidentified samples were taxonomically classified in the Laboratory of Ichthyology at Maejo University and specimens were kept in the Maejo Aquatic Resources Natural Museum (MARNM), Chiangmai, Thailand.

Environmental variables were recorded at each sampling station, consisting of 9 physicochemical and 2 geo-morphological variables. Alkalinity (mg l^{-1}), hardness (mg l^{-1} as $CaCO_3$), Total Dissolved Solid (mg l^{-1}), conductivity (µS.cm^{-1}), dissolved oxygen (DO: mg l^{-1}), and pH were measured in-situ using a YSI Model 85 instrument. The ammonia (mg l^{-1}), nitrite (mg l^{-1}) and total phosphorus (mg l^{-1}) were measured in the laboratories according to the standard methods of APHA (1991). Stream width and depth were measured every 25 m along 100 m stream reach and then averaged to be a single estimator. In the reservoir, depth was measured at the sampling station, where gillnets were set. Meanwhile, width was estimated at 100 m according to the length of the series of gillnets.

Data analyses and modeling procedures

The contribution of individual species was presented as the percentage of the relative abundance (%RA) and the percentage of occurrence frequency (%OF). A data matrix was constructed with each row comprised of 66 species and 11 environmental variables of 144 surveys (i.e. the combination of station * month, e.g. L09 is the survey of station L in September). To present the fish assemblages, a self-organizing map (SOM), which is an unsupervised algorithm of an artificial neural network model (Kohonen 2001), was used. The advantage is that this method can be used to analyze complex data sets and for the analysis of non-linear relationships (Kohonen 2001), and to obtain a two-dimensional map for easy interpretation. The SOM has proved to be an effective and powerful tool for describing species distributions and assemblages (Suryanarayana et al. 2008)

The principle of SOM analysis is to classify the sample vectors (SVs), described by a set of descriptors on the map according to the similarities between the descriptors (i.e. fish species). Two SVs that are similar (from the descriptor point of view) are classified in the same or neighboring cells, whereas two different SVs are classified in separated cells that could be distant from each other (Tudesque et al. 2008). The processing elements in the network, called neurons, are arranged in a layered structure. The first layer, called the input layer, connects with the input variables. In our case, this was comprised of 66 neurons connected to the corresponding 144 surveys (i.e. 144 SVs). Then the second layer is the output layer that connects to the output variables. The output layer was made up of 56 output units in the hexagonal lattice (i.e. 8 x 7 cells), which provided the best results with which to classify community structures. The learning process of the SOM was carried out by using the SOM Toolbox (Vesanto et al. 1999) and the similarities between each cluster by mean of an analysis of similarities (ANOSIM) by analyzing the occurrence probability (*OP*) of individual species, which was obtained from the weighted vectors of the trained SOM (Kohonen 2001). The analysis of similarity (ANOSIM), a non-parametric test of significant difference between two or more groups, based on any distance measure (Clarke 1993), was used to assess significant differences between communities.

The predictive power and contribution of each environmental parameter to the patterns of fish assemblages was carried out by using the Classification and Regression Tree (CART: dé Ath and Fabricius 2000). CART explains variations in a single response variable using one or more predictor variables. To make a tree, the entire data set is referred to as the root node of the tree. This root node is partitioned into subsets of data that then comprise subsequent nodes. If a node is not subject to further partitioning, that node is called a terminal node (Anderson et al. 2000). The process is repeated until the tree can no longer be grown based on a set of stopping rules and cross-validation of the model. The graphics and statistical analyses were carried out with version 2.7.0.0 of the R-Program (R Development Core Team 2009).

RESULTS

Species composition and community assemblages

A total of 11,763 individuals from 66 species and 21 families (Table 1) were sampled. The dominant families were Cyprinidae (34.9 %), Balitoridae and Cobitidae (10.6 %) and Bagridae (6.1%). In terms of the trophic guilds, they were dominated by invertivores (47.5 %), followed by carnivores (31.8 %) and herbivores (20.7 %). The first three species that had highest percentage of relative abundance (%RA) were *Henicorhynchus siamensis* (Sauvage, 1881), *Mystacoleucus marginatus* (Valenciennes, 1842) and *Puntioplites proctozysron* (Bleeker, 1865) (Fig. 2). The highest percentages of occurrence frequency (%OF) were shown by *M. marginatus*, *Oxyeleotris marmorata* (Bleeker, 1852), and *Hampala macrolepidota* Kuhl & Van Hasselt, 1823 (Fig. 2).

According to the nature of the surveys contained in each cluster (Fig. 3), the clusters can be designated into reservoir-, stream-, and intermediate- communities, in which there were highly significant variations in the community structures (i.e. occurrence probability (*OP)* of individual species) among communities (ANOSIM, R=0.757, P<0.001). The reservoir community (RC) was characterized by the surveys

Table 1 Species composition of fish collected in the Mae-ngad reservoir and its tributaries between October 2002 and September 2003

Family	Scientific name	Abbrev.	Habitat	Guilds	Total length (mm)	
					Mean ±SD	Range
Notopteridae	*Notopterus notopterus* (Pallas, 1769)	Nnot	IC	CAR	239.4±44.3	132-395
Cyprinidae	*Barilius koratensis* (Smith, 1931)	Bkor	SC	INV	51.2±11.3	32-86
	Barilius pulchellus (Smith, 1931)	Bpul	SC	INV	57.8±14.7	30-105
	Danio albolineatus (Blyth, 1860)	Dalb	SC	INV	52.3±7.6	43-69
	Esomus metallicus Ahl, 1923	Emet	SC	INV	49.8±6.0	40-61
	Rasbora paviana Tirant, 1885	Rpav	SC	INV	50.7±12.3	10-90
	Barbonymus gonionotus (Bleeker, 1850)	Bgon	IC	HER	226.8±73.6	15-580
	Barbonymus altus (Günther, 1868)	Balt	IC	HER	180.0	180
	Cirrhinus cirrhosus (Bloch, 1795)	Ccir	RC	HER	325	325
	Cyclocheilichthys armatus (Valenciennes, 1842)	Carm	IC	INV	48.0±25.9	22-132
	Cyprinus carpio Linnaeus, 1758	Ccar	RC	HER	295.0	295
	Discherodontus schroederi (Smith, 1945)	Dshc	SC	INV	46.2±10.1	26-88
	Garra cambodgiensis (Tirant, 1883)	Gcam	SC	HER	43.5±11.8	11-99
	Hampala macrolepidota Kuhl & Van Hasselt, 1823	Hmac	IC	CAR	225.9±67.5	9-600
	Henicorhynchus siamensis (Sauvage, 1881)	Hsia	IC	HER	220.6±30.8	10-320
	Labeo chrysophekadion (Bleeker, 1850)	Lchr	RC	HER	218.3±19.8	175-265
	Labeo rohita (Hamilton, 1822)	Lroh	RC	HER	242	242
	Labiobarbus lineatus (Sauvage, 1878)	Llin	IC	HER	221.9±33.2	114-275
	Mystacoleucus marginatus (Valenciennes, 1842)	Mmar	IC	INV	67.0±28.0	15-152
	Neolissochilus stracheyi (Day, 1871)	Nstr	SC	HER	162.0	162
	Puntioplites proctozysron (Bleeker, 1865)	Ppro	IC	HER	179.9 ±26.6	10-235
	Puntius brevis (Bleeker, 1850)	Pbre	SC	INV	41.5±16.5	10-96
	Puntius stoliczkanus (Day, 1871)	Psto	SC	INV	39.1±7.9	25-55
	Puntius orphoides (Valenciennes, 1842)	Porp	IC	INV	111.5±64.8	12-210
Balitoridae	*Homaloptera smithi* Hora, 1932	Hmit	SC	INV	25.8±5.9	19-48
	Homaloptera zollingeri Bleeker, 1853	Hzol	SC	INV	27.3±5.6	15-55
	Nemacheilus binotatus Smith, 1933	Nbin	SC	INV	28.3±9.6	15-52
	Schistura breviceps (Smith, 1945)	Sbre	SC	INV	36.0±13.4	15-75
	Schistura obeini Kottelat, 1998	Sobe	SC	INV	42.7±16.7	21-72
	Schistura sexcauda (Fowler, 1937)	Ssex	SC	INV	40.3±13.3	21-72

Table 1 (cont.) Species composition of fish collected in the Mae-ngad reservoir and its tributaries between October 2002 and September 2003

Family	Scientific name	Abbrev.	Habitat	Guilds	Total length (mm)	
					Mean ±SD	**Range**
	Tuberoschistura baenzigeri (Kottelat, 1983)	Tbae	SC	INV	32.2±7.5	20-34
Cobitidae	*Acanthopsoides delphax* Siebert, 1991	Adel	SC	INV	39.4±10.3	24-66
	Acantopsis choirorhynchos (Bleeker, 1854)	Acho	SC	INV	57.3±13.8	28-154
	Acantopsis thiemmedhi Sontirat, 1999	Athe	SC	INV	63.1±18.1	32-95
	Syncrossus beauforti (Smith, 1931)	Sbea	SC	INV	67.5±20.0	21-90
	Yasuhikotakia morleti (Tirant, 1885)	Ymor	SC	INV	47.4±11.7	39-71
	Lepidocephalichthys hasselti (Valenciennes, 1846)	Lhas	SC	INV	41.8±11.5	27-75
	Pangio anguillaris (Vaillant, 1902)	Pang	SC	INV	68.7±18.7	52-89
Amblycipitidae	*Amblyceps mucronatum* Ng & Kottelat, 2000	Amuc	SC	INV	54.0	54
Bagridae	*Hemibagrus nemurus* (Valenciennes, 1840)	Hnem	IC	CAR	191.7±87.3	38-390
	Pseudomystus siamensis (Regan, 1913)	Pssi	IC	CAR	37.1±20.0	15-69
	Mystus mysticetus Roberts, 1992	Mmys	IC	CAR	137±66.7	135-315
	Mystus singaringan (Bleeker, 1846)	Msin	IC	CAR	107.1±29.9	55-167
Clariidae	*Clarias batrachus* (Linnaeus, 1758)	Cbat	SC	CAR	119.4±28.5	95-180
	Clarias hybrid	Chyb	RC	CAR	250.0	250
Pangasiidae	*Pangasianodon gigas* Chevey, 1931	Pgig	RC	HER	940	940
	Pangasianodon hypophthalmus (Sauvage, 1878)	Phyp	RC	HER	679.4±101.2	305-900
Sisoridae	*Glyptothorax trilineatus* Blyth, 1860	Gtri	SC	INV	47.5±17.7	27-59
Loricariidae	*Pterygoplichthys disjunctivus* (Weber, 1991)	Pdis	RC	HER	301.0	301
Synbranchidae	*Monopterus albus* (Zuiew, 1793)	Malb	SC	INV	300.7±132.9	46-888
Mastacembelidae	*Macrognathus siamensis* (Günther, 1861)	Msia	SC	INV	99.7±48.2	54-150
	Mastacembelus armatus (Lacepède, 1800)	Marm	SC	INV	95.7±18.4	60-145
	Mastacembelus cf. tinwini Britz, 2007	Mtin	SC	INV	92.8±17.8	80-124
Belonidae	*Xenentodon cancila* (Hamilton, 1822)	Xcan	SC	INV	166.4±48.2	90-222
Chandidae	*Parambassis siamensis* (Fowler, 1937)	Psia	IC	INV	34.3±3.9	28-45
Cichlidae	*Oreochromis* hybrid	Ohyb	IC	HER	180.0	180
	Oreochromis niloticus (Linnaeus, 1758)	Onil	IC	HER	156.4±97.3	30-400

Table 1 (cont.) Species composition of fish collected in the Mae-ngad reservoir and its tributaries between October 2002 and September 2003

Family	Scientific name	Abbrev.	Habitat	Guilds	Total length (mm)	
					Mean ±SD	Range
Eleotridae	*Oxyeleotris marmorata* (Bleeker, 1852)	Omar	IC	CAR	141.1±94.4	20-450
Anabantidae	*Anabas testudineus* (Bloch, 1795)	Ates	IC	CAR	151.5±18.3	120-190
Osphronemidae	*Osphronemus goramy* Lacepède, 1801	Ogor	IC	HER	162.7±58.1	115-380
	Trichogaster trichopterus (Pallas, 1770)	Ttri	SC	INV	74.6±18.9	50-92
	Trichopsis vittata (Cuvier, 1831)	Tvit	SC	INV	40.2±10.4	22-55
Nandidae	*Pristolepis fasciatus* (Bleeker, 1851)	Pfas	IC	INV	141.5±17.1	100-187
Channidae	*Channa gachua* (Hamilton, 1822)	Cgac	IC	CAR	95.2±32.0	40-178
	Channa striata (Bloch, 1793)	Cstr	IC	CAR	209.9±154.3	15-590
Tetraodontidae	*Tetraodon leiurus* Bleeker, 1851	Tlei	RC	CAR	126.9±11.4	95-148

Note: Habitats: RC=Reservoir community, IC=Intermediate community, SC=Stream community; Fish guilds: INV=Invertivorous (including; benthic invertebrate, insectivorous, molluscivorous), CAR=Carnivorous, HER=Herbivorous (including; planktivorous, omnivorous) during the early and late part of the year from the reservoir stations (e.g. L01 and U10). The stream community (SC) contained the surveys from stream stations during the beginning and late part of the year (e.g. K02 and T04) and only one survey from the reservoir (U05) was included in this group. The remaining surveys were grouped together in the intermediate communities that included almost all the surveys during the mid part of the year that coincided with the rainy season.

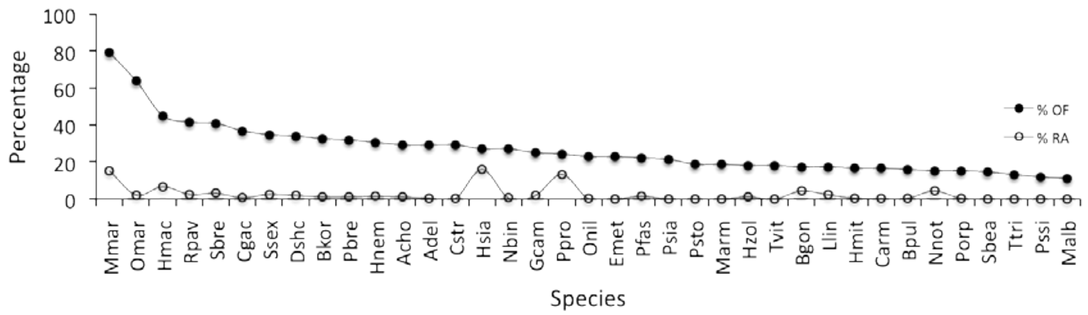

Figure 2. Percentages of relative abundance (%RA) and occurrence frequency (%OF) of the fish samples found in the overall study

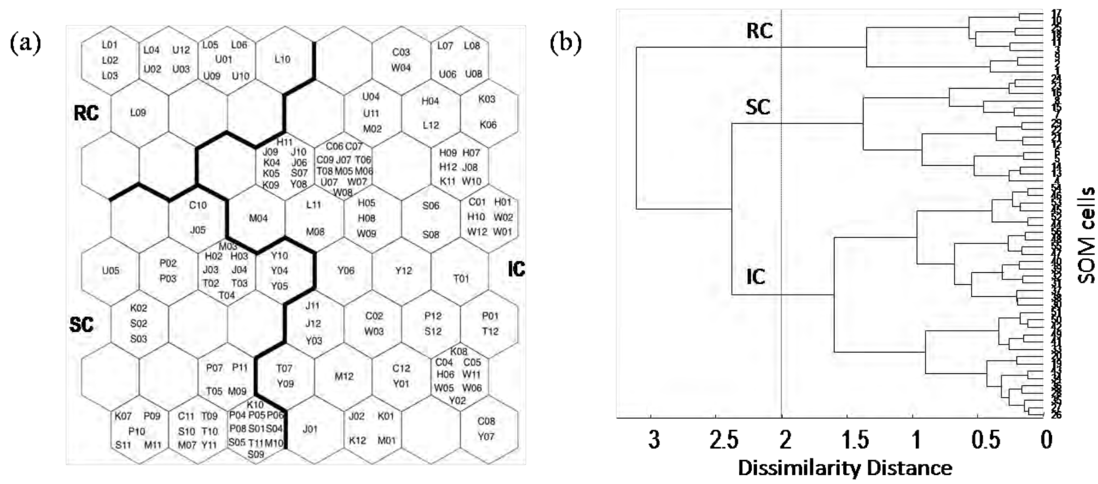

Figure 3. Results of the SOM model (a) Distribution of the surveys based on the SOM map of 144 surveys according to the similarity of fish composition. Each survey is represented by the abbreviated station-month names (e.g. S02 is sampling at the Huay Mesoon station in February) (b) Hierarchical clustering of sampling stations showing the three communities.

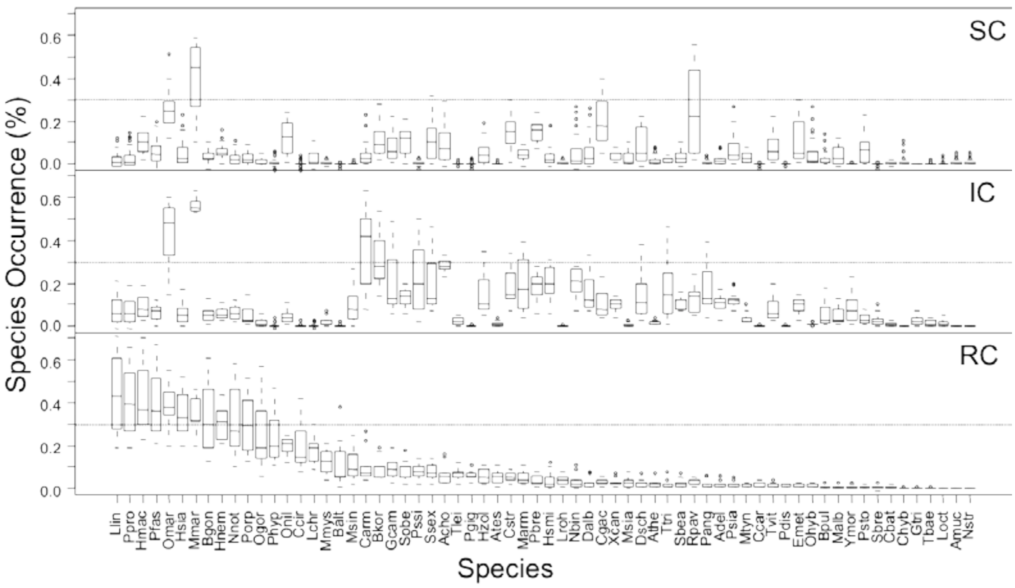

Figure 4 Community characteristics for each cluster as shown by the occurrence probability (*OP*) of individual species. The dotted line at 0.3 indicates the dominant species. Species abbreviations are shown in Table 1.

Table 2 Mean values ±SD of environmental variables in the three communities

Variables	RC	IC	SC
Alkalinity (Alk: mg l^{-1})	110.16±36.9^{a}	116.16±64.84^{a}	102.87±47.2^{b}
Hardness (Har: mg l^{-1} as $CaCO_3$)	84.2 ± 13.4^{a}	93.2 ± 42.4^{ab}	104.4 ± 31.5^{b}
Total dissolved solid (TDS: mg l^{-1})	130.7 ± 23.7^{a}	149.9 ± 65.1^{a}	121.8 ± 67.4^{a}
Conductivity (Con: µS·cm^{-1})	158.6 ± 40.7^{a}	185.2 ± 115.7^{a}	160.0 ± 85.1^{a}
Ammonia (Amm: mg l^{-1})	0.2 ± 0.2^{a}	0.5 ± 0.4^{b}	0.3 ± 0.3^{ab}
Phosphate (Pho: mg l^{-1})	0.06 ± 0.02^{a}	0.10 ± 0.03^{b}	0.09 ± 0.05^{ab}
Nitrite (Nit: mg l^{-1})	0.03 ± 0.04^{a}	0.03 ± 0.04^{a}	0.03 ± 0.03^{a}
Dissolved oxygen (DO: mg l^{-1})	6.5 ± 0.3^{a}	6.9 ± 0.5^{a}	6.8 ± 0.3^{a}
pH	6.7 ± 0.3^{a}	6.7 ± 0.5^{a}	7.0 ± 0.4^{a}
Depth (Dep: m)	2.2 ± 0.0^{a}	0.9 ± 0.5^{b}	0.8 ± 0.1^{b}
Width (Wid: m)	100.0 ± 0.0^{a}	32.4 ± 25.9^{b}	21.2 ± 7.8^{b}

Note: The same letter above a value indicates that the values are not statistically different (Tukey HSD tests; α = 0.05)

The distributions of *OP* of each species in each community can be expressed as the community characteristics (Fig. 4) and the base line of 0.3 was arbitrarily set to show the dominant species in each community but two species gave the highest *OP* of all communities i.e. *M. marginatus* and *O. marmorata*. Two other species contributed to a high *OP* in the SC i.e. *Rasbora paviana* (Tirant, 1885) and *Channa gachua* (Hamilton, 1822). The IC was dominated by *Cyclocheilichthys armatus* (Valenciennes, 1842), *Barilius koratensis* (Smith, 1931), *Garra cambodgiensis* (Tirant, 1883), *Pseudomystus siamensis* (Regan, 1913), *Schistura sexcauda* (Fowler, 1937), *Acantopsis choirorhynchos* (Bleeker, 1854) and *Mastacembelus armatus* (Lacepède, 1800). It is also worthy to note that the dominant species in the SC and IC were either invertivores or carnivores. Meanwhile, the RC was dominated by a number of species that were mostly herbivores e.g. *Labiobarbus lineatus*, (Sauvage, 1878), *P. proctozysron*, *H. macrolepidota*, *Pristolepis fasciatus* (Bleeker, 1851) and *H. siamensis*.

Table 3 Confusing matrix showing the cross validation of the CART model using the six environmentalvariables on 3 communities (overall percentage of successful prediction is 66.0 %)

		Predicted			% success
		RC	IC	SC	
Observed	RC	14	0	0	100
	IC	8	15	64	73.6
	SC	1	17	25	39.5

Prediction of community assemblages and the contribution of environmental variables

The average values of the physicochemical and geo-morphological variables, obtained from the three communities, are shown in Table 2 and they were used as predictors in the CART model to discriminate the clusters of fish communities. Based on the three communities (i.e. RC, IC, and SC), six environmental variables (i.e. water depth, ammonia, hardness, alkalinity, phosphorus and nitrite) were selected to predict the response variables, i.e. community types (Fig. 5). The major variables corresponding to assemblages were water depth, which separated the RC from the other communities. Meanwhile, the overlaps between the IC and SC were distinguished by physicochemical variables such as hardness, ammonia, alkalinity, orthophosphate and nitrite. The overall predictive power of this model, i.e. how successfully the model could predict the assigned survey to the right community, was on average 66.0 % (Table 3).

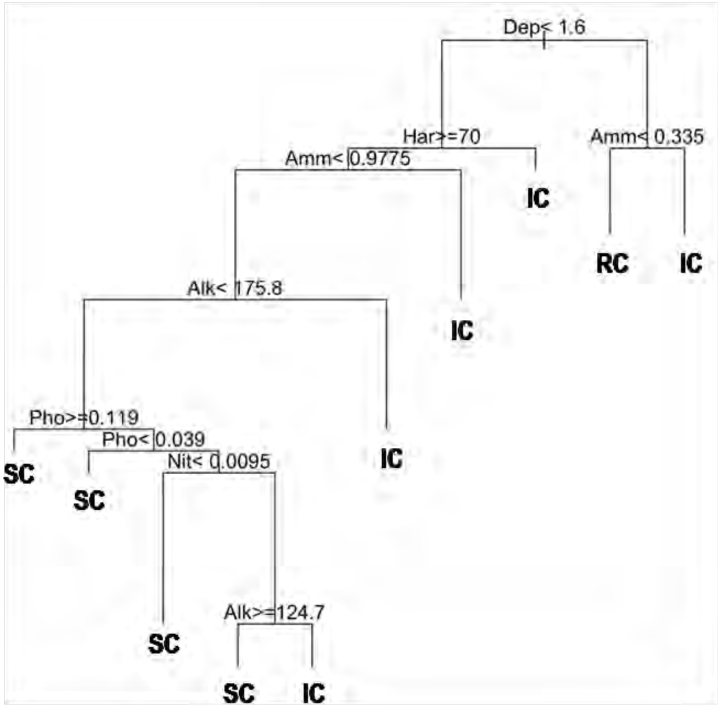

Figure 5. CART model of the fish communities in the study area by using 6 environment variables as predictors.

DISCUSSION

The fish communities in highland tropical streams connected to a reservoir were dominated by cyprinids. Three communities of fish were found in this study. The reservoir community was located in the reservoir with well-adapted riverine species e.g. *Labiobarbus leptocheila*, *Henicorhynchus siamensis*, and *Hampala macrolepidota*. The stream community was located in the uppermost part of the stream; it was dominated by *Channa gachua* and *Rasbora paviana*. The intermediate community was located between the other two communities: it contained transitional species e.g. *Cyclocheilichthys armatus* and *Pseudomystus siamensis*. There were clear differences between fish species in the RC and the other communities, although some species were overlapping between the IC and SC. Particularly, two species were found to be well adapted to all the communities i.e. *Mystacoleucus marginatus* and *Oxyeleotris marmorata*. Water depth had the main impact on the change in the communities.

Fish in tropical Southeast Asia river basins are dominated by cyprinids followed by silurids (Matin-Smith 1998; Campbell et al 2006; Nguyen and De Silva 2006) but being followed by the Balitoridae and Cobitidae, as in this study, is unique for the stream areas in the region (Kottelat 1998). Meanwhile there are the silurids and characids with fusiform bodies and expanded pectoral fins in the Neotropical regions (Casatti and Castro 2006). These groups are commonly insectivores and this was also reflected in the predominance of this trophic guild in the SC and IC since various stages of insects need to develop in highly oxygenated water (Kottelat 1998; Casatti and Castro 2006; Rolla et al. 2009).

Differences in the observed communities can be provided as an assessment of the ecological status (Lasne et al. 2007). The two communities, i.e. SC and RC, which showed the most distinct differences could be described as the communities under “stream environment” and “reservoir environment”, respectively and could be related to the distinction between the rhithron and the potamon in the river course (Welcomme et al. 2006), where the hydrological regime was the major factor controlling fish community patterns (Welcomme and Halls 2005). It was the periods between the beginning and late parts of the year, which coincided with the dry season that made the difference between the RC and SC. During June to October is a rainy season in the area, which results in an increase in the water surface of the reservoir. The increase in the water surface also improves the connectivity between the reservoir and the tributaries and that increases the aquatic biodiversity (Amoros and Bornette 2002; Falke and Gido, 2006) as seen in the results obtained for the IC.

The variation in the occurrence probability (*OP*) of individual species in each cluster indicated the preferred habitat of the species. In the SC, the members were mostly rheophilic species such as *B. koratensis*, *G. cambodgiensis* and *S. sexcauda*, commonly found in small to medium-sized streams in upland areas (Kottelat 1998). They were sensitive to catastrophic and habitat flows (Welcomme et al. 2006) and required strong flow conditions to live. Meanwhile *C. gachua* lives in the backwaters of first order streams and *R. paviana* is usually found in shallow and moderately flowing streams (Kottelat 1998). In the RC, the species found were the lentic-adapted species, the so called “facultative reservoir species”: they are generally native to the lower portions of a river course (Falke and Gido, 2006).

There is a general consensus that fish which are originally riverine concentrate in the reservoir environment that is most similar to a river, i.e. the tributary and littoral areas of reservoirs (see Prchalová et al. 2008). Variations and high overlaps among communities could be due to some species moving in and out of the tributaries during their life cycle (Borcherding et al. 2002). For example, the cyprinid species such as *L. lineatus*, *P. proctozysron*, *H. macrolepidota* and *H. siamensis* migrate upstream annually to spawn on shallow gravel beds at the confluence or in small rivers during short periods in rainy season, i.e. June to August (de Graaf et al. 2005). This is why these fish also showed ample *OP* in the IC. Meanwhile, high *OP* in all communities of *O. marmorata* and *M. marginatus* could be caused by movement either for feeding or spawning purposes (Kottelat 1998).

The community structure in the headwater depends on abiotic- rather than biotic- factors (Schlosser 1987). Among the selected controlling variables in this study, water depth is the main environmental factor that affected the fish community patterns. An increase in species diversity along the river course from the shallow upstream areas to the deeper areas downstream was emphasized (Martin-Smith 1998). Prchalová et al. (2009) mentioned that the complexity of species composition in a reservoir, increased heading towards the tributary and peaked close to or at the tributary part of reservoir, which agreed with our results obtained for the complexity of the *OP* in the IC. Other selected variables in the CART to discriminate between the SC and IC were related to the major nutrients in the ecosystem i.e. phosphorus and nitrogen (i.e. in forms of nitrite in this study). Both nutrients always increase during the rainy season and are released from upstream to downstream as well as from the land to the water body and then stimulate primary productivity in the ecosystem (Allen 2001; Wondie et al. 2007). This phenomenon is eventually made more complex in the fish community in the area, at least for feeding purpose (Hoeinghaus et al. 2008). The one hundred percent predictive power for the RC indicated that the community assemblages in that area were relatively stable, while the low predictive power for the SC (39.5 %) implied the movement of downstream species into the stream (Grossman et al. 1990).

CONCLUSION

Results of the study showed two distinct fish community modes that were induced by the reservoir environment (Lienesch et al. 2000), the lentic-adapted species were common in the reservoir (i.e. the RC) and they could invade the tributaries during a certain period in rainy season as shown in the IC and SC (Fig. 4). Meanwhile, the species in the SC could be found in the IC but they were not found in the reservoir area (Fig. 4). Further studies on the function of individual species in each community are recommended. Moreover, an examination of the fish larvae and juveniles in the system should be also be considered since they also move and distribute in the reservoir (Quist et al. 2004); This would also provide information on species interaction and recruitment to the reservoir system.

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