ISSN: 1683-1489

Mekong River Commission

Report on the 2006 biomonitoring survey of the lower Mekong River and selected tributaries

MRC Technical Paper
No. 22

July 2009

Meeting the Needs, Keeping the Balance

Mekong River Commission

Report on the 2006 biomonitoring survey of the lower Mekong River and selected tributaries

MRC Technical Paper No. 22

July 2009

Published in Vientiane, Lao PDR in July 2009 by the Mekong River Commission

Cite this document as:

Chanda VONGSOMBATH, PHAM Anh Duc, NGUYEN Thi Mai Linh, Tatporn KUNPRADID, Supatra Parnrong DAVISON, Yuwadee PEERAPORNPISAL, SOK Khom, MENG Monyrak (2009) Report on the 2006 biomonitoring survey of the lower Mekong River and selected tributaries, *MRC Technical Paper No. 22*. Mekong River Commission, Vientiane. 124 pp.

Editors: B.C. Chessman, V.H. Resh and T.J. Burnhill

Graphic design: T.J. Burnhill

184 Fa Ngoum Road, Unit 18, Ban Sithane Neua, Sikhottabong District,
Vientiane 01000, Lao PDR
Telephone: (856-21) 263 263 Facsimile: (856-21) 263 264
E-mail: mrcs@mrcmekong.org
Website: www.mrcmekong.org

Table of contents

Table of Figures

Table of tables

Acknowledgements

The authors thank Mr Monyrak Meng and the staff of the Environment Programme of the Mekong River Commission for their assistance in coordinating the sampling programme in 2006. The authors also express their appreciation for the support given to the study by representatives from the National Mekong Committees of Cambodia, Lao PDR, Thailand, and Viet Nam, particularly for the help they provided in the field.

The authors are indebted to Prof. Vince Resh and Dr Bruce Chessman for their guidance during the field programme and their help with drafting this paper. The authors also express their appreciation to Dr Hakan Berg, Dr Dao Huy Giap, Dr Vithet Srinetr, and Dr Hanne Bach for their comments and suggestions when reviewing this paper.

Abbreviations and acronyms

ATSPT:	Average Tolerance Score Per Taxon
BDP:	Basin Development Plan programme of the MRCS
BMWP:	Biological Monitoring Working Party
LMB:	Lower Mekong Basin
MRC:	Mekong River Commission
MRCS:	Mekong River Commission Secretariat
NMC:	National Mekong Committee
SDS:	Site Disturbance Score

Glossary of biomonitoring terms

Abundance: This is a measurement of the number of individual plants or animals belonging to a particular biological indicator group counted in a sample. Low abundance is sometimes a sign that the ecosystem has been harmed.

Average Tolerance Score per Taxon (ATSPT): Each taxon of a biological indicator group is assigned a score that relates to its tolerance to pollution. ATSPT is a measure of the average tolerance score of the taxa recorded in a sample. A high ATSPT may indicate harm to the ecosystem, as only tolerant taxa survive under these heavily disturbed conditions.

Benthic macroinvertebrates: In this report, the use of this term refers to animals that live in the deeper parts of the riverbed and its sediments, well away from the shoreline. Because many of these species are not mobile, benthic macroinvertebrates respond to local conditions and, because some species are long living, they may be indicative of environmental conditions that are long standing.

Biological indicator group: These are groups of animals or plants that can be used to indicate changes to aquatic environments. Members of the group may or may not be related in an evolutionary sense. So while diatoms are a taxon that is related through evolution, macroinvertebrates are a disparate group of unrelated taxa that share the character of not having a vertebral column, or backbone. Different biological indicator groups are suitable for different environments. Diatoms, zooplankton, littoral and benthic macroinvertebrates, and fish are the biological indicator groups most commonly used in aquatic freshwater environments. In addition, although not strictly a biological group, planktonic primary productivity can also be used as an indicator. However, for a number of logistical reasons fish and planktonic primary production are not suitable for use in the Mekong.

Diatoms: Single-celled microscopic algae (plants) with cell walls made of silica. They drift in river water (planktic/planktonic) or live on substrata such as submerged rocks and aquatic plants (benthic/benthonic). They are important primary producers in aquatic food webs and are consumed by many invertebrate animals. Diatoms are a diverse group and respond in many ways to physical and chemical changes in the riverine environment. Diatom communities respond rapidly to environmental changes because diatoms have short generation times.

Environmental variables: These are chemical and physical parameters that were recorded at each sampling site at the same time as samples for biological indicator groups were collected. The parameters include altitude, water transparency and turbidity, water temperature, concentration of dissolved oxygen (DO), electrical conductivity (EC), activity of hydrogen ions (pH), and concentrations of chlorophyll-a, as well as the physical dimensions of the river at the site.

Littoral macroinvertebrates: In this report, the use of this term refers to animals that live on, or close to, the shoreline of rivers and lakes. This group of animals is most widely used in biomonitoring exercises worldwide. They are often abundant and diverse and are found in a variety of environmental conditions. For these reasons littoral macroinvertebrates are good biological indicators of environmental changes.

Littoral organisms: Those organisms that live near the shores of rivers, lakes, and the sea.

Macroinvertebrate: An informal name applied to animals that do not have a vertebral column, including snails, insects, spiders, and worms, which are large enough to be visible to the naked eye. Biomonitoring programmes often use both benthic and littoral macroinvertebrates as biological indicators of the ecological health of water bodies.

Primary producer: Organisms at the bottom of the food chain, such as most plants and some bacteria (including blue-green algae), which can make organic material from inorganic matter.

Primary production: The organic material made by primary producers. Therefore, planktonic primary production is the primary production generated by plants (including diatoms) and bacteria (including blue-green algae) that live close to the surface of rivers, lakes, and the sea.

Primary productivity: The total organic material made by primary producers over a given period of time.

Reference sites: These are sampling sites that are in almost a natural state with little disturbance from human activity. To be selected as a reference site in the MRC biomonitoring programme, a site must meet a number of requirements including pH (between 6.5 and 8.5), electrical conductivity (less than 70 mS/cm), dissolved oxygen concentration (greater than 5 mg/L) and average SDS (between 1 and 1.67). Reference sites provide a baseline from which to measure environmental changes.

Richness: This is a measurement of the number of taxa (types) of plants or animals belonging to a particular biological indicator group counted in a sample. Low species richness is often a sign that the ecosystem has been harmed.

Sampling sites: Sites chosen for single or repeated biological and environmental sampling. Although locations of the sites are geo-referenced, individual samples may be taken from the different habitats at the site that are suitable for particular biological indicator groups. Sites were chosen to provide broad geographical coverage of the basin and to sample a wide range of river settings along the mainstream of the Mekong and its tributaries.

Site Disturbance Score (SDS): This is a comparative measure of the degree to which the site being monitored has been disturbed by human activities, such as urban development, water resource developments, mining, and agriculture. In the MRC biomonitoring programme, the SDS is determined by a group of ecologists who attribute a score of 1 (little or no disturbance) to 3 (substantial disturbance) to each of the sampling sites in the programme after discussion of possible impacts in and near the river.

Taxon/taxa (plural): This is a group or groups of animals or plants that are related through evolution. Examples include species, genera, or families.

Zooplankton: Small or microscopic animals that drift or swim near the surface of rivers, lakes, and the sea. Some are single celled while others are multi-cellular. They include primary consumers than feed on phytoplankton (including diatoms) and secondary consumers that eat other zooplankton. Zooplankton can be useful biological indicators of the ecological health of water bodies because they are a diverse group that has a variety of responses to environmental changes. Zooplankton communities respond rapidly to changes in the environment because zooplankton species have short generation times.

Summary

The aquatic resources of the Mekong River and its tributaries are essential to the livelihoods of a large portion of the 60 million people who live in the Lower Mekong Basin. Maintaining the ecological health of the river is the basis of the sustainable management of these resources. The Environment Programme of the Mekong River Commission (MRC) has monitored the ecological health of the Mekong river-system using biological indices since 2003, and continues to do so. This report describes the Programme's biomonitoring activities in 2006. During that year the Programme's biologists sampled 21 localities in Cambodia and Viet Nam. On the basis of the results of work the Programme conducted during the preceding years, the 2006 monitoring study used benthic diatoms, zooplankton, littoral macroinvertebrates, and benthic macroinvertebrates as biological indicator groups. At the same time, the physical and chemical properties of the river were recorded at each of the sampling sites.

The objectives of this paper are to (i) describe the floral and faunal components of the assemblages in the samples collected during 2006, (ii) develop quantitative tolerance-to-stress values for all species collected in this survey and earlier surveys conducted in 2004 and 2005, and (iii) use this information to evaluate the ecological health of the sites examined in 2006.

The suite of 2004–2006 field surveys provides records for 43 sites in the basin and contains a total of 57 'sampling events' (some of the sites were sampled in more than one year). A visual assessment of human disturbance (called the Site Disturbance Score — SDS) was made for each of these 57 sampling events.

Littoral and benthic macroinvertebrates had a higher proportion of intolerant species than did diatoms or zooplankton. The tolerance of each species present at an individual site was used to calculate an Average Tolerance Score Per Taxon (ATSPT) for each site. In general, ATSPT values increased in a downstream direction in the mainstream of the river, while tributaries generally recorded scores indicative of lower stress than did sites in the mainstream.

Five biological metrics were calculated and evaluated for their applicability to the Mekong's ecosystems. The metrics were: (i) richness (number of taxa), (ii) abundance (numbers of individuals), (iii) the Shannon-Wiener Diversity Index, (iv) the Berger-Parker Dominance Index, and (v) the ATSPT.

A regression analysis of the average SDS against all five biological metrics was undertaken. Significant correlations were found for all metrics in the case of littoral macroinvertebrates, for two metrics (diversity and ATSTP) in the case of zooplankton, and for only ATSPT in the case of diatoms and benthic macroinvertebrates. Sites that were sampled in multiple years had consistent ATSPT values, confirming the broad validity of this approach to biomonitoring in the Lower Mekong Basin.

The ATSPT determined from the 2006 study clearly can serve as a basis for a long-term monitoring programme to evaluate ecological health. Studies in 2007 will include an independent assessment of the relationship of ATSPT to visual assessments of human disturbance, and evaluate further the use of ATSPT and other metrics in environmental assessment and management.

1. Introduction

Arguably, the Mekong is the most important river in the world in terms of human dependency on riverine aquatic resources for sustenance and survival. The quality of life of the 60 million people living in the Lower Mekong Basin depends on both the economic and the ecological health of the river. The river-system is also an important centre of biodiversity. During the period from 1999 to 2001, four localities in the basin were designated as Ramsar sites, and a number of possible future sites were identified.

This 2006 paper describes ongoing studies in the lower Mekong River that were conducted to evaluate the overall ecological health of the river. It builds on activities initiated in 2003, when pilot studies were undertaken to determine which biological indicator groups should be used to evaluate ecological health. In 2004, emphasis was placed on evaluating intra-site variability in biological assemblages and on establishing the association between environmental factors and the composition of the assemblages. The 2004 and 2005 surveys were designed to sample all the sub-basins in the LMB, to characterise the biological communities, and to develop tools for evaluating ecological health. The following metrics were calculated for all sites sampled in 2004 and 2005: (i) richness (number of taxa), (ii) abundance (numbers of individuals), (iii) the Shannon-Wiener Diversity Index, (iv) the Berger-Parker Dominance Index, (v) the proportion of pollution sensitive taxa, and (vi) the proportion of pollution sensitive individuals. All six metrics were tested for their potential as indicators of human impact through regression analysis against an average site disturbance score (SDS). The 2005 study found that the correlation between the average SDS and the six biological metrics differed among the four biological groups. Therefore, an objective of the 2006 study was to focus on expanding and improving the assessment of the sensitivity to pollution of the various taxa.

The objectives of this report are to: (i) describe the faunal and floral characteristics of the biological communities sampled quantitatively at 21 sites during the 2006 survey; (ii) develop quantitative tolerance scores based on data collected at 20 sites in 2004, 16 sites in 2005, and 21 sites in 2006; and (iii) report biotic condition scores for each of the sites examined in 2006.

Four of the six biological metrics investigated in the 2005 study (richness, abundance, the Shannon-Wiener Diversity Index, and the Berger-Parker Dominance Index) were evaluated further in 2006 study. A new biological metric—Average Tolerance Score Per Taxon (ATSPT)—was also added. Regression analyses were undertaken to assess the correlation between the five biological metrics and the SDS.

Four biological assemblages were used in this analysis: littoral and benthic macroinvertebrates, diatoms, and zooplankton. Benthic macroinvertebrates are the group of organisms that is most widely used for biological monitoring. The most frequently cited advantages of using these organisms include: their wide diversity, which includes the large number of species and their various responses to environmental change; their wide distribution;

their limited mobility; the ease in sampling them; the long life-span of some species; and the fact that taxonomic keys, at least to higher identification levels, are available for most regions of the world. Because different species occur in the deeper parts of river channels and in the littoral zone, the survey sampled each zone separately, and this report presents data on each of the littoral and benthic macroinvertebrates individually.

Although benthic macroinvertebrates are the most widely used group of organisms in biomonitoring, they do not respond to all stressors, and they are very dependant on local habitat conditions. For these reasons, we have also included two other groups of organisms in the analysis, benthic diatoms and zooplankton.

Benthic diatoms are increasingly used in biomonitoring programs but they are usually used in conjunction with macroinvertebrates rather than as a separate unit. They offer some similar advantages to macroinvertebrates, including the ease with which they can be sampled, the diversity of their responses, and their widespread occurrence. However, because of their shorter generation time, they also often show more rapid responses to disturbance than do macroinvertebrates.

Riverine zooplankton are less commonly used in biomonitoring than either macroinvertebrates or diatoms but the reason for this is that most programmes evaluate smaller, wadeable streams and rivers rather than large rivers like the Mekong. Zooplankton also have high diversity and clearly are an essential part of the ecosystem in large rivers. Their response time to disturbance is shorter than that of macroinvertebrates and longer than that of diatoms, and so they provide a complementary, intermediate role in the assemblages used to monitor ecological health.

Biomonitoring programmes elsewhere in the world commonly use species of freshwater fish as indicators of riverine ecological health. (In terms of their frequency of use for biomonitoring, they are intermediate between macroinvertebrates and diatoms.) Previous reports on the earlier Mekong surveys provide details of why, after pilot studies conducted in 2003, fish were not used in the biomonitoring analysis. In short, fish were excluded from the biomonitoring programme because they could not be sampled adequately in the short period (2–3 hours) allocated per site, and because, in any case, fisheries data were available from other sources.

2. Sampling sites and programme

The 2004–2006 suite of samples includes records of 57 sets of samples collected from 43 sites on the Mekong and its tributaries (some sites were sampled in more than one year — see Table 2.1).

Table 2.1. *Sites sampled during the 2004–2006 biomonitoring surveys.*

Country	Site	2004	2005	2006
Cambodia	CBS			X
	CKM		X	X
	CKT	X		X
	CMR		X	X
	CNL			X
	CPP	X		X
	CPS	X		
	CPT			X
	CSJ		X	X
	CSK			X
	CSN			X
	CSP	X	X	X
	CSS	X	X	
	CSU		X	X
	CTU	X		X
Lao PDR	LKD	X		
	LKL		X	
	LKU		X	
	LMH		X	
	LMX		X	
	LNG	X		
	LNK		X	
	LNO	X		
	LOU		X	
	LPB	X	X	
	LPS	X		
	LVT	X		
Thailand	TCH	X		
	TKO	X	X	
	TMC		X	
	TMI		X	
	TMU	X		
	TSK	X		
Viet Nam	VCD	X		X
	VCL			X
	VCT			X
	VKT	X		
	VSP	X		
	VSS			X
	VLX			X
	VSR	X		X
	VTC	X		X
	VTR			X

The sites were chosen to provide broad geographical coverage of the basin, to include each of the 'sub-basins' as defined by the MRC's Basin Development Plan (BDP), and to sample the mainstream of Mekong River and each of its major tributaries (Figure 2.1).

2004 Biomonitoring survey

The sites surveyed in 2004 represent a broad geographic coverage across the Lower Mekong Basin (Figure 2.2). They include localities on the Mekong and its major tributaries, in each of the BDP sub-areas, and in each of the MRC member countries — Cambodia, Lao PDR, Thailand and Viet Nam. The sampling localities cover a range of river settings from the rock-cut channels in northern Lao PDR and northeast Thailand, through the alluvial channel systems of central and southern Lao PDR and the plains of Cambodia, to the distributary system of the Mekong Delta in southern Cambodia and Viet Nam. The sites also exhibit varying disturbance from human activity. Some are located in or close by villages or towns, some are next to fields where crops are grown and livestock graze, some are upstream or downstream of dams and weirs, and at some there is moderate to heavy river traffic. Details of the sites sampled in 2004 can be found in *MRC Technical Paper* No. 13 (MRC, 2006).

2005 Biomonitoring survey

The geographic coverage of the 2005 survey was more focused than the 2004 survey (Figure 2.3). The sites fall into two groups: (i) northern Lao PDR and the northern provinces of Thailand (mainly Chiang Rai), which lie in BDP Sub-area 1 (Northern Laos) and Sub-area 2 (Chiang Rai), and (ii) southern Lao PDR and eastern Cambodia, which lie largely in Sub-area 7 (Se San/Sre Pok/Se Kong). They also include localities in a range of river settings and anthropogenic influences.

2006 Biomonitoring survey

The 2006 survey focused on the mainstream and its major tributaries downstream of the Ramsar site at Stung Treng in northern Cambodia (Figure 2.4). The survey included localities in Sub-area 6 (Southern Laos), Sub-area 7 (Se San/Sre Pok/Se Kong), Sub-Area 8 (Kratie), Sub-area 9 (Tonle Sap), and Sub-area 10 (Delta). Again the sites represented a range of river settings and anthropogenic influences. Details of the location and geographic characteristics of the sites are given below (Table 2.2).

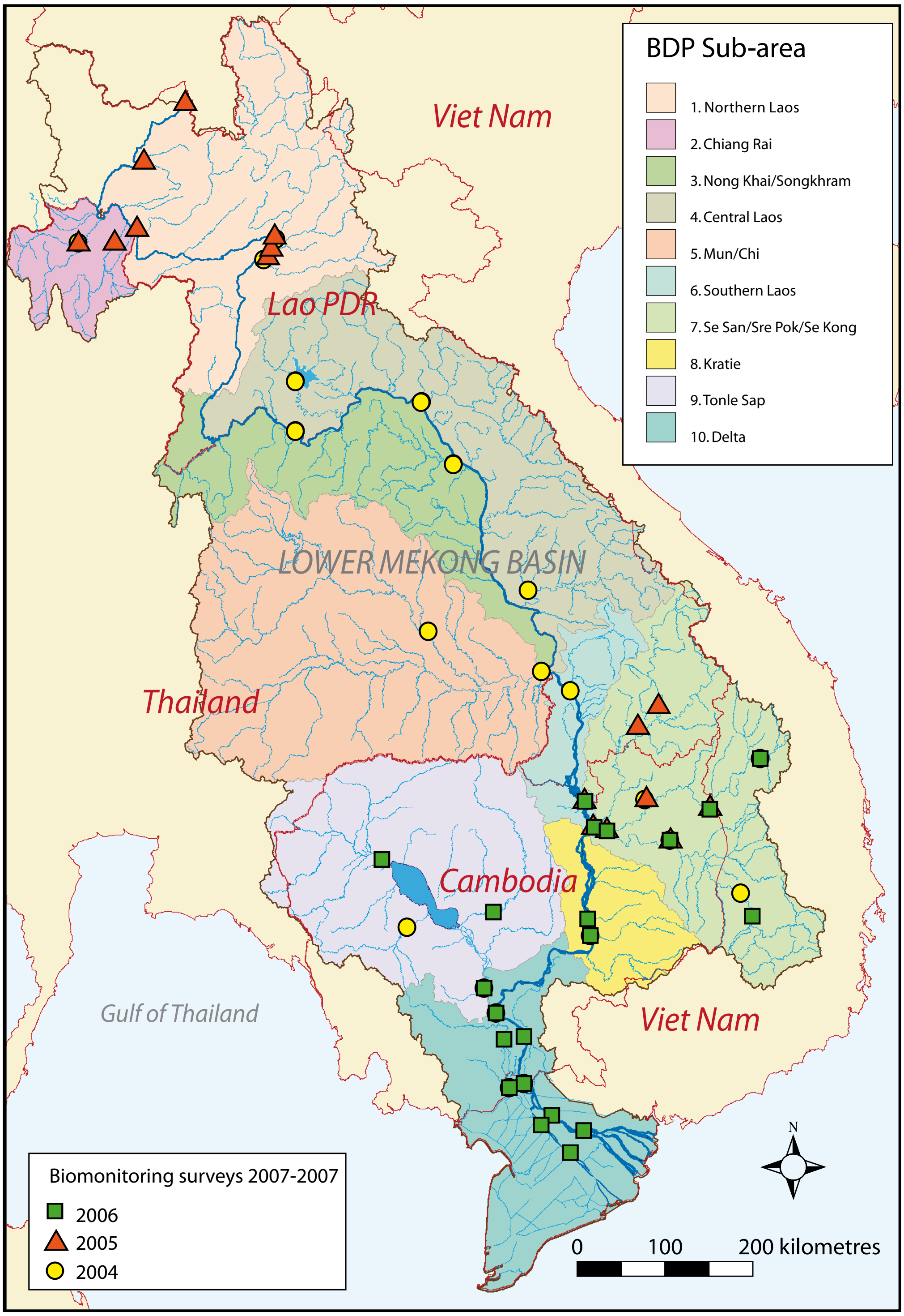


Figure 2.1. Location of the sites sampled during the 2004, 2005, and 2006 biomonitoring surveys.

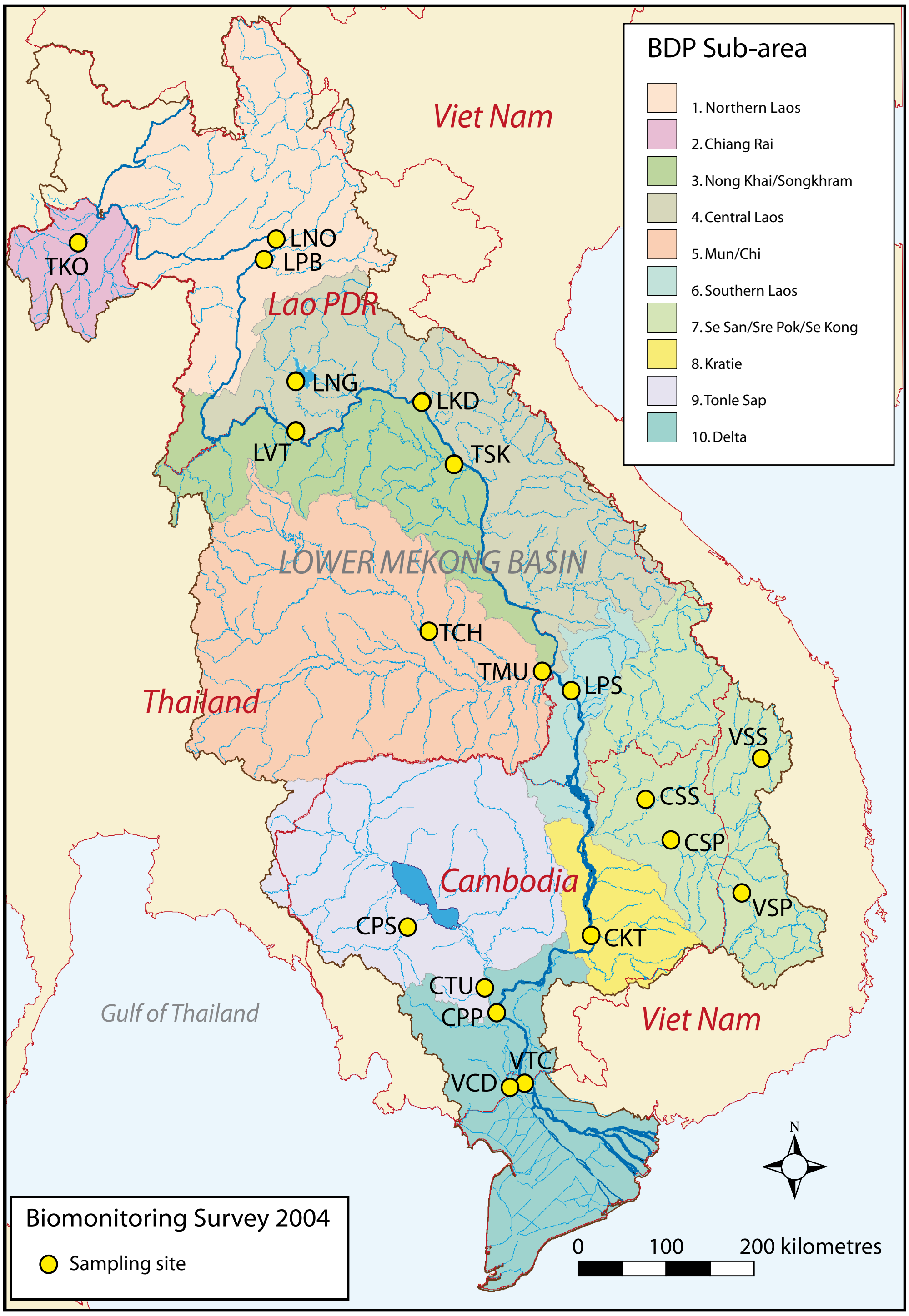


Figure 2.2. Location of the sites sampled during the 2004 biomonitoring survey.

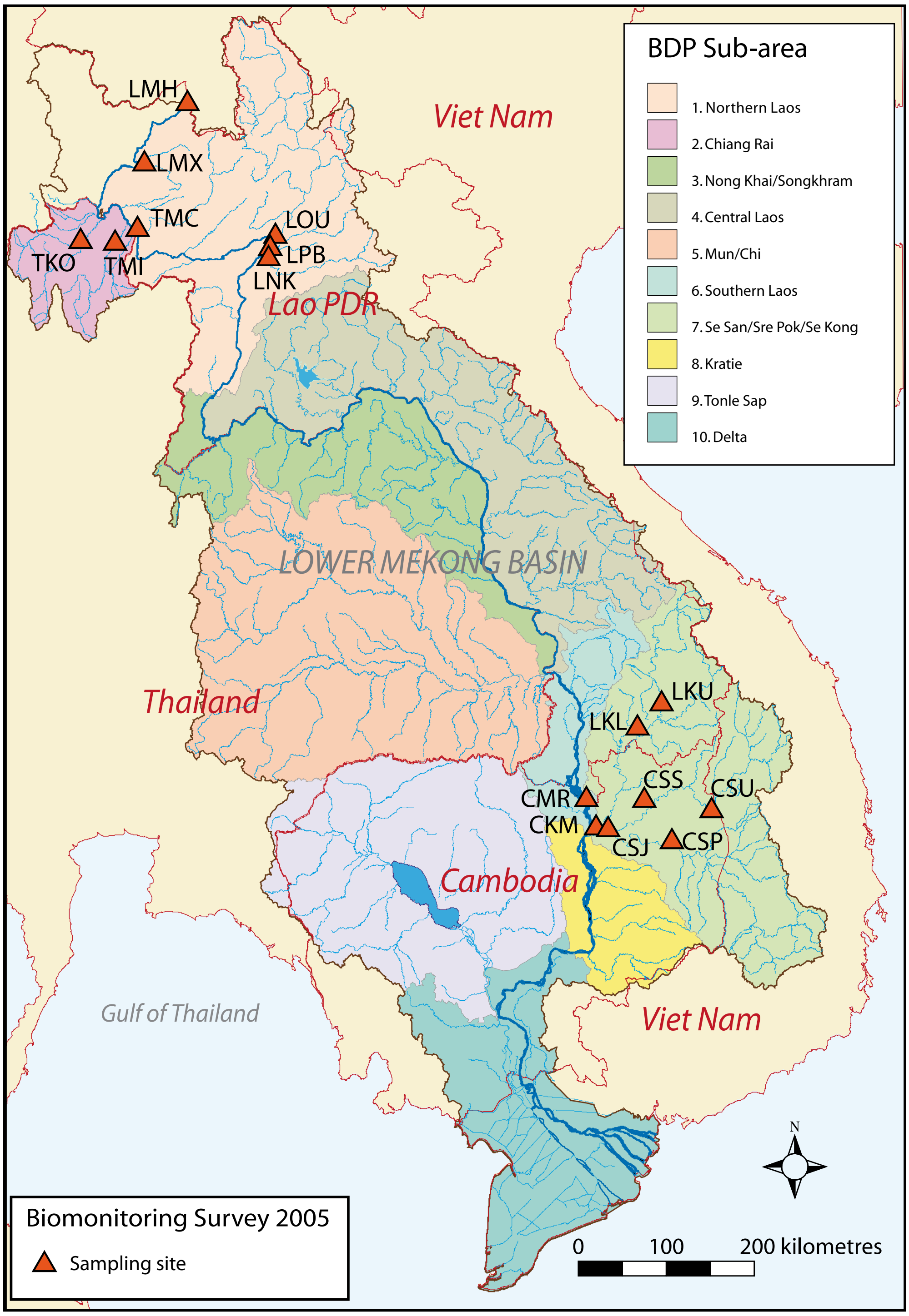


Figure 2.3. Location of the sites sampled during the 2005 biomonitoring survey.

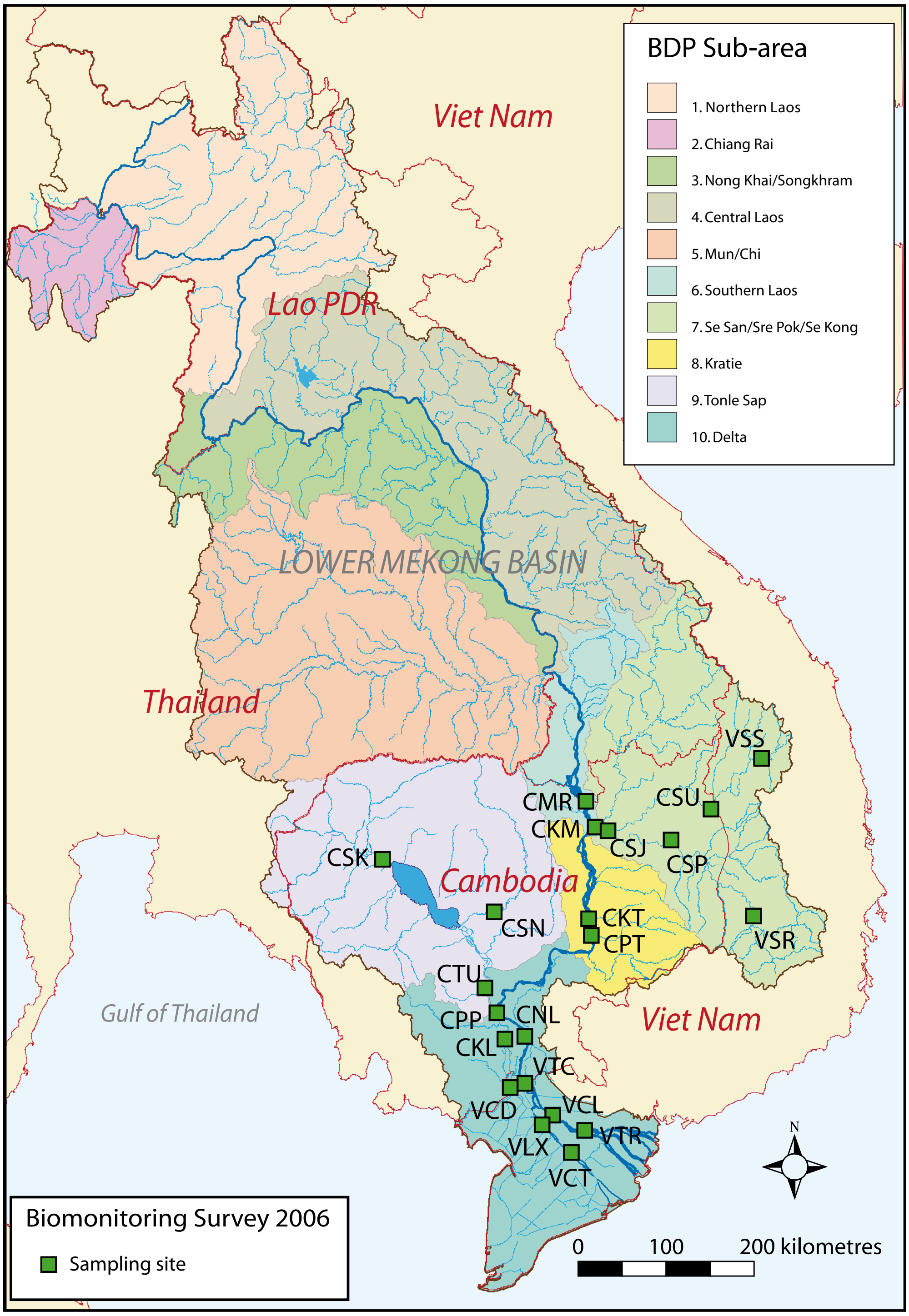


Figure 2.4. Location of the sites sampled during the 2006 biomonitoring survey.

Table 2.2. *Location and geographic characteristics of the sites sampled in the 2006 biomonitoring survey.*

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Tonle Sap river at Phnom Penh Port	CPP	6/3/06	491666 (E) 1280205 (N)	491960 (E) 1280553 (N)	6	460	7–8	12	5–6	Houses and docks	Houses and docks	Mud; sand; garbage; bamboo sticks	R–Mud; little clay	Sewage discharge; urban runoff; rubbish disposal; spillage and leakage from docks
													M–Sand	
													L–Sand; clay; little mud	
Bassac at Koh Khel	CKL	7/3/06	503327 (E) 1246641(N)	503520 (E) 1246340 (N)	2–3	298	4	7	4–8	Villages and gardens; bananas	Villages and gardens	Sand; mud; water hyacinth	R–Sand; mud	Agricultural runoff; disposal of human and animal wastes
													M–Sand; a few granules	
													L–Mud; fine sand; debris	
Mekong at Nak Loeung	CNL	8/3/06	528321 (E) 1250852 (N)	530580 (E) 1249937 (N)	8–14	1629	3	15	4–12	Fields; few houses	Sand banks; fields; villages	Sand; a little mud; filamentous algae	R–Mud; little sand	Agricultural runoff; disposal of human and animal wastes
													M–Sand; little mud	
													L–Sand; clay	

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Tonle Sap river at Prek Kdam	CTU	9/3/06	478364 (E) 1307071 (N)	479071 (E) 136700 (N)	3	522	3	10	5	Houses; fish pens; some trees on bank; ferry downstream	Houses and floating houses; fish cages	Firm mud; sticks	R – Clay; sand M – Mud; sand; clay L – Mud; debris; a little sand	Human wastes; urban runoff; rubbish disposal; fish farming
Stoeng Sen	CSN	10/3/06	490998 (E) 1401845 (N)	490910 (E) 1401770 (N)	6	66	1.0	1.2	3.0 – 4.5	Farms; vegetable gardens; few houses; stable sloping and terraced banks	Steep, bare, eroded bank; trees and fields at top	Mud over firm sand	R – Mud; little sand M – Mud; sand L – Mud	Agricultural runoff; disposal of human and animal wastes; bank erosion
Stoeng Sangke	CSK	11/3/06	348375 (E) 1465699 (N)	348895 (E) 1465772 (N)	5	127	0.5 – 0.7	1.5 – 2.0	0.5 – 1.0	Open forest; fish pens; floating hut; floating village downstream	Open forest; fish pens	Silt; flooded bushes	R – Mud; debris M – Mud; little debris L – Mud; debris	Human wastes and rubbish disposal from downstream village; fish farming
Prek Te	CPT	13/3/06	613899 (E) 1374811 (N)	613871 (E) 1374792 (N)	9 – 13	39	1.5	1.6	1.1	Village; vegetable gardens; cattle grazing; trees at bank top; steep, partly eroded banks with weed cover on lower bank	Rice fields; cattle grazing; few trees; eroded banks with moderate slope and partial weed cover on lower bank	Mud; debris	R – Mud; debris M – Mud; debris L – Mud; debris	Agricultural runoff; disposal of human and animal wastes; livestock damage to banks; bank erosion

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Mekong at Kampi	CKT	14/3/06	609207 (E) 1393544 (N)	610943 (E) 1393808 (N)	10–13	1300	1.7	7–8	1.7	Few houses; tourist area; moderate slope; some erosion	Steep, eroded bank; some trees on face; many on top; few houses	Sand; some stones	R – Sand; rock; little debris M – Sand; rock; algae L – Sand; rock; algae	Bank erosion
Mekong at Ramsar site	CMR	15/3/06	604976 (E) 1539456 (N)	605586 (E) 1539777 (N)	58	450	1.5	7–8	1–1.5	Forest, few houses	Forest, few houses	Sand; pebbles; cobbles; bedrock; filamentous algae	R – Sand; rock; little debris M – Sand; little debris L – Sand; debris	Disposal of human and animal wastes; livestock damage to banks; bank erosion
Se San downstream of Srepok River junction	CSJ	16/3/06	620973 (E) 1499412 (N)	620973 (E) 1499412 (N)	48-52	622	1	3	1	Forest; water buffalo	Forest; water buffalo	Sand; pebbles; cobbles; bushes	R – Sand; rock M – Rock; cobbles; sand L – Sand; rock; little debris	Livestock damage to banks; bank erosion
Lower Se Kong	CKM	16/3/06	615508 (E) 1500632 (N)	NA	47-50	386	0.5	1–2	0.5	Forest; few houses; eroded banks	Forest; few houses; eroded banks		R – Sand; little debris M – Rock L – Sand; mud; debris	Livestock damage to banks; bank erosion

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Lumphat	CSP	18/3/06	717424 (E) 1490804 (N)	717397 (E) 1490604 (N)	98-102	200	1.7	2.8	1	Forest, small scale agriculture; ferry crossing	Forest; small scale agriculture; ferry crossing	Bedrock and cobble, with many small channels	R – Clay and mud, bamboo leaves M – Sand L-Mud with few leaves	Some agricultural influences and small boat traffic; sewage from village
Pam Pi (Se San at border)	CUS	19/3/06	764506 (E) 1526065 (N)	764635 (E) 1526043 (N)	134	173	1.1-1.5	~ 15	~ 1.5	Forest, bamboo bush; cashew nut behind riparian	Forest and bamboo bush; fruit trees behind riparian	Boulders on bedrock	R-Sand; debris M – Rock; sand L – Sand; mud; debris	Dam upstream; 2 days before sampling there was no flow; sewage inputs; some erosion
Upper Se San	VSS	20/3/06	180527 (E) 1588158 (N)	180585 (E) 1588158 (N)	527	167	5	0.5	1.5	Bamboo bush; banana fields; island with farming in centre of site	Sand extraction; banana; housing	Cobble and gravel	R – Sand; mud; debris M – Sand; L – Sand; mud; debris	Agriculture; banana; Cassava rice; village
Upper Sre Pok	VSP	21/3/06	817329 (E) 1396950 (N)	817731 (E) 1396584 (N)	298-312	93-106	2	5	2.5	Grassy hill side; bamboo bush and trees; large amounts of mimosa	Houses; banana fields; large amounts of mimosa; agricultural pumps; decomposing material	Cobble, gravel, sand	R – Mud; organic material M – Sand; cobble L – Mud; organic material	Agriculture cassava, banana, coffee; trees cleared on right bank; erosion ; navigation

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Vinh Long	VVL	23/3/06	603976 (E) 1135759 (N)	603576 (E) 1134724 (N)	4-9	1064-1070	5.2	4.8	2	Housing; fish farms; water hyacinth	Few trees; agriculture of cashew and fruit crops	Mud; debris	R – Mud; organic material M – Sand L – Mud; organic debris	Navigation; sand collection; agriculture; sewage; erosion; fishing
Can Tho (Bassac)	VCT	24/3/06	588365 (E) 1110673 (N)	587117 (E) 1110902 (N)	7-10	872	3.2	6.9	3	Agricultural; fruit trees	Forest	Hard mud	R – Sand; mud; some organic matter M – Sand; mud L – Clay; sand; mud; some organic material	Navigation; bridge construction; sewage treatment plant construction
Long Xuyen	VLX	25/3/06	551878 (E) 1143546 (N)	551925 (E) 1144518 (N)	7	662	6.9-7	7.2-7.7	7.2-7.4	Navigation; Agriculture along bank ;Eroding shoreline; Banana; mango ;papaya; cassava Construction of bridge; Increasing siltation; Very strong flow; Sewage and waste from factories	High human population density; Fish farm; some scattered bamboo bush	Mud from erosion	R – Mud; clay; organic material; debris M – Soil; clay L – Mud; soil; clay	Agriculture; construction; bank erosion

Site	Code	Date	Coordinates (UTM)		GPS elevation (m)	Width (m)	Depth (m)			Land use cover		Substratum		Potential human impacts
			Right	Left			L	M	R	Left bank	Right bank	Littoral	Channel	
Cao Lanh	VCL	26/3/06	563807 (E) 1153868 (N)	564116 (E) 1196192 (N)	7	1084-1090	0.7	10-15	4.5	Upstream of island; grasses and shrubs; floating fish traps and brush traps	Agriculture; fruit trees; banana; corn; some bamboo bush and trees. More human influence than left bank	Mud; some sand	R – Clay; mud M – Sand L – Sand; mud; organic material	Agriculture; navigation especially on the right bank; erosion on right bank (from agriculture and navigation)
Tan Cha	VTC	27/3/06	524259 (E) 1195808 (N)	524706 (E) 1196192 (N)	6	1060-1180	5.5	8.5	>12	30% agriculture but mostly trees; measurements taken 307 m from shore; increase of shallow water and sandy bottom; heavy navigation	Nearly all banks is agriculture; more erosion than left bank; samples taken 170 m from right bank	Sand	R – Clay; mud M – Sand; mud L – Sand; mud	Agriculture; navigation; domestic waste
Cha Doc	VCD	28/3/06	510969 (E) 1188413 (N)	510829 (E) 1188311 (N)	5	255	5.4	7.4	3.14	Agriculture; few trees (Teak; Eucalyptus); bamboo bush; mimosa; morning glory; garbage	Water hyacinth; vegetable patches; fish cages; garbage; next to road; higher slope	Medium hard mud	R – Mud; organic material M – Mud; organic material L – Mud; organic material	Agriculture; garbage; navigation; sewage from floating houses

3. Calculation of tolerance scores and development of biological indices of stress

3.1 Introduction

Group of organisms that are most useful for biomonitoring contain species with widely differing tolerances to environmental stressors. This is the most commonly stated justification for macroinvertebrates as the basis of biomonitoring, the second most common justification for zooplankton and other algae (after ease of sampling), and the most common justification for zooplankton. In contrast, this is rarely given as a reason to choose fish as the basis of a biomonitoring programme.

Tolerance values are typically based on expert opinion, whereby species, genera, or families are subjectively assigned to broad categories (e.g. very pollution sensitive, pollution sensitive, pollution tolerant, or very pollution tolerant) or given numerical scores (e.g. 1 – 10). Quantitative analysis has been used to develop tolerance scores only relatively recently (Chessman *et al*., 1997; Walley and Hawkes 1997).

The 2006 biomonitoring study of the Lower Mekong Basin (i) developed regional tolerance values for species of diatoms, zooplankton, littoral macroinvertebrates, and benthic macroinvertebrates; (ii) used appropriate formulae to express the tolerance of an assemblage at a site; and (iii) grouped scores into ranges with associated descriptions for the purpose of interpretation and communication.

3.2 Methods

Development of tolerance values

A tolerance value was calculated for each taxon that was collected during the studies conducted in 2004, 2005, and 2006. Tolerance values were derived by assessing the relationship between the presence and absence of species in samples from each study site and the value of an independently measured 'Site Disturbance Score' (SDS) for each site.

In order to determine the Site Disturbance Score, a team of 8 to 10 ecologists/biologists individually rated each site they had visited in terms of their observations of the stressors generated by human activities. Light stress was rated 1, medium stress 2, and heavy stress 3. Sites were initially scored independently. The results were then discussed among the group of assessors and a small percentage (-1%) of scores were changed. The 10 scores were averaged to obtain the overall Site Disturbance Score for each site.

The tolerance of each species (or higher taxon where identification to species was not possible) was calculated as the average Site Disturbance Score for all sites at which that species occurred weighted by the number of samples per site in which the species was recorded. The tolerance values were then re-scaled so that they ranged from 0 to 100, where 0 represents low tolerance and 100 represents high tolerance to human-generated stress such as water pollution.

The Average Tolerance Score per Taxon (ATSPT) was then calculated for each sample collected. ATSPT is the average tolerance of all taxa recorded in a sample, calculated without regard to their abundances. A worked example[1] on the calculations is given in figure 3.1.

1 This worked example was extracted from the zooplankton survey in 2004. For demonstration purposes, it has been simplified by considering only three taxa (*Ceratium* spp., *Chironomidae* sp., and *Copepoda* sp. (nauplius) and only four sites (LNO, LPB, LVT, and LNG).

Zooplankton were sampled at four different sites. Three samples of zooplankton were collected at each site (at Left, Middle and Right). Data in the table is number of individual found per sample.

Taxa Name	Site 1			Site 2			Site 3			Site 4		
	L	M	R	L	M	R	L	M	R	L	M	R
Taxon A			1	196	149	145	1	8		13	7	6
Taxon B	2	1		1	2	1	2	3	2			
Taxon C		2	1	3		1	1		5	42	38	78

Step	Example	Calculation
Step 1: Calculation of SDS for each site SDS is determined by a group of ecologists who attribute a score of 1 (little or no disturbance) to 3 (substantial disturbance) to each of the sampling sites.	Eight participants gave the following scores:	
	for Site 1: 1, 1, 1, 1, 1, 1, 1, 1	→ SDS1 = (1+1+1+1+1+1+1+1)/8 = **1.00**
	for Site 2: 1, 1, 2, 1, 1, 1, 1, 2	→ SDS2 = (1+1+2+1+1+1+1+2)/8 = **1.25**
	for Site 3: 1, 1, 2, 1, 2, 2, 2, 3	→ SDS3 = (1+1+2+1+2+2+2+3)/8 = **1.75**
	for Site 4: 3, 3, 3, 3, 3, 2, 3, 3	→ SDS4 = (3+3+3+3+3+2+3+3)/8 = **2.88**
Step 2. Calculation of the Tolerance Score for each taxon This is calculated as the average of the SDSs for all samples in which the particular taxon was collected.	Taxon A was found in: 1, 3, 2, 3 samples from Sites 1, 2, 3, 4 respectively.	→ The tolerance score of taxon A would be: (1.00*1+1.25*3+1.75*2+2.88*3)/(1+3+2+3) = **1.88**
	Taxon B was found in: 2, 3, 3, 0 samples from Sites 1, 2, 3, 4 respectively.	→ The tolerance score of taxon B would be: (1.00*2+1.25*3+1.75*3+2.88*0)/(2+3+3+0) = **1.38**
	Taxon C was found in: 2, 2, 2, 3 samples from Sites 1, 2, 3, 4 respectively.	→ The tolerance score of taxon C would be: (1.00*2+1.25*2+1.75*2+2.88*3)/(2+2+2+3) = **1.85**
Step 3. Re-scaling of Tolerance Scores Tolerance scores were then re-scaled to range from 0 – 100 instead of 1 – 3, in order to make a more sensible range.	The re-scaling is done by subtracting 1 from the average tolerance score and then multiplying the remainder by 50.	→ Re-scaling of Tolerance Score (taxon A) = (1.88-1.00)*50 = **43.75** Re-scaling of Tolerance Score (taxon B) = (1.38-1.00)*50 = **18.75** → Re-scaling of Tolerance Score (taxon C) = (1.85-1.00)*50 = **42.36**
Step 4. Calculation of the Average Tolerance Score Per Taxon for each individual sample from a site	Site 1, sample 1: taxa B was found	→ =(43.75*0+18.75*1+42.36*0)/(0+1+0) = **18.75**
	Site 1, sample 2: taxa B, C were found	→ =(43.75*0+18.75*1+42.36*1)/(0+1+1) = **30.56**
	Site 1, sample 3: taxa A, C were found	→ =(43.75*1+18.75*0+42.36*1)/(1+0+1) = **43.06**
	Site 2, sample 1: taxa A, B, C were found	→ =(43.75*1+18.75*1+42.36*1)/(1+1+1) = **34.95**
	Site 2, sample 2: taxa A, B were found	→ =(43.75*1+18.75*1+42.36*0)/(1+1+0) = **31.25**
	Site 2, sample 3: taxa A, B, C were found	→ =(43.75*1+18.75*1+42.36*1)/(1+1+1) = **34.95**
	Site 3, sample 1: taxa A, B, C were found	→ =(43.75*1+18.75*1+42.36*1)/(1+1+1) = 34.95
	Site 3, sample 2: taxa A, B were found	→ =(43.75*1+18.75*1+42.36*0)/(1+1+0) = **31.25**
	Site 3, sample 3: taxa B, C were found	→ =(43.75*0+18.75*1+42.36*1)/(0+1+1) = **30.56**
	Site 4, sample 1: taxa A, C were found	→ =(43.75*1+18.75*0+42.36*1)/(1+0+1) = **43.06**
	Site 4, sample 2: taxa A, C were found	→ =(43.75*1+18.75*0+42.36*1)/(1+0+1) = **43.06**
	Site 4, sample 3: taxa A, C were found	→ =(43.75*1+18.75*0+42.36*1)/(1+0+1) = **43.06**
Step 5. Calculation of the mean Average Tolerance Score Per Taxon for each site	ATSPT for Site 1	→ =(18.75+30.56+43.06)/3 = **30.79**
	ATSPT for Site 2	→ =(34.95+31.25+34.95)/3 = **33.72**
	ATSPT for Site 3	→ =(34.95+31.25+30.56)/3 = **32.25**
	ATSPT for Site 4	→ =(43.06+43.06+43.06)/3 = **43.06**

Figure 3.1. Illustration of the calculation of ATSPT

4. Environmental variables

4.1 Introduction

Variables describing the physical and chemical environment provide essential information for characterising aquatic ecosystems, because these factors directly influence the structure and function of an ecosystem's biological components. Physical and chemical variables are widely used to set water-quality standards and can be used to assist in interpreting biological trends and patterns. Although the biological monitoring programme has only recently begun, the Mekong River Commission has been monitoring physical and chemical water-quality in the Mekong River Basin for over 20 years (Campbell, 2007).

The objectives of the study of the physical and chemical factors completed in 2006 were as follows: (i) to describe selected physical and chemical characteristics of sites in the lower Mekong River, and (ii) to provide environmental data that could be related to various biological patterns. To address these objectives, the study collected data on altitude, river width, water depth, water transparency, turbidity, water temperature, dissolved oxygen, electrical conductivity (EC), and pH. The amounts of chlorophyll-a and various algal groups were also measured.

4.2 Study sites and sampling methods

Study sites

In March 2006, various environmental variables were measured at 21 sites in the Mekong River and its tributaries. Details of the study sites are provided in Chapter 2. Study sites sampled in 2004 and 2005 are presented in the biomonitoring reports for those years (MRC 2006; MRC, in press).

Field methods

The sampling methods in the 2006 survey generally followed those used in the 2005 survey (MRC, in press). The map coordinates and altitudes of the sampling sites were determined with a Garmin GPS 12xL, and stream width was measured with a Newcon Optik LRB 7x50 laser rangefinder. At each site, water-quality measurements were made in three sections of the river: near the left bank, near the right bank, and in the centre of the river. A Secchi disc was used to determine water transparency. The disc was slowly lowered into the water, and the depth at which it could no longer be seen was recorded. The disc was then lowered another metre and slowly pulled up until it reappeared. If it reappeared at a depth more than 0.05 m different from the depth at which it disappeared, the procedure was repeated. Water turbidity was measured at the water surface with a Hach 2100P turbidity meter. Temperature, DO, EC, and pH were measured with YSI 556MP5 meter, calibrated according to the manufacturer's instructions. Readings were taken at the surface and at a depth of 3.5 m, or the maximum of the river, whichever was less.

The amount of chlorophyll-a in water was measured at the surface with an Aquaflour hand-held fluorimeter. In addition, the amounts of pigments for four algal groups (green, blue green, diatoms, and cryptomonads) in the water column were averaged from readings at different depths taken with a Ts. UV Fluorimeter.

Data analysis

The environmental variables were reported as average values. Site comparisons were made for selected variables in a simple graphic form. In Chapter 9, correlation coefficients are reported between selected environmental variables and ATSPT values for all biological assemblages examined (data from Chapters 5–8).

4.3 Results

Environmental data collected in 2006

The environmental variables showed a broad range of values across the 21 study sites (Table 4.1). For example, altitude varied from 3 masl (metres above sea level) at sites CBS and CTU to 527 masl at site VSS. Channel width varied from as narrow as 39 m at CPT to as wide as 1,629 m at CNL. Water transparency (Secchi depth) ranged from 0.2 m at CSN to 1.5 m at site CMR. Over the sites sampled, average transparency was 0.76 m (with standard deviation of ±0.37 m). Turbidity was generally higher at sites in the main channel than at sites in tributaries, except for VSR where the site sampled was downstream (~ 6 km) from a dam construction site. The average turbidity was 19.01 (±17.19) NTU with the lowest value of 6 NTU at CSJ and the highest of 71 NTU at VSR. Chlorophyll-a ranged between 0.27 and 3.99 µg/L with an average of 1.26 (±1.09) µg/L.

Water temperature (Fig. 8.1) varied slightly from site to site, with an average of 29.6ºC (±1.4ºC). Dissolved oxygen (DO) concentrations (Fig. 8.1) were generally high compared to those typically reported for tropical waters, with an average of 6.8 mg/L (±1.67 mg/L). The highest value of 10.5 mg/L was at site CMR, and lower DO values were found at sites with human activities, such as site CSK and site VCD. The lowest value of 3.8 mg/L was recorded at site CSK.

Table 4.1. *Altitude, river width, maximum water depth and average water transparency (Secchi depth), turbidity and the amount of chlorophyll-a for 21 sites sampled in 2006.*

Site	Altitude (m)	Width (m)	Depth (m)	Secchi Depth (m)	Turbidity (NTU)	Chlorophyll-a (µg/L)
CPP	6	460	12.0	0.54	25.87	3.36
CBS	3	298	7.0	0.72	14.37	2.13
CNL	14	1,629	15.0	0.78	21.53	0.72
CTU	3	522	10.0	0.52	29.97	1.12
CSN	6	66	4.5	0.20	12.93	2.04
CSK	5	127	2.0	0.33	37.50	3.45
CPT	13	39	1.6	0.26	55.50	3.99
CKT	13	1,300	8.0	1.30	5.87	0.27
CMR	58	450	8.0	1.50	5.89	0.42
CSJ	52	622	3.0	1.10	5.67	0.61
CKM	50	386	2.0	1.18	6.05	0.57
CSP	102	200	2.8	1.07	6.77	0.61
CSU	134	173	15.0	1.17	7.51	0.39
VSS	527	167	1.5	0.98	9.14	0.40
VSR	312	106	5.0	0.18	71.08	0.98
VTR	9	1,070	5.2	0.68	13.17	0.82
VCT	10	872	6.9	0.63	15.93	1.20
VLX	7	662	7.7	0.67	12.55	0.97
VCL	7	1,090	15.0	0.59	14.27	0.97
VTC	6	1,180	12.0	0.97	8.26	0.73
VCD	5	255	7.4	0.55	19.32	0.63

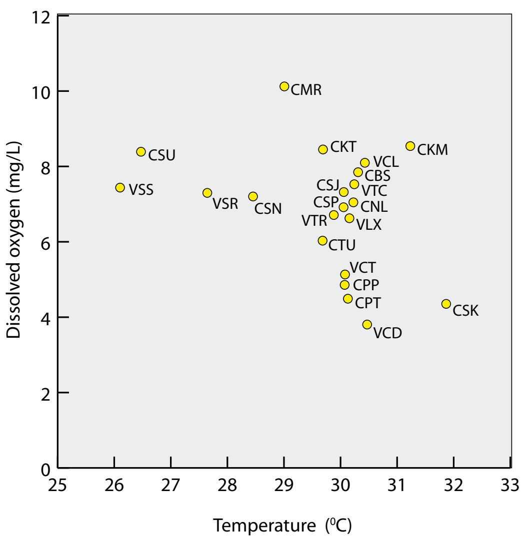


Figure 4.1. Dissolved oxygen concentration (mg/L) and temperature (°C) at the water surface, based on averages of measurements taken at the left bank, right bank, and centre of the channel at 21 sites sampled in 2006.

The river water was slightly alkaline at most of the sites, with pH varying between 5.2 and 7.9 and averaging 7.2 (± 0.6) (Figure 4.2). Electrical conductivity varied from 40 to 230 µS/cm, with an average of 130 µS/cm (± 63 µS/cm). Higher conductivities were found at sites CMR, CKT, and CNL in the main channel, and sites in Delta areas (e.g. VTR, VCT, VLX, VCL, VTC, and VCD). Lower conductivity was found at sites in the tributaries, including the sites CSJ, CKM, CSP, CSU, VSS, and VSR (Figure 4.2).

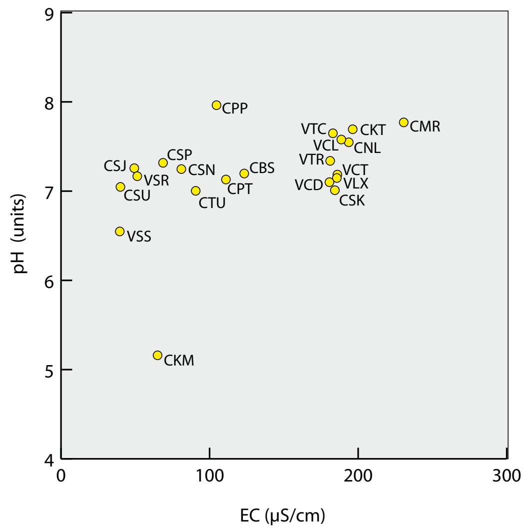


Figure 4.2. Conductivity (µS/cm) and pH at the water surface, based on averages of measurements taken at the left bank, right bank, and centre of the channel at 21 sites sampled in 2006.

Green algae was the most abundant of the four algal groups measured (green, blue-green, diatoms, and cryptomonads). It made up over 50% of the total biomass of the major algal groups at most of the sites, the exceptions including CBS, CNL, VCL and VTC where the blue green algae was the most abundant group. At site CKT, diatoms and cryptomonads were the most abundant and made up about 40% each to the total algal biomass (Table 4.2).

The average total major algal biomass at the 20 of the 21 sites (no data were obtained at one site) ranged from 0.47 µg/L to 6.24 µg/L, with an overall average of 1.87 (±1.59) µg/L. The highest algal biomass (6.24 µg/L) was found at the CPT site, where the channel is narrow, and the water was still and shallow, with a Secchi depth of only 0.26 m. Site CBS also had high algal biomass values (Table 4.2).

Table 4.2. *Biomass of green, blue green algae, diatoms, and cryptomonads for 21 sites sampled in 2006.*

Site	Green algae (µg/L)	Blue green algae (µg/L)	Diatoms (µg/ L)	Cryptomonads (µg/L)	Total (µg/L)
CPP	0.40	0.15	0.12	0.01	0.68
CBS	1.89	3.58	0.07	0.13	5.66
CNL	0.19	0.33	0.06	0.10	0.68
CTU	0.40	0.26	0.17	0.14	0.97
CSN	1.79	1.05	0.42	0.49	3.75
CSK	1.31	0.58	0.07	0.06	2.02
CPT	2.63	2.47	1.03	0.11	6.24
CMR			NA		
CKT	0.05	0.09	0.35	0.37	0.86
CSJ	1.07	0.72	0.07	0.05	1.90
CKM	1.07	0.60	0.18	0.06	1.92
CSP	0.67	0.50	0.15	0.00	1.32
CSU	0.45	0.13	0.01	0.06	0.65
VSS	0.23	0.05	0.18	0.00	0.47
VSR	0.67	0.36	0.08	0.00	1.11
VTR	0.73	0.51	0.08	0.00	1.32
VCT	1.05	0.49	0.08	0.06	1.68
VLX	0.82	0.66	0.06	0.02	1.56
VCL	0.77	0.83	0.40	0.03	2.03
VTC	0.59	0.96	0.36	0.03	1.94
VCD	0.33	0.28	0.00	0.02	0.64

4.4 Discussion

Physical and chemical conditions in the Mekong River System

The environmental variables at the sampling sites were mostly within the natural ranges expected for surface waters in this region. Conductivity was within the natural range although it was slightly higher at the main channel sites and sites in the Delta area. The pH, DO, and temperature data were also within the ranges defined for aquatic ecosystems according to the standards for surface water quality set by Thailand, Viet Nam, and Cambodia (MRC, 2005; PCD, 2004). The distinctly low pH value of 5 at CKM may have been caused by recent activities upstream of that sampling site. This conclusion is based on the pH value of 7.5 taken at the same site in 2005 (MRC, in press).

Dissolved oxygen values were high, even at those sites showing evidence of human disturbances from villages, agriculture, or dam construction. Most of the sites had DO values higher than, or very close to 6 mg/L, falling within Class 2 (very clean) of Thailand's water quality standards and within the range specified for biodiversity conservation for Cambodian rivers. Although sites CSK, VCD, and CPT had low DO, they were still within Class 3 (suitable for agriculture, navigation).

The high turbidity and low Secchi disk depth at site VSR were most probably caused by the sediments released from the dam construction site, 6 km upstream.

Nutrients are important factors affecting algal assemblages and biomass in natural waters. The high total algal biomasses at sites CBS and CPT were also associated with high levels of blue green algae. These may have been caused by high nutrient inputs from human activities including agriculture and sewage disposal nearby.

5. Benthic diatoms

5.1 Introduction

Algae, including diatoms, are important primary producers in aquatic ecosystems. The major function of these small photosynthetic organisms is as a base for pathways by which energy and materials are transferred in aquatic food-webs. Moreover, algae have many human uses in areas such as in aquaculture, environmental monitoring, and medicine.

Diatoms have been studied in Southeast Asia since the late 19th century, when early taxonomic studies were undertaken by foreign scientists. Ostrup reported 81 species of diatoms from Koh Chang Island, after the Danish expeditions to Thailand in 1899 – 1900 (Peerapornpisal *et al.,* 2000). Patrick (1939) reported 185 diatom species in her study of the intestinal contents of tadpoles from Thailand and the Federal Malay States. In 1961 – 1962, material collected by the Joint Thai-Japanese Biological Expedition to Southeast Asia was identified by Hirano and has served as a valuable species list of potential taxa present.

The objective of this chapter is to (i) describe the characteristics of the diatom community that was quantitatively sampled at 21 sites in 2006, (ii) report tolerance scores based on the diatom community present at each of the sites examined in 2006, and (iii) relate tolerance scores and other metrics to the Site Disturbance Score.

5.2 Study sites and sampling methods

Study sites

In March 2006, benthic diatoms were sampled along the shore at 21 sites in the Mekong River and its tributaries. These sites are listed in Chapter 2. Details of the sample sites examined in 2004 and 2005 are given in the biomonitoring reports for those years (MRC, 2006; MRC, in press).

Field methods

Locations for sampling of benthic diatoms were chosen where the water depth was less than 1 m and substrata suitable for sampling extended over 100 m. The most appropriate substrata were cobbles and other stones with a surface area that was greater than 10 cm^2, but still small enough to fit in a sampling bowl of 20–30 cm diameter. At sites that lacked stones but had predominantly muddy or sandy beds, suitable substrata included bamboo sticks, aquatic plants, and artificial substrata.

Ten points were sampled at intervals of about 10 m. At each point a single stone was selected that appeared to be covered by a thin brownish film or have a slippery feel, which are often signs of a coating of abundant benthic diatoms. For each point that had no stones, the nearest hard substratum was sampled. To sample the diatoms, a plastic sheet with a 10 cm^2 square cutout was placed on the upper surface of the selected stone or other substratum, and benthic diatoms were brushed and washed off into a plastic bowl until the cutout area was completely clear. Each sample was transferred to a plastic container and labelled with the site name, location code, date, and replicate number. The collector's name and substratum type were also recorded. Samples were preserved with Lugol's solution.

Laboratory methods

In the laboratory, the samples were cleaned by digestion in concentrated acid, and then centrifuged at 3500 rpm for 15 minutes. The diatom cells (the brown layer between the supernatant and solid particles) were siphoned into an 18 cm core tube. Strong acid (H_2SO_4, HCl or HNO_3) was added and the tubes were heated in a boiler (70−80 ^{o}C) for 30−45 minutes. The samples were then rinsed with de-ionized water 4−5 times and adjusted to a volume of 1 mL. 2−3 drops of each sample (0.02 mL per drop) were placed on a microscope slide and dried. A mounting agent such as Naphrax or Durax was added to make a permanent slide for diatom identification and counting, which were done under a compound microscope; about 300 diatom cells were counted per slide and used to estimate total numbers per sample. Identification was based on frustule type, size, special characteristics, and structure, as described and illustrated in textbooks, monographs and other publications on tropical and temperate diatoms (Foged, 1971, 1975, 1976; Krammer & Lange-Bertalot, 1986, 1988, 1991a, 1991b; Pfister, 1992). In many cases, species-level identifications were not possible and presumptive species were designated by numbers. All samples of diatoms collected from 2004 – 2006 have been standardised in terms of the numerical designations used to describe the taxa. The permanent slides are kept in the Applied Algal Research Laboratory Collection at Chiang Mai University.

Multimetric analysis

The following metrics were calculated for all sites sampled in 2006 : (i) taxonomic richness (i.e. number of taxa), (ii) abundance (numbers of individuals per unit area sampled), (iii) the Shannon-Wiener Diversity Index, and (iv) the Berger-Parker Dominance Index. The Shannon-Wiener Diversity Index (H') is based on species richness and evenness in abundance among species (Pinder, 1999; Stiling, 2002), and is calculated by the following formula:

$$H' = -\sum_{i=1}^{s} pi.\log(pi)$$

where *pi* is the proportion of individuals in the sample that belong to the *i*th of *s* taxa. The Berger-Parker Index (*D*) expresses the dominance of the single most abundant taxon as (from Stiling, 2002):

$$D = 1 - \frac{N\max}{N}$$

where *N*max is the number of individuals of the most common taxon and *N* is the total number of individuals in the sample.

The above metrics were related to the Average Site Disturbance Scores, which were calculated for each site as described in Chapter 3.

Tolerance values

Tolerance values were calculated for each taxon of benthic diatoms collected in 2004, 2005 and 2006, as described in Chapter 3. The Average Tolerance Score per Taxon (ATSPT) was calculated for each sample and then averaged over all samples in each sampling event from 2004 – 2006. Average ATSPT values were rated as described in Chapter 9.

5.3 Results

Biota collected in 2006

The 21 sites sampled in 2006 yielded a total of 79 species of benthic diatoms out of the 2100 cm^2 of algal samples collected; 75 species were in the order Pennales and 4 in the order Centrales (Appendix 1.1). *Navicula symmetrica*, *Gomphonema parvulum* and *Nitzschia clausii* had the widest distribution and each occurred at all sites sampled.

Species richness

Species richness per site ranged from 13 to 38 at the 2006 sites (Table 5.1). The highest richness occurred at sites CKM (38 species) and CSJ (35 species), while the lowest richness was found at the lower Mekong River sites that had sandy and muddy substrata, such as sites VCT (13 species) and CSU (14 species).

Abundance

The average density of diatoms ranged from 72 to 377 cells/cm^2 at the 2006 sites (Table 5.1). The highest abundance occurred at site CPP (377 cells/cm^2), while the lowest abundance was found at the lower Mekong River sites in Viet Nam that had hard muddy substrata, such as site VCT (72 cells/cm^2).

Table 5.1. *Diatom metrics for 2006.*

Site	No. of species	Density (cell/cm^2)
CPP	19	377.1
CBS	19	311.1
CNL	22	313.6
CTU	13	219.1
CSN	19	221.3
CSK	13	107.0
CPT	24	268.3
CKT	26	134.3
CMR	28	216.8
CSJ	35	313.5
CKM	38	249.8
CSP	30	308.0
CSU	14	140.0
VSS	25	334.1
VSR	31	161.2
VTR	21	100.1
VCT	13	72.1
VLX	18	316.5
VCL	23	179.7
VTC	19	234.4
VCD	19	279.5

Shannon-Wiener diversity index

The Shannon-Wiener diversity index ranged from 1.2 to 2.5 at the 21 sites examined (Figure 5.1). The values for diversity were highest at sites that had sandy and hard substrata, such as CKT and CMR (2.52 and 2.64), while the lowest diversity index values were at the sites that had muddy and debris substrata, such as site CPT (1.18).

Dominance index

The Berger-Parker dominance index ranged from 0.30 to 0.85 in the 2006 sites (Figure 5.1). The lowest dominance index value occurred at sites that had muddy and debris substrata, such as site CPT (0.30), while the highest dominance index was at sites that had sandy and hard substrata, such as CKT and CMR (0.84 and 0.85 respectively).

There is a strong direct relationship between the values of the species diversity index and the dominance index (Figure 5.1).

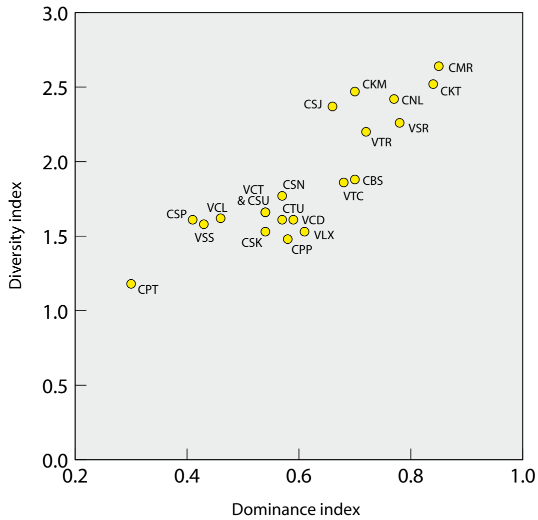
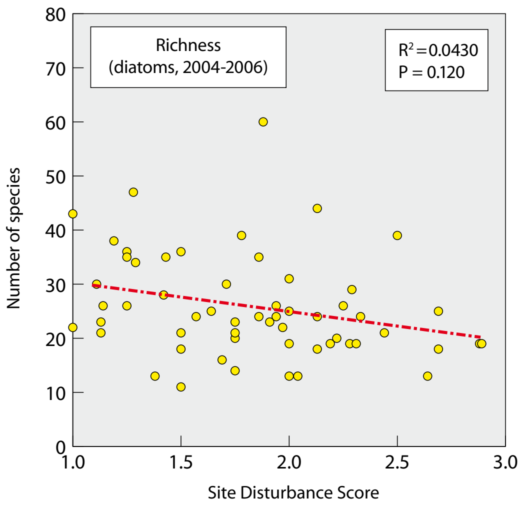
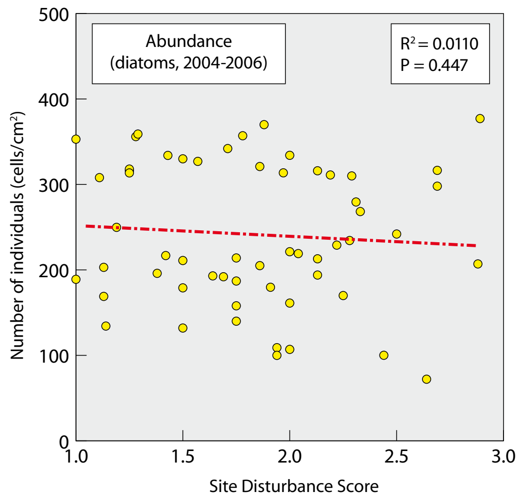


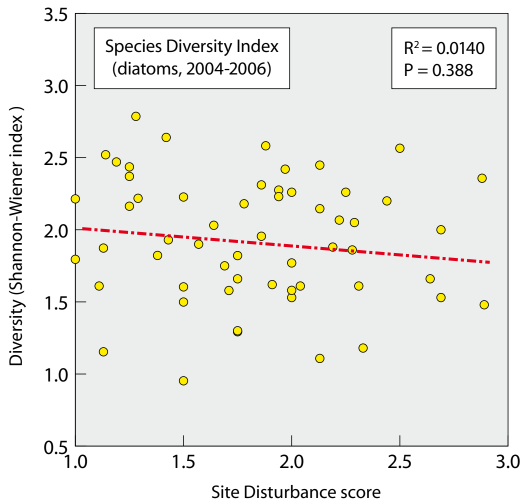
Figure 5.1 Values of the diversity index (H') and dominance index (D) for benthic diatoms at 21 sites in 2006.

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score

Taxonomic richness, number of individuals, and the values of the species diversity index and the dominance index from 57 sampling events at 43 sites, 2004–2006, showed no statistically significant relationships with the Average Site Disturbance Score (P > 0.05; Figures 5.2 – 5.5). Likewise, a log transformation of abundance data did not produce a statistically significant relationship.







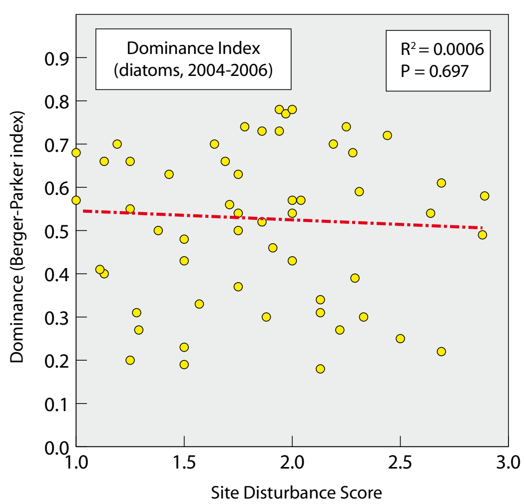


Figure 5.2 Top left. Regression relationship between taxonomic richness of benthic diatoms and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 5.3 Top right. Regression relationship between abundance of benthic diatoms and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 5.4 Bottom left. Regression relationship between the Shannon-Wiener diversity index for benthic diatoms and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 5.5 Bottom right. Regression relationship between the Berger-Parker dominance index for benthic diatoms and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Variation in ATSPT among sampling sites in the Lower Mekong, 2004-2006

The tolerance values for individual taxa of benthic diatoms collected from 2004–2006 varied from 4 to 75 (Appendix 1.2) and middle-range values were most numerous (Chapter 9). The ATSPT varied greatly among the sites examined in 2004–2006, ranging from 28 to 52. These scores ranged up to 4.3 standard deviations above the mean for reference sites, placing the sites in classes A–C (low–medium stress). No sites ranked in the high or very high tolerance levels. There was a very strong, statistically significant, relationship between ATSPT and Average Site Disturbance Score (Figure 5.6).

There was a general trend of increasing the ATSPTs from north to south indicating a decrease in pollution sensitive species. Generally, ATSPTs were lower in the upper and tributaries sites than in the lower Mekong sites.

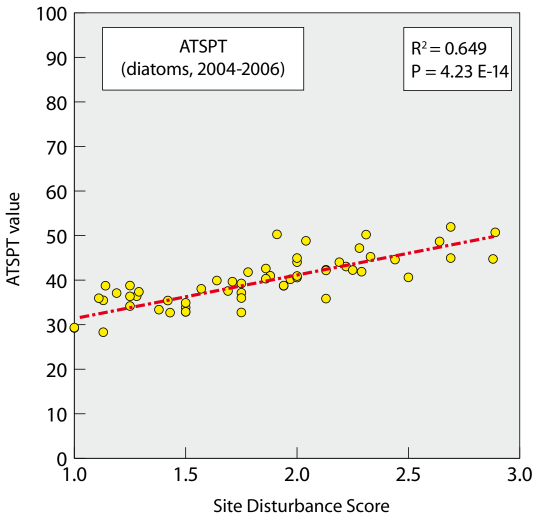


Figure 5.6 Regression relationship between the ATSPT for benthic diatoms and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

5.4 Discussion

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score

No statistically significant relationships were found between the above metrics from 57 sampling events at 43 sites and the Average Site Disturbance Score from these sites. In addition, log transformation of abundance did not produce a statistically significant relationship. Values of all these metrics were highly variable among the sites, probably because of differences in habitat. For example, the high richness occurring at tributaries of the Mekong River, sites TKO (52 species), TSK (41 species) and CKM (38 species), and the island in the Mekong River, VTC (37 species), was associated with appropriate substrata (i.e. hard substrata such as cobbles and stones), and physical conditions, such as high transparency and low disturbance, that made these sites conducive to a rich flora of benthic diatoms. In contrast, the coarse sand, mud and clay substrata at main-channel sites VTC (13 species), CTU (13 species), LKL (14 species), and CSU (14 species) were an obvious limiting factor for richness of benthic diatoms. Variations in abundance and values of the species diversity and dominance indices can be attributed to the same factors.

Tolerance scores

The distribution of tolerance scores for the taxa of diatoms collected in 2004–2006 indicates a flora that has some sensitive taxa but is predominantly composed of taxa with middle-range pollution tolerance. This is similar to the results for zooplankton but different from those for benthic and littoral macroinvertebrates, which included a higher proportion of sensitive taxa.

Some stress-sensitive taxa were found as numerically dominant species in the sites with low human impact. For example, *Synedra ulna* var. *aequalis*, with a tolerance value of 33.6 that is indicative of a stress-sensitive species, was found in high abundance at site CPS, which had a somewhat higher ATSPT (43).

Variation in ATSPT among sampling sites in the Lower Mekong, 2004–2006

The distribution of ATSPT values at the 43 sites visited reflects a gradient of increasing stress from north to south. For example, the sites with lower Average Site Disturbance Scores (LMH, LMX, LNO, LNK, LPB, LKL, CSJ, CKM, CKT) had lower ATSPT values than Mekong River sampling sites down river, where the Average Site Disturbance Scores and the ATSPT values are higher (e.g. sites CTU, CPP, CNL, CBS, VTC, VCD, VCL, VLX, VTR, and VCT). Furthermore, the ATSPTs calculated for the benthic diatoms in lower Mekong River sites were higher than the values of sites in the tributaries. The average ATSPT in the sites sampled in the four countries from 2004–2006 ranged from a low in Lao PDR (35), through Cambodia (38) and Thailand (41), to a high in Viet Nam (45).

6. Zooplankton

6.1 Introduction

Zooplankton are widely distributed and present in most water bodies in the world. In rivers, the smallest members of the zooplankton are protozoans and rotifers (Kudo, 1963), and the larger zooplankton are mostly crustaceans (Hynes, 1970). The zooplankton community is composed of both primary consumers, which feed on bacteria and phytoplankton, and secondary consumers, which feed on other zooplankton. Zooplankton link the primary producers (phytoplankton) with larger organisms at higher trophic levels, and they are important as food for forage fish species and for larval stages of all fish.

Zooplankton are excellent indicators of environmental conditions because they respond to low concentrations of dissolved oxygen, high levels of nutrients and non-living organic matter, and toxic contaminants. The main groups of zooplankton, especially Crustacea and Eurotatorea, have long been assessed quantitatively and considered useful in evaluating environmental quality (Crivelli and Catsadorakis, 1997). Recently, zooplankton have been increasingly used in biological monitoring programs. For example, zooplankton were used as indicators in an ecological health assessment for estuaries in Australia (Deeley and Paling, 1999). However, in the Mekong River system, studies of zooplankton have been limited. Most studies have concerned the Mekong Delta in Viet Nam (e.g. Doan *et al.*, 2000; Le and Pham, 2002) and have focused on taxonomy and food resources for fisheries.

The objective of this report is to: (i) describe the characteristics of the zooplankton community that was quantitatively sampled at 21 sites in 2006; (ii) tolerance scores based on the zooplankton community for each of the sites examined in 2006, and (iii) relate tolerance scores and other metrics to the Site Disturbance Score.

6.2 Study sites and sampling methods

Study sites

In March 2006, zooplankton samples were collected at 21 sites in the Mekong River and its tributaries within two countries, Cambodia and Viet Nam, as listed in Chapter 2. Details of the sample sites examined in 2004 and 2005 are given in biomonitoring reports for those years (MRC, 2006; MRC, in press).

Field methods

Three samples were collected at each site. One was taken near the left bank of the river, at a distance of about 4 – 5 m from the water's edge. A separate sample was taken at a similar distance from the right bank, and another in the middle of the river. The samples were taken at least 1 m from potentially contaminating substances such as debris and aquatic plants, and at least 2 m from vertical banks. At sites where the water current was too fast to sample exactly in the mid-stream, samples were collected closer to the left or the right bank, but not as close to the bank as where the 'side samples' were taken.

Before sampling at each site, the sampling equipment (a net, bucket, and plastic jar) was washed to remove any organisms and other matter left from the previous site. Quantitative samples were collected at a depth of 0 to 0.5 m in a bucket having a volume of 10 L. The 10 L of river water collected was filtered slowly through a plankton net (mesh size of 20 µm) to avoid any overflow. When the water volume remaining in the net was about 150 mL, the water was transferred to a plastic jar (250 mL volume). The samples were immediately fixed in the field with 4% formaldehyde. The sample jars were labelled with the site name, site code, sampling position, sampling date, and the sample number.

Laboratory methods

In the laboratory, large debris particles were removed from the samples with forceps. Each sample was filtered via a net with a mesh size of 10 µm and rinsed with distilled water, and then settled in a graduated cylinder. Excess water was discarded until about 50 mL of water and settled material remained. This was transferred into a petri dish and examined under a stereo-microscope at a magnification of 40x to identify the large species of zooplankton (> 50 µm in diameter). The smaller species and details of larger species were examined on a microscope slide under a compound microscope at a magnification of 100 – 400 x. All individuals collected were counted and identified to lowest level of taxonomy possible, generally species. Identification was based on morphology as described in Vietnamese and international references (e.g. Dang *et al*., 1980; Eiji, 1993). After analysis, samples were returned to the bottles and preserved. All specimens are kept at Ton Duc Thang University, Ho Chi Minh City, Viet Nam.

Multimetric analysis

Zooplankton results from all sites sampled in the years 2004, 2005 and 2006 were used to calculate the following metrics: (i) species richness (number of taxa per site), (ii) abundance (number of individuals per sample), (iii) the Shannon-Wiener Diversity Index, and (iv) the Berger-Parker Dominance Index. The above metrics were tested for their potential use as indicators of human impact by regressing them against the 'Average Site Disturbance Score' derived for all sites sampled in 2004, 2005, and 2006 as described in Chapter 3. For each metric examined against this index, p values and R^2 values were calculated from linear least-squares regression.

Tolerance values

Tolerance values were calculated for each taxon of zooplankton collected in 2004, 2005, and 2006, as described in Chapter 3. The Average Tolerance Score per Taxon (ATSPT) was calculated for each sample, and then averaged over all samples in each sampling events for 2004 – 2006. The ATSPT was rated as described in Chapter 9.

6.3 Results

Biota collected in 2006

In total 20,825 individuals were collected in the zooplankton samples taken at the 21 sites examined in 2006. These comprised 105 species in 56 genera and 28 families, and 4 forms of larva. The zooplankton included four main groups: Crustacea (including Copepoda, Brachiopoda, and Ostracoda), Eurotatorea, Protozoa and larvae (Table 6.1). Eurotatorea had the most taxa (30 genera and 12 families comprising 58.7% of the total zooplankton taxa collected). The Brachionidae (Eurotatorea), Difflugiidae (Protozoa) and Lecanidae (Eurotatorea) were richest families with 17, 11 and 10 taxa, respectively (Appendix 2.1). The Ostracoda was represented by only one taxon, which was recorded at some sites in the Mekong Delta (Appendix 2.1).

Table 6.1. *Total number of taxa of zooplankton recorded at 21 sites sampled in March 2006.*

Group	Number of taxa
Crustacea	23
- Copepoda	12
- Ostracoda	1
- Branchiopoda	10
Eurotatorea	64
Protozoa	18
Larvae	4

Eurotatorea, Protozoa, and larvae were recorded at all 21 sites, while Copepoda and Brachiopoda were found at 16 – 18 sites. Some taxa had a wide distribution from fresh water to brackish water (Crustacea: Pseudodiaptomidae, Eurotatoria: Brachionidae) whereas others were found only at some sites in Mekong Delta. Copepod nauplii (larval forms) had the widest distribution, occurring at all sites. *Arcella vulgaris* (Protozoa: Arcellidae), *Centropyxis aculeatus* (Protozoa: Centropyxidae), *Polyarthra vulgaris* (Eurotatorea: Synchaetidae), *Philodina roseola* (Eurotatorea: Philodinidae), and *Thermocyclops hyalinus* (Crustacea: Cyclopidae) also had a wide distribution and occurred at 16–19 sites. The fauna was dominated by the Eurotatorea (families Synchaetidae, Brachionidae, Hexathridae) and Protozoa (families Arcellidae, Centropyxidae, Difflugidae).

Species richness

Taxon richness at a site varied widely at the 21 sites sampled in 2006. Richness ranged from 12 to 52 taxa (Table 6.2).

The number of taxa was highest at site CPT, where the richness of Eurotatorea was the highest encountered at the 21 sampling sites (71% of total taxa). Taxa richness was lowest at site CPP, where Ostracoda and Brachiopoda were absent from the samples (Table 6.2).

Table 6.2. *Zooplankton taxon richness and abundance (individuals/10 L) at 21 sites sampled in March 2006.*

Site	No. of taxa		Abundance	
	Total	Range	Mean	Range
CPP	12	5–10	92	55–126
CBS	28	21–24	844	576–990
CNL	25	13–21	265	207–318
CTU	13	6–10	66	41–94
CSN	28	17–23	297	268–329
CSK	44	30–38	1431	1121–1674
CPT	52	39–41	2965	2546–3184
CKT	19	11–13	27	21–35
CMR	16	8–10	24	17–36
CSJ	30	16–23	62	41–90
CKM	18	9–12	21	12–26
CSP	20	10–16	70	28–112
CSU	41	29–34	176	134–227
VSS	23	15–20	60	46–71
VSR	14	4–11	15	8–27
VTR	14	7–8	21	14–32
VCT	19	6–18	55	34–92
VLX	25	13–19	148	131–165
VCL	26	13–17	127	105–171
VTC	24	13–15	79	68–95
VCD	24	9–15	97	76–127

Abundance

Abundance at a site also varied at the 21 sites sampled in 2006. Mean abundance ranged from 15 to 2,965 individuals/10L (Table 6.2). As with number of taxa, the number of individuals was highest at site CPT (2,546 – 3,184 individuals/sample). Site CSK also had high abundance (1,121 – 1,674 individuals/sample). The dominant species present were those well adapted to nutrient-rich conditions and belonged to the families Synchaetidae and Brachionidae (Eurotatorea). The lowest abundance was at VSR (8 – 27 individuals/sample) where no or few crustaceans were present.

The species of the families Centropyxidae and Difflugidae (Protozoa) were numerically dominant, and these species characteristically occur in sites with high turbidity and slow water currents (Appendix 2.1).

Shannon-Wiener diversity index and dominance index

The Shannon-Wiener Diversity Index ranged from 0.63 to 2.91 in 2006 (Figure 6.1). The diversity index value was highest at site CSU, where there was high taxa richness. The diversity index value was lowest at site CPP, where the number of taxa was also lowest.

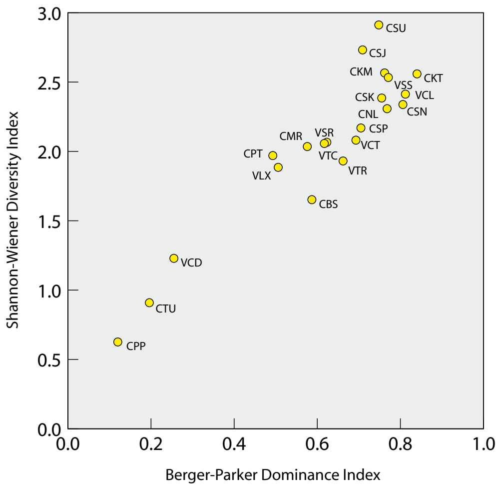
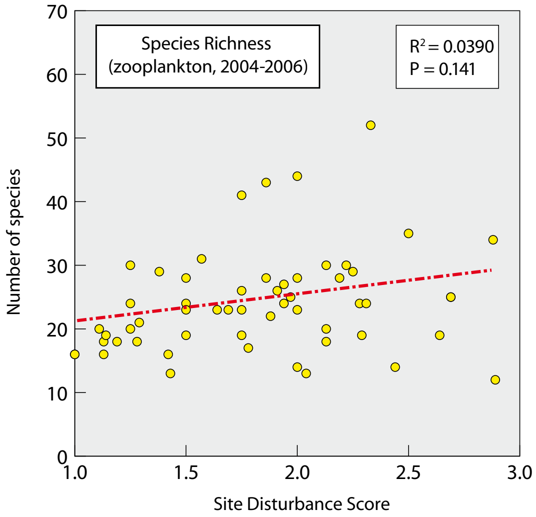
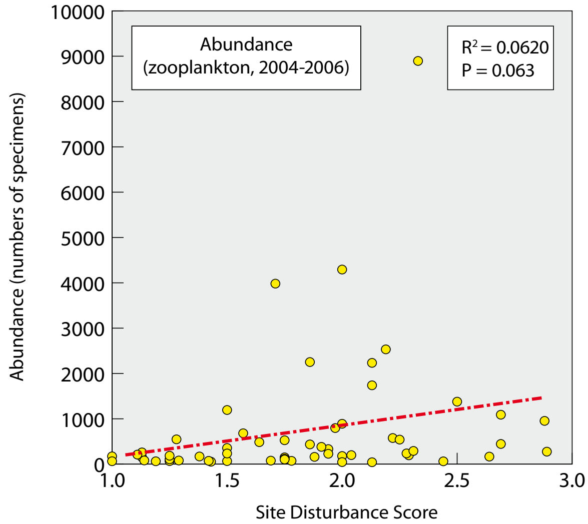
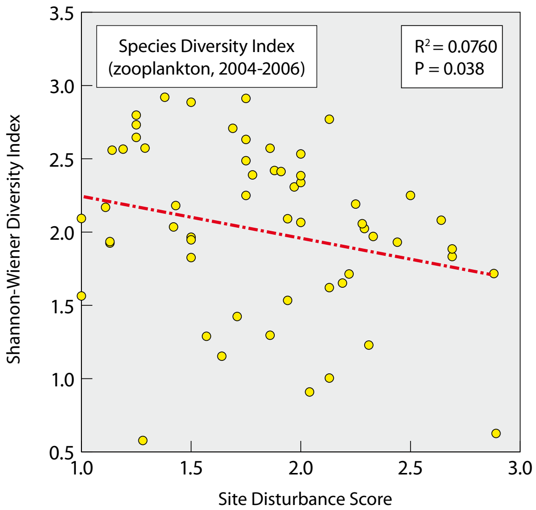


Figure 6.1 The diversity and dominance index values of zooplankton at 21 sites in 2006.

The Berger-Parker Dominance Index ranged from 0.12 to 0.84 in 2006 (Figure 6.1). The dominance index value was highly correlated with the diversity index value; the lowest dominance index value was at site CPP, where the diversity index value was also lowest. The highest dominance index value was at site CKT, where the value of diversity index was also high (Figure 6.1).







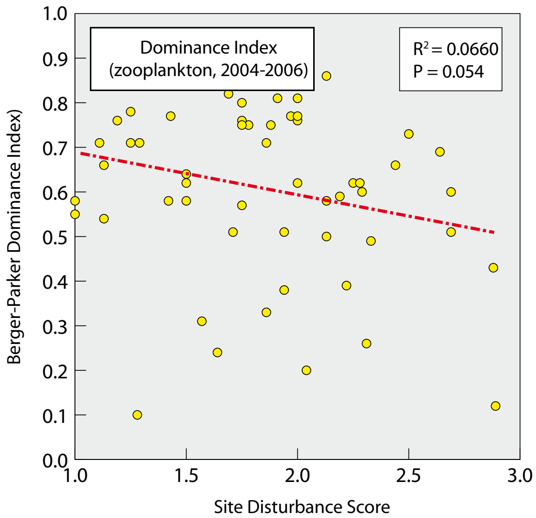


Figure 6.2 Top left. Relationship between the richness of zooplankton and the Average Site Disturbance Score for sites sampled in 2004, 2005, and 2006.

Figure 6.3 Top right. Relationship between the abundance of zooplankton and the Average Site Disturbance Score for sites sampled in 2004, 2005, and 2006.

Figure 6.4 Bottom left. Relationship between the diversity index of zooplankton and the Average Site Disturbance Score for sites sampled in 2004, 2005, and 2006.

Figure 6.5 Bottom right. Relationship between the dominance index of zooplankton and the Average Site Disturbance Score for sites sampled in 2004, 2005, and 2006.

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score

For combined results for 57 sampling events at 43 sites (2004, 2005 and 2006), the relationship between richness and the Average Site Disturbance Score was not statistically significant ($P > 0.05$) (Figure 6.2).

Abundance did not have a statistically significant relationship with the Average Site Disturbance Score ($P > 0.05$). (Figure 6.3).

The correlation between the diversity index and the Average Site Disturbance Score at 57 sites was statistically significant ($P = 0.038$) (Figure 6.4).

The relationship between the dominance index and the Average Site Disturbance Score was not statistically significant ($P = 0.054$) (Figure 6.5).

Variation in ATSPT among sampling sites in the Lower Mekong River, 2004-2006

The tolerance values for individual taxa of zooplankton collected from 2004-2006 varied from 0 to 94. The ATSPT varied greatly among the sites examined in 2004-2006, ranging from 22 to 54 (Figure 6.6). There was a statistically significant relationship between the ATSPT values and the Average Site Disturbance Score ($P < 0.05$) (Figure 6.6).

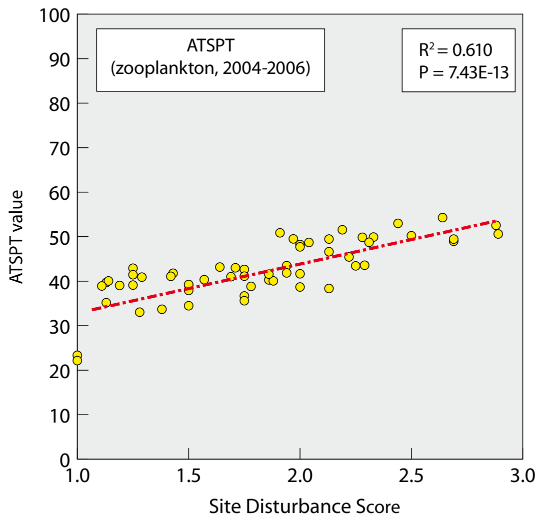


Figure 6.6 Relationship between the Average Tolerance Score Per Taxon of zooplankton and the Average Site Disturbance Score for sites sampled in 2004, 2005, and 2006.

In general, there was trend of increased ATSPT from north to south, indicating a decrease in pollution sensitive species.

6.4 Discussion

Relationship of richness, abundance, species diversity index values, and dominance index values, to the Average Site Disturbance Score

For the 57 sampling events at 43 sites, the relationships of species diversity index values to the average Site Disturbance Score were statistically significant. There was no significant relationship between richness, abundance, or the dominance index and the Average Site Disturbance Score, which may have been the result of natural variations in natural habitat suitability.

Zooplankton abundance was high at some sites where the Average Site Disturbance Score was also high. This suggests that at some sites the rich-nutrient environments, resulting from human activities, were favourable to the growth of the zooplankton community.

The species diversity index had a statistically significant relationship with the Average Site Disturbance Score, with the expected trend of decreasing diversity values as the Average Site Disturbance Score values increased. For example, site CPP (in 2006) had the highest value of Average Site Disturbance Scores (2.89) and the lowest value of the diversity index (0.626). In contrast, at some sites like LOU (in 2005) and LKU (in 2005), the Average Site Disturbance Score was low (1.0 and 1.13), the diversity index was high (2.09 and 1.93). This suggests that the diversity is reduced as human impact increases.

Variation in ATSPT among sampling sites in the Lower Mekong, 2004 – 2006

The range of tolerance values for the 195 taxa of zooplankton collected from 2004 – 2006 represent a fauna that has a predominance of taxa of intermediate stress tolerance (Appendix 2.2).

The distribution of ATSPT at the 43 sites visited reflects a gradient of increasing pollution or human impact levels from north to south. For example, the sites with lower human impact (LOU, LNO, LPB, LNK, LKU, LKL) are north of the sites with higher human impact (CSK, CSN, CTU, CPP, CBS, VTC, VCD, VCL, VLX, VTR, VCT).

7. Littoral macroinvertebrates

7.1 Introduction

Littoral macroinvertebrates have been used widely in bioassessment activities primarily in temperate areas, but they have also been used in tropical countries. For example, Thorne and Williams (1997) applied a variety of rapid assessment methods for macroinvertebrates in Brazil, Ghana, and Thailand. They tested 20 analytical methods that have been used in temperate regions, including representatives of the five major types identified by Resh and Jackson (1993): richness indices, enumerations, diversity and similarity measures, biotic indices, and functional measures. Seven of the 20 methods behaved as expected in response to pollution gradients, but these did not include any enumeration or 'functional feeding' measures. Two diversity indices also failed to respond to pollution gradients in the predicted manner, whereas three 'similarity/ loss indices' all met the test criteria. The Biological Monitoring Working Party (BMWP) score and the Average Score Per Taxon (ASPT) performed satisfactorily.

Mustow (1997) studied the macroinvertebrate community at 23 sites on the Mae Ping River in northern Thailand and suggested some modifications of the BMWP score to suit local conditions. According to Mustow (1997), 71 of the 85 BMWP families are known to occur in Thailand and 65 of these, together with an additional 33 that do not occur in the U.K., were found in the Mae Ping system. He incorporated 10 of these additional families in a modified BMWP scoring system, which he called the $BMWP^{THAI}$ score. In addition, Pinder (1999) applied similar approaches to biomonitoring that are applicable to other areas of Southeast Asia as well.

The objective of this chapter is to: (i) describe the characteristics of the littoral macroinvertebrate community that was quantitatively sampled at 21 sites in 2006, (ii) report tolerance scores based on the littoral macroinvertebrate community for each of the sites examined in 2006, and (iii) relate tolerance scores and other metrics to the Site Disturbance Score.

7.2 Study sites and sampling methods

Study sites

In March 2006, samples of littoral macroinvertebrates were collected at the 21 sites in the Mekong River basin listed in Chapter 2. Details of the sample sites examined in 2004 and 2005 are given in the biomonitoring reports for those years (MRC, 2006; MRC, in press).

Field methods

At each site littoral macroinvertebrate samples usually were taken on only one side of the river. In most instances this was the depositional side where sampling was easier because of the gradual shelving of the bottom that occurs in this setting in contrast to the steeper bottom that is characteristic of the erosional side. In addition, the depositional side tends to support more aquatic vegetation, which also provides more habitat suitable for invertebrates. Because the study area was large, a wide range of littoral habitat types was sampled. As far as possible, similar habitats were selected at each site to facilitate comparisons among sites.

In 2006, as in 2003 and 2005, both sweep and kick sampling methods were used. A D-frame net with 30 cm x 20 cm opening and mesh size of 475µm was used for both sweep and kick sampling. Sweep samples were taken along the shore at intervals of about 20 m. To obtain each sweep sample, the collector stood in the river about 1.5 m from the water's edge and swept the net toward the bank 10 times near the substrate surface. Each sweep was done for about 1 m at right angles to the bank, in water no deeper 1.5 m, and did not overlap the previous sweep. Kick sampling was done off-riverbank in areas of rapid current. Sampling involved kicking the substrate in an area of 30 x 30 cm, or using fingers to disturb this area, for about 20 seconds. A range of substrates was sampled, including cobbles, gravel, sand, silt, mud, and aquatic plants. Five kick and five sweep samples were taken per site, unless there was no suitable habitat for kick sampling, in which case ten sweep samples were taken.

After sample collection, the net contents were washed to the bottom of the net. The net was inverted and its contents were emptied into a metal sorting tray, with any material adhering to the net being washed off with clean water. Invertebrates were picked from the tray with forceps and placed in a jar of 70% ethanol. Small samples were kept in 30 mL jars and large samples were kept in 150 mL jars. During the picking process, the tray was shaken from time to time to redistribute the contents, and tilted occasionally to look for animals adhering to it. Sorting proceeded by working back and forth across the tray until no more animals were found. A second person then checked the tray to be sure that no animals remained. The sample jars were labelled with the site location code, date, and sample replicate number. The collector's name, the sampling site, and replicate characteristics (including substrate types sampled) were recorded in a field notebook.

Laboratory methods

In the laboratory, the samples were identified under a stereomicroscope with a 2x–4x objective lens and a 10x eyepiece. Identification was done to the lowest taxonomic level that could be applied accurately, which was usually to genus. The references used for identification included Sangpradub and Boonsoong (2004), Nguyen *et al*. (2000), and Merritt and Cummins (1996). Specimens were divided into orders, kept in separate jars. All specimens were stored in the Department of Biology at the National University of Laos.

Multimetric analysis

For all sites sampled in 2004, 2005, and 2006, the following metrics were calculated: (i) taxonomic richness (i.e. number of taxa), (ii) abundance (i.e. numbers of individuals per sample), (iii) the Shannon-Wiener Diversity Index, and (4) The Berger-Parker Dominance Index. The four metrics were tested for their potential as indicators of human impact by regressing values for all three years (57 sampling events for 43 sites) against the Average Site Disturbance Score, which was derived as described in Chapter 3. For each metric examined against this index, p values and r^2 values were calculated from linear regression analyses.

Tolerance values

Tolerance values were calculated for each taxon of littoral macroinvertebrates collected in 2004, 2005, and 2006, as described in Chapter 3. The Average Tolerance Score per Taxon (ATSPT) were calculated for each sample, and then averaged over all samples in each sampling events for 2004–2006 (Appendix 3.3). ATSPT values were rated as described in Chapter 9.

7.3 Results

Biota collected in 2006

In 2006, 24,242 individuals and 116 taxa of littoral macroinvertebrates were collected at the 21 sites sampled (Appendix 3.1).

The Trichoptera, Ephemeroptera, Mesogastropoda, and Hemiptera were the richest orders of littoral macroinvertebrates with 28, 26, 24 and 20 taxa respectively. Hemiptera and Decapoda had the widest distribution, being found at all sites, while species of Nematoda and Basommatophora were found at only one and two sites each (Table 7.1). Two other groups, Diptera and Mesogastropoda, were also widely distributed. The groups that were widespread include taxa occurring in nutrient-rich conditions.

Almost half of the 21 sites examined in 2006 had more than 20 taxa and high abundance (Appendix 3.1).

Table 7.1. *Numbers of taxa within each major group of littoral macroinvertebrate taxa recorded at each site in 2006.*

Site	Amphipoda	Arcoida	Basommatophora	Coleoptera	Collembola	Decapoda	Diptera	Ephemeroptera	Hemiptera	Lepidoptera	Megaloptera	Mesogastropoda	Mytiloida	Nematoda	Neogastropoda	Odonata	Oligochaeta	Plecoptera	Polychaeta	Sphaeromatidae	Trichoptera	Unionoida	Veneroida	Total taxa
CPP	0	0	0	0	0	3	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	7
CBS	0	1	0	0	0	2	2	2	2	0	0	0	4	1	0	1	2	1	0	0	1	4	1	24
CNL	0	0	0	0	0	2	2	2	1	0	0	7	1	0	0	0	0	0	0	0	1	1	1	18
CTU	0	1	0	0	0	2	1	0	1	0	0	4	0	0	1	0	0	0	1	0	0	0	1	12
CSN	0	0	0	0	0	2	1	0	1	0	0	5	1	0	1	1	1	0	0	0	0	1	1	15
CSK	0	0	0	0	0	3	1	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	9
CPT	0	0	0	0	0	2	2	0	2	0	0	6	0	0	1	2	1	0	0	0	0	2	1	19
CKT*	0	0	1	1	0	4	3	8	3	0	0	8	0	0	1	3	1	0	0	0	3	0	1	37
CMR*	0	0	1	1	0	5	2	3	2	0	0	11	0	0	1	0	1	0	0	1	0	0	0	28
CSJ*	0	0	0	5	0	2	5	15	5	0	0	7	0	1	1	6	1	1	0	0	9	0	1	59
CKM*	0	0	0	1	0	6	3	13	4	1	0	7	0	0	0	4	0	1	0	0	12	1	0	53
CSP*	0	0	0	7	0	4	8	14	7	1	1	2	0	0	0	6	1	2	0	0	19	0	1	73
CSU*	0	0	0	3	0	2	1	11	7	1	0	0	0	0	1	0	0	1	1	0	4	0	1	33
VSS*	0	0	0	2	0	3	5	15	6	2	1	0	0	0	0	6	1	1	0	0	10	0	1	53
VSR*	0	0	0	4	0	2	4	13	11	0	0	1	0	0	1	5	0	0	0	0	6	0	1	48
VTR	0	1	0	0	0	4	1	0	2	0	0	4	0	0	1	1	0	0	1	0	0	0	1	16
VCT	0	1	0	0	0	1	1	0	2	0	0	0	0	0	1	0	1	0	1	0	0	0	0	8
VLX	1	0	0	0	0	2	1	1	1	0	0	2	0	0	1	2	1	0	0	1	0	0	1	14
VCL	0	0	0	0	0	2	1	1	2	0	0	3	1	0	1	0	1	0	1	1	0	0	1	15
VTC	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
VCD	0	0	0	1	1	1	3	1	2	0	0	3	0	0	1	1	1	0	1	0	0	0	0	16
All sites	1	1	1	13	1	9	13	26	20	2	1	24	1	1	1	11	1	2	2	1	28	4	1	165

Note: At sites with asterisks, both sweep and kick sampling were applied.

Taxonomic richness

The number of taxa collected per site ranged from 3 to 73. The highest richness occurred at sites having substrata with cobbles and gravels, such as sites CSP (73 taxa), CSJ (59 taxa), and VSS and CKM (53 taxa each). In contrast, the lowest richness was at sites with muddy substrata, such as at sites VCT (8 taxa), CPP (7 taxa) and VTC (3 taxa) (Table 7.1). In sites with highest richness, such as sites CSP, CSJ, VSS, and CKM, taxa of Trichoptera and Ephemeroptera were common and abundant. These taxa occurred in substrata containing cobbles, pebbles and gravels.

Abundance

The number of individuals per site was highly variable, ranging from 54 (CTU) to 2062 (CMK) individuals (Table 7.2). As with numbers of taxa, the highest abundances occurred at sites with sandy and rocky substrata, while the lowest abundances occurred at sites with muddy and debris substrata. In the sites with the highest abundance, such as CMK, CSP, and CSU, species of Decapoda, Mesogastropoda, Ephemeroptera, Hemiptera, and Trichoptera were dominant. These common species occur in both rocky substrata and nektonic habitats.

Table 7.2. *Number of individual littoral macroinvertebrates at 21 sites in 2006.*

Site	Amphipoda	Arcoida	Basommatophora	Coleoptera	Collembola	Decapoda	Diptera	Ephemeroptera	Hemiptera	Lepidoptera	Megaloptera	Mesogastropoda	Mytiloida	Nematoda	Neogastropoda	Odonata	Oligochaeta	Plecoptera	Polychaeta	Sphaeromatidae	Trichoptera	Uniontoida	Veneroida	Total
CPP	0	0	0	0	0	47	0	0	5	0	0	0	0	0	1	0	1	0	0	1	0	0	0	55
CBS	0	6	0	0	0	68	10	66	561	0	0	46	2	0	4	22	10	0	0	2	0	18	2	817
CNL	0	0	0	0	0	12	21	110	50	0	0	543	3	0	0	0	0	0	0	0	2	8	69	828
CTU	0	1	0	0	0	24	2	0	1	0	0	7	0	0	3	0	0	0	4	4	0	0	8	54
CSN	0	0	0	0	0	36	18	0	89	0	0	427	1	0	1	1	1	0	0	0	0	11	42	627
CSK	0	0	0	0	0	388	1	0	63	0	0	9	0	0	0	0	0	0	0	0	0	0	0	461
CPT	0	0	0	0	0	21	3	0	7	0	0	131	0	0	1	12	3	0	0	0	0	33	22	231
CKT*	0	0	49	1	0	50	34	77	18	0	0	514	0	0	5	21	16	0	0	0	8	0	2	795
CMK*	0	0	82	2	0	942	3	20	25	0	0	947	0	0	2	0	11	0	0	1	0	0	0	2062
CSJ*	0	0	0	19	0	14	39	268	13	0	0	198	0	4	4	17	2	2	0	0	119	0	6	705
CMR*	0	0	0	12	0	57	7	257	31	1	0	40	0	0	0	7	0	1	0	0	51	1	0	465
CSP*	0	0	0	19	0	13	116	507	95	1	1	6	0	0	0	42	1	4	0	0	303	0	45	1153
CSU*	0	0	0	5	0	7	4	528	589	1	0	0	0	0	1	0	0	1	1	1	8	0	4	1150
VSS*	0	0	0	7	0	17	106	289	15	3	1	0	0	0	0	26	2	33	0	0	62	0	3	564
VSR*	0	0	0	5	0	5	110	288	236	0	0	1	0	0	1	13	0	0	0	0	22	0	9	690
VTR	0	3	0	0	0	101	11	0	96	0	0	11	0	0	26	1	0	0	4	4	0	0	16	273
VCT	0	1	0	0	0	84	6	0	25	0	0	0	0	0	1	0	2	0	2	0	0	0	0	121
VLX	2	0	0	0	0	119	7	1	7	0	0	2	0	0	1	4	1	0	0	2	0	0	2	148
VCL	0	0	0	0	0	83	19	2	54	0	0	6	2	0	5	0	3	0	1	12	0	0	10	197
VTC	0	0	0	0	0	6	0	0	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	114
VCD	0	0	0	2	2	1	5	1	45	0	0	15	0	0	1	1	1	0	1	1	0	0	0	76
Total	2	11	131	72	2	2095	532	2414	2133	6	2	2930	8	4	57	167	54	41	13	30	575	71	238	11588

Note: At sites with asterisks, both, sweep and kick sampling were applied.

Shannon-Wiener diversity index

The Shannon-Wiener Diversity Index ranged from 0.24 to 3.27 (Figure 7.1). The highest diversity value was found at site CKM and the lowest diversity at site VTC. This trend is similar to that observed for taxon richness. The highest diversity index values were found at sites with sandy and rocky substrata, such as at site CSJ, CSP and CKM, while low diversity index values were found at sites located in the Delta area, such as at VTC, VLX, and VCT (Appendix 3.3).

Dominance index

The Berger-Parker Dominance Index ranged from 0.05 to 0.88 at the 2006 sampling sites (Figure 7.1). The lowest dominance value was found at site VTC, and the highest value of dominance was found at site CKM. The Dominance Index showed the same trend as the taxon richness and diversity index values (Appendix 3.3).

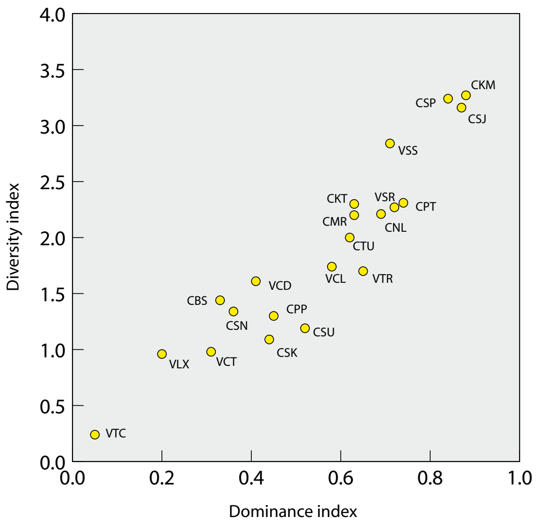
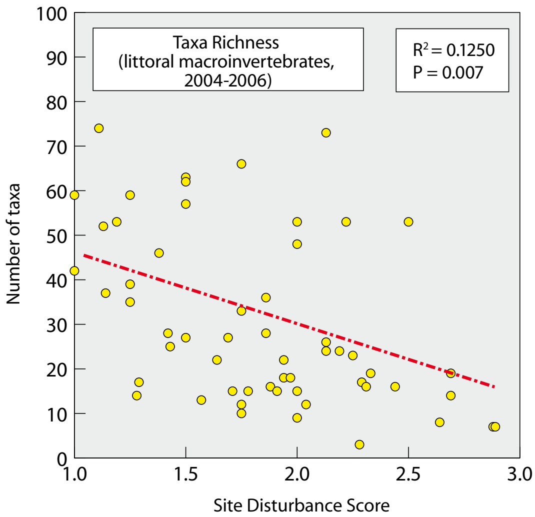
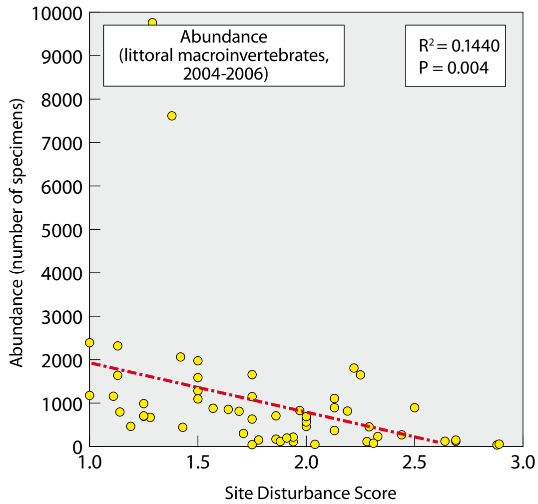


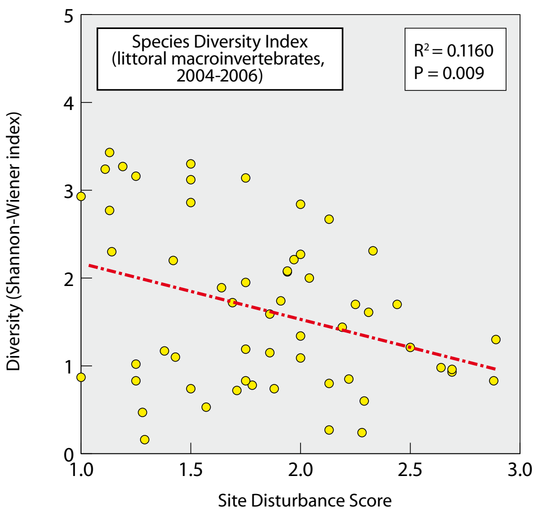
Figure 7.1 The diversity and dominance index values of littoral macroinvertebrates at 21 sites in 2006.

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score

The values for taxonomic richness, number of individuals, the species diversity index, and the dominance index from 57 sampling events at 43 sites, 2004–2006, all showed statistically significant relationships with the Average Site Disturbance Score ($P < 0.05$; Figure 7.2–7.5).







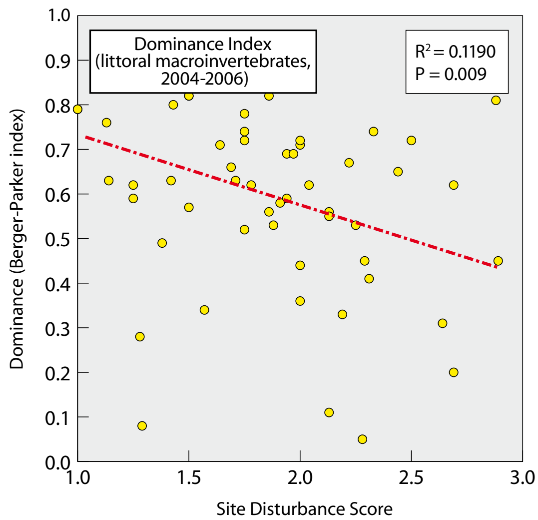


Figure 7.2 Top left. Regression relationship between taxonomic richness of littoral macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 7.3 Top right. Regression relationship between abundance of littoral macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 7.4 Bottom left. Regression relationship between the Shannon-Wiener diversity index for littoral macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 7.5 Bottom right. Regression relationship between the Berger-Parker dominance index for littoral macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Average Tolerance Score Per Taxon

The Average Tolerance Score Per Taxon (ATSPT) of littoral macroinvertebrates of sweep samples taken from 2004–2006 ranged from 20 to 52, with the highest value found at site VCD and the lowest found at site LOU. These scores ranged up to 6.5 standard deviations above the mean of reference sites, placing sites in the classes A–D (from low to high, but not extreme, stress)(see Chapter 9).

There was a general trend of increasing tolerance scores in a north to south direction, indicating a decrease in pollution sensitive species. Generally, the tolerance scores calculated for the Delta sites were higher than for other areas.

The relationship between the ATSPT and the Average Site Disturbance Score for all sites examined in 2004-2006 was statistically significant ($p<0.001$, Figure 7.6).

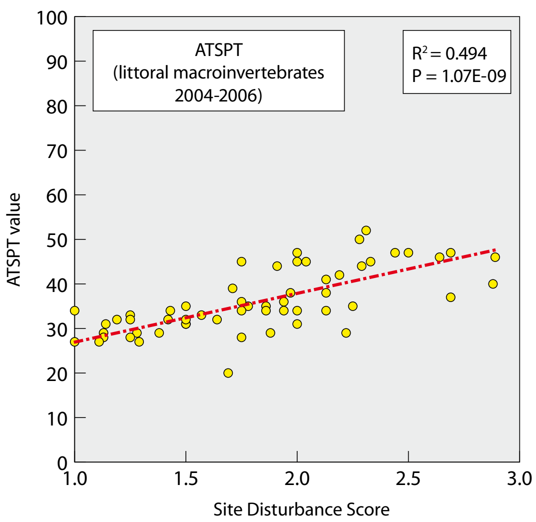


Figure 7.6 Regression relationships between the Average Tolerance Score Per Taxon for littoral macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

7.4 Discussion

Relationship of richness and abundance, and of taxon diversity and dominance index values, to the Average Site Disturbance Score

All these metrics used to describe the littoral macroinvertebrates had statistically significant relationships with the Average Site Disturbance Score for the 57 sampling events at 43 sites, sampled in 2004 – 2006. Values of all these metrics were highly variable among the sites, probably because of differences in both human impact and habitat. For example, high richness was found at sites with cobble, pebble and gravel substrata, such as at sites CSP (74 taxa in 2006), CSU (33 taxa in 2006), CSS (33 taxa in 2004), CKM (62 taxa in 2005), LKL (63 taxa in 2005), LOU (42 taxa) and CSJ (59 taxa in 2006). These sites are located on tributaries (Sre Pok, Se San, Se Kong, and Nam Ou) of the Mekong. The high richness found in these sites probably resulted from a combination of suitable habitats and sampling accessibility (as both sweep and kick sampling were possible). In contrast, sites with soft sediments of mud and sand, and often with decreased water-quality and other disturbance from human activities, are limited in their ability to develop a rich fauna of littoral macroinvertebrates. They include sites CSK (9 taxa), VCT (8 taxa), CPP (7 taxa), and VTC (3 taxa). The same factors that determine taxon richness probably account for the patterns in abundance and values of the taxon diversity index and the dominance index.

Variation in ATSPT among sampling sites in the Lower Mekong, 2004 – 2006

The distribution of tolerance values for the 323 taxa of littoral macroinvertebrates collected in 2004 – 2006 represent a fauna that has a predominance of taxa that are stress-sensitive (Appendix 3.2). Littoral macroinvertebrates had a lower median value (34) and included more stress-sensitive taxa (203) than either the zooplankton or diatoms; however, they are comparable to the benthic macroinvertebrates in terms of their stress sensitivity (see Chapter 9).

The distribution of ATSPT values at the 57 samples from 43 sites visited reflects a gradient of increasing pollution or human impact levels from north to south, which is consistent with patterns of development and human population density.

8. Benthic macroinvertebrates

8.1 Introduction

The benthic macroinvertebrates occurring at the bottom of river channels are promising indicators of health for the lower Mekong River. The objective of this chapter is to: (i) describe the characteristics of the benthic macroinvertebrate community that was quantitatively sampled at 21 sites in 2006, (ii) report biotic condition scores based on the benthic macroinvertebrate community for each of the sites examined in 2006, and (iii) relate tolerance scores and other metrics to the Site Disturbance Score.

8.2 Study sites and sampling methods

Study sites

In March 2006, samples of benthic macroinvertebrates were collected at the 21 sites in the Mekong River basin listed in Chapter 2. Details of the sample sites examined in 2004 and 2005 are given in the biomonitoring reports for those years (MRC, 2006; MRC, in press).

Field methods

Sample locations at each site were selected in each of the right, middle, and left parts of the river. Five locations were sampled at each of these parts of the river. At some sites, the middle of the river could not be sampled because of the presence of hard beds or fast currents. Also, sites narrower than 30 m were not sampled in the middle portion.

Prior to sampling, all the equipment to be used was thoroughly cleaned to remove any material left from the previous sampling site. At each sampling location, a composite of four samples was taken with a Petersen grab sampler, covering a total area of 0.1 m^2. Grab contents were discarded if the grab did not close properly because material such as wood, bamboo, large water-plants, or stones jammed the grab's jaws. In these cases the sample was retaken. The sample was washed through a sieve (0.3 mm) with care taken to ensure that macroinvertebrates did not escape. The contents of the sieve were then placed in a white sorting tray and dispersed in water. All the animals in the tray were picked out with forceps and pipettes, placed in jars, and fixed with formaldehyde. Samples of less experienced sorters were checked by an experienced sorter. The sample jar was labelled with site name, location code, date, position within the river, and replicate number. The sampling location conditions, collector's name and sorter's name were recorded on a field sheet.

Sometimes, samples could not be sorted on site because the boat was poorly balanced, because a very large number of animals were collected, because there was insufficient time at a site, or because the presence of lumps of clay caused the samples to cloud continually. In these cases, samples were sorted in the laboratory.

Laboratory methods

All individuals collected were identified and counted under a compound microscope (with magnifications of 40 – 1200 x) or a dissecting microscope (16 – 56 x). Oligochaeta, Gastropoda, Bivalvia, and Crustacea were generally identified to species level. Insecta and Insecta larvae were classified only to genus level. The results were recorded on data sheets and specimens are kept at the Ton Duc Thang University, HCMC, Viet Nam.

Multimetric analysis

For all sites sampled in 2004, 2005, and 2006, the following metrics were calculated: (i) taxonomic richness (i.e. number of taxa); (ii) abundance (i.e. numbers of individuals per sample); (iii) the Shannon-Wiener Diversity Index; (iv) the Berger-Parker Dominance Index. The four metrics were tested for their potential as indicators of human impact by regressing values for all three years (57 sampling events for 43 sites) against the Average Site Disturbance Score, which was derived as described in Chapter 3. For each metric examined against this index, p values and r^2 values were calculated from linear regression analyses.

Tolerance values

Tolerance values were calculated for each taxon of benthic macroinvertebrates collected in 2004, 2005, and 2006, as described in Chapter 3. The Average Tolerance Score per Taxon (ATSPT) was calculated for each sample, and then averaged over each sampling event for 2004 – 2006. ATSPTs were rated as described in Chapter 3.

8.3 Results

Biota collected in 2006

In 2006, 4,586 individuals and 95 taxa of benthic macroinvertebrates were collected (Appendix 4.1). The Insecta was the most species-rich group and occurred at each of the sites (Table 8.1). Molluscs also occurred at all sites. The fauna at sites that were not affected by the tides from the South China Sea consisted entirely of freshwater taxa such as insects, oligochaetes, and some freshwater crustaceans and molluscs. In contrast, sites that were influenced by these tides included polychaetes, and other species of molluscs and crustaceans.

The Oligochaeta were widely distributed, with species of the family Tubificidae found at most sites, while species of Naididae were found at only a few sites. Relatively few species of Crustacea and Polychaeta were encountered. In mid-basin or upstream sites, crustaceans were absent in samples collected from deep-water habitats, and tended to occur among aquatic plants or rocky substrata.

Table 8.1. *Numbers of taxa of major groups of benthic macroinvertebrates collected at 21 sites in 2006.*

Sampling Site	Annelida		Mollusca		Arthropoda		Total
	Polychaeta	Oligochaeta	Gastropoda	Bivalvia	Crustacea	Insecta	
CPP	-	2	5	3	2	5	17
CBS	-	2	4	11	-	5	22
CNL	-	2	1	4	4	5	16
CTU	-	2	3	7	1	6	19
CSN	-	2	3	2	1	8	16
CSK	-	2	3	4	-	6	15
CPT	-	2	1	6	-	7	16
CKT	-	2	5	1	-	6	14
CMR	-	2	4	-	-	4	10
CSJ	-	1	2	1	-	4	8
CKM	-	-	2	1	-	5	8
CSP	-	1	3	1	-	11	16
CSU	-	2	-	1	-	12	15
VSS	-	1	-	1	-	5	7
VSR	-	1	-	1	-	8	10
VTR	3	2	2	4	2	4	17
VCT	1	2	1	3	7	4	18
VLX	2	2	6	5	3	5	23
VCL	-	2	-	4	3	2	11
VTC	-	2	2	6	4	5	19
VCD	1	2	4	4	3	4	18

Chironomid midge larvae had the widest distribution of any taxon collected in 2006, and occurred at all sites. Several other taxa (tubificid worms, the clam *Corbicula tenuis,* and larvae of the caddisfly family Philopotamidae) were also widely distributed (Appendix 4.1). A number of the species that were widespread are characteristic of those occurring in nutrient-rich conditions. These include: the worms *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi* (Oligochaeta, Tubifichidae); the polychaetes *Scoloplos* sp., *Prionospio* sp. and *Polydora* sp; species of Stenothyridae and Hydrobiidae (Mollusca, Gastropoda); the phantom midge *Chaoborus* sp. (Diptera, Chaoboridae); and the midge larvae *Chironomus* sp*., Parachironomus* sp*., Cryptochironomus* sp., *Sergentia* sp*.,* and *Polypedilum* sp. (Diptera, Chironomidae).

Most of the 95 taxa were found at only one or two sites, usually in low abundance (Appendix 4.1). Some of these uncommon taxa belong to groups that are not normally associated with soft sediments. For example, Neritidae snails (Mollusca, Gastropoda), Leptophlebiidae mayflies (Insecta, Ephemeroptera), and Ryacophilidae caddisflies (Insecta, Trichoptera) normally occur on rocks, stones, and aquatic plants. Many of these taxa could be considered 'vagrants' in the collections made in the soft-sediment habitats.

Taxonomic richness

Taxon richness at a site ranged widely, from 7 to 23, at the 21 sites sampled in 2006 (Table 8.1). The highest richness occurred at sites having substrata with mud and debris, such as CBS (22 species) and VXL (23 species), while the lowest richness was at sites with sandy and rocky substrata, such as sites CSJ (8 species), CKM (8 species), and VSS (7 species) (Table 8.1). In the sites with moderately high richness, such as sites CTU, VTC, VCD, and VCT, species in the families Tubificidae (Oligochaeta), Corbiculidae (Mollusca, Bivalvia), and Chironomidae (Insecta, Diptera) were dominant. These common species occurred in mixed substrata containing mud and debris.

Abundance

The mean number of individuals at a site was highly variable, ranging from 30 to 480 individuals/m^2. As with numbers of taxa, the highest abundances occurred at sites with muddy and debris substrata such as CTU (480 indv./m^2), while the lowest abundances occurred at sites with sandy and rocky substrata, such as sites CSJ, CKM and VSS (30 indiv./m^2) (Table 8.2). In the sites with highest abundance, such as CSN, CPT, CMR, VLX and VCD, species in the families Tubificidae (Oligochaeta), Hydrobiidae (Mollusca, Gastropoda), Corbiculidae (Mollusca, Bivalvia), Palingeniidae (Insecta, Ephemeroptera), and Chironomidae (Insecta, Diptera) were dominant. These common species occurred in mixed substrata containing mud, gravel, and debris (Appendix 4.1).

Table 8.2. *Density (individuals/m²) of benthic macroinvertebrates at 21 sites in 2006.*

Site	Right	Middle	Left	Average
CPP	60-140	10-30	10-160	60
CBS	60-450	20-50	20-610	170
CNL	20-180	0	10-190	80
CTU	360-910	170-450	280-720	480
CSN	20-320	240-420	100-390	240
CSK	40-200	30-160	20-150	110
CPT	190-310	170-450	80-220	220
CKT	40-300	20-170	10-30	80
CMR	270-1250	10-30	20-220	240
CSJ	10-50	0	10-120	30
CKM	10-30	0	10-100	30
CSP	10-70	10-20	40-210	60
CSU	20-110	10-20	100-350	100
VSS	10-90	0	10-50	30
VSR	170-370	0	30-190	150
VTR	90-300	10-100	80-340	140
VCT	40-90	30-50	30-170	70
VLX	60-640	0	50-300	250
VCL	40-380	0	10-150	90
VTC	40-510	180-380	20-170	180
VCD	160-370	320-500	20-120	230

Shannon-Wiener diversity index and dominance index

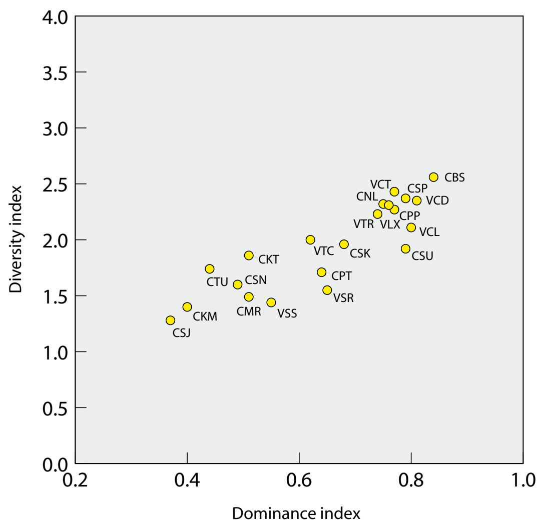
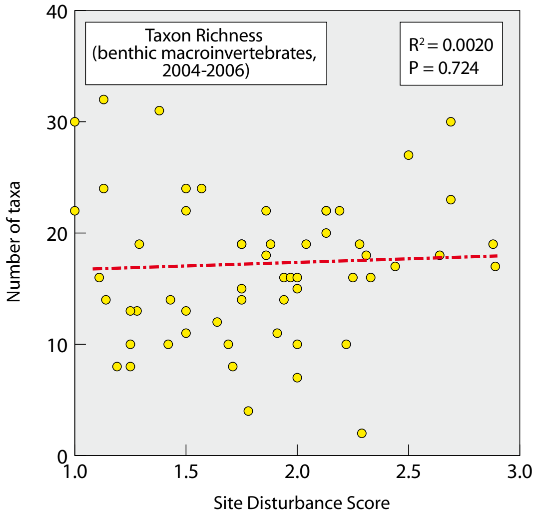


Figure 8.1 Values of the diversity (H') and dominance (D) indices for benthic macroinvertebrates at 21 sites in 2006.

Values for the diversity and dominance indices at the 21 sites sampled in 2006 ranged greatly (Figure 8.1). Both indices ranked site CBS and as having the highest and sites CSJ and CKM as having the lowest diversity and dominance. While there were some differences in relative rankings, the values for the two indices were highly correlated.

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score.

The values of taxonomic richness, number of individuals, the taxon diversity index, and the dominance index from 57 sampling events at 43 sites, 2004–2006, did not have statistically significant relationships with the Average Site Disturbance Score ($P > 0.05$; Figure 8.2–8.5).



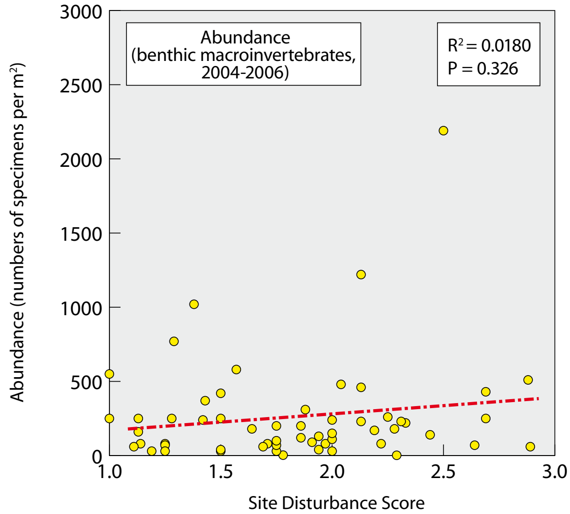
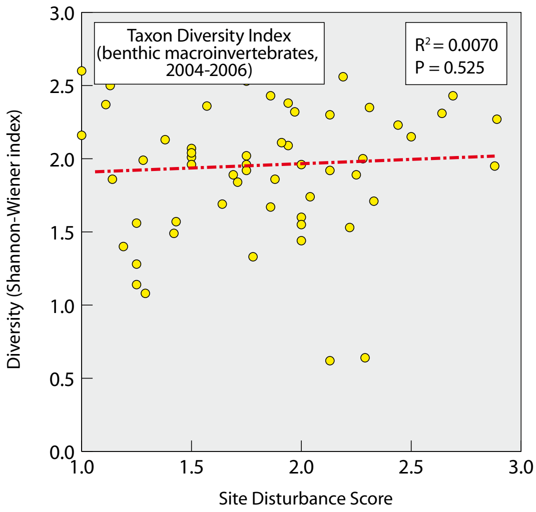


Figure 8.2 Left. Regression relationship between taxonomic richness of benthic macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 8.3 Right. Regression relationship between abundance of benthic macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.



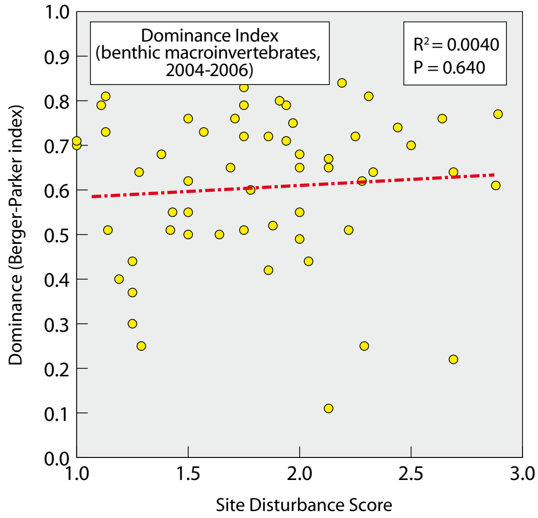


Figure 8.4 Left. Regression relationship between the Shannon-Wiener diversity index for benthic macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Figure 8.5 Right. Regression relationship between the Berger-Parker dominance index for benthic macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

Variation of ATSPT among sampling sites in the Lower Mekong River, 2004 – 2006

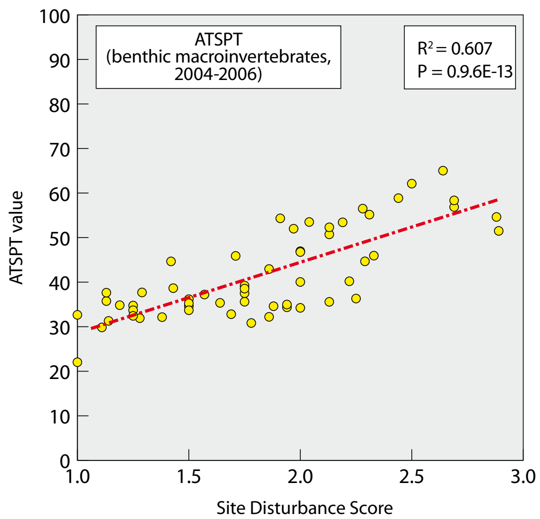


Figure 8.6 Regression relationship between the Average Tolerance Score per Taxon for benthic macroinvertebrates and the Average Site Disturbance Score for sites sampled in 2004, 2005 and 2006.

The tolerance values for individual taxa of benthic macroinvertebrates collected from 2004–2006 varied from 0 to 95 (Appendix 4.2). Mean ATSPT values ranged up to 6.4 standard deviations above the mean for reference sites, placing sites in classes A-D (from low to high, but not extreme, stress) (see Chapter 9). There was a very high statistically significant relationship between the ATSPT values and the Average Site Disturbance Score (Figure 8.6).

There was a general trend of increasing tolerance scores from north to south, indicating a decrease in stress-sensitive species. Generally, the ATSPTs calculated for the benthic macroinvertebrates in the Delta sites were higher than those of other sites.

8.4 Discussion

Relationship of richness and abundance, and of species diversity and dominance index values, to the Average Site Disturbance Score

No statistically significant relationships were found when these metrics from 57 sampling events at 43 sites, 2004–2006, were compared to the Average Site Disturbance Score from these sites. In addition, log transformation of abundance did not produce a statistically significant relationship ($P > 0.05$). Values of all these metrics were highly variable among the sites, probably because of differences in habitat. For example, the high richness at main channel sites CTU (22 taxa), CBS (22 taxa), VTC (27 taxa), VCD (30 taxa) and VLX (23 taxa) and in tributaries LNO (30 taxa), LNK (31 taxa), LKU (24 taxa) and LKL (24 taxa) probably resulted from the soft sediments of mud and sand, and the presence of many aquatic plants and abundant amounts of organic debris, which made these sites conducive to a rich fauna of benthic macroinvertebrates. In contrast, the coarse sandy, clay, and rocky substrata at main channel sites LMX (14 taxa), LPB (10 taxa), LVT (4 taxa), TMC (12 taxa), and CKT (10 taxa) and in tributaries CSJ (8 taxa), CKM (8 taxa), and VSS (7 taxa) were an obvious limiting factor for richness of benthic macroinvertebrates. Abundance and values of the taxon diversity and dominance indices can be explained by the same reasons.

Relationship of tolerance scores to sampling sites in the Lower Mekong, 2004–2006

The distribution of tolerance values for the 160 taxa of benthic macroinvertebrates collected in 2004–2006 indicates a fauna that has a predominance of taxa that are stress-sensitive (Appendix 4.2). Benthic macroinvertebrates had a lower median value than the littoral macroinvertebrates (35), but their median value (27) was comparable to this group.

The distribution of ATSPT scores at the 43 sites visited reflects a gradient of increasing pollution or human impact levels from north to south. This pattern is consistent with the results obtained from other ecological health monitoring programmes being conducted in the south of Viet Nam (including the Mekong Delta), where the benthic macroinvertebrates indicate higher levels of human impact on water and sediment quality in comparison with the results from phytoplankton or zooplankton studies.

9. Overall results and discussion

9.1 Relationship between environmental variables and ATSPT

Several physical and chemical variables showed statistically significant relationships when correlated with the ATSPT values obtained for the different groups and based on 57 sampling events at 43 sites. Dissolved oxygen concentration and Secchi disc depths showed significant negative correlation with ATSPT for all the groups. Altitude was significantly negatively correlated with ATSPT for all groups except for diatoms. Conductivity showed no statistically significant correlations with any of the biological assemblages.

Although there were many statistically significant correlations, the *r* values were often low (Table 9.1). For example, r values exceeded 0.50 in only 2 of 11 significant correlations.

Table 9.1. *Correlation coefficients (r) and p-values from regression analysis of physical and chemical factors and average tolerance score per taxon (ATSPT) values for diatoms, zooplankton, and littoral and benthic macroinvertebrates based on samples from 2004–2006.*

	p values				Correlation coefficients (r)			
	Diatoms	Zooplankton	Littoral Macro sweep	Benthic Macro.	Diatoms	Zooplankton	Littoral Macro sweep	Benthic Macro
DO	0.006	0.001	0.000	0.001	-0.36	-0.42	-0.47	-0.41
Altitude	0.103	0.013	0.007	0.001	-0.27	-0.40	-0.43	-0.52
Secchi depth	0.000	0.005	0.007	0.019	-0.54	-0.37	-0.35	-0.31
Conductivity	0.554	0.887	0.546	0.585	0.08	0.02	0.08	0.07

9.2 Tolerance values for the fauna

The distribution of sensitivities varied among the faunal assemblages examined (Figure 9.1). Macroinvertebrates (found in both the littoral and the benthic collections) had a higher proportion of sensitive taxa than either the diatoms or the zooplankton. This is evident in both the skewness of the distributions and the median value for each of the biological assemblages.

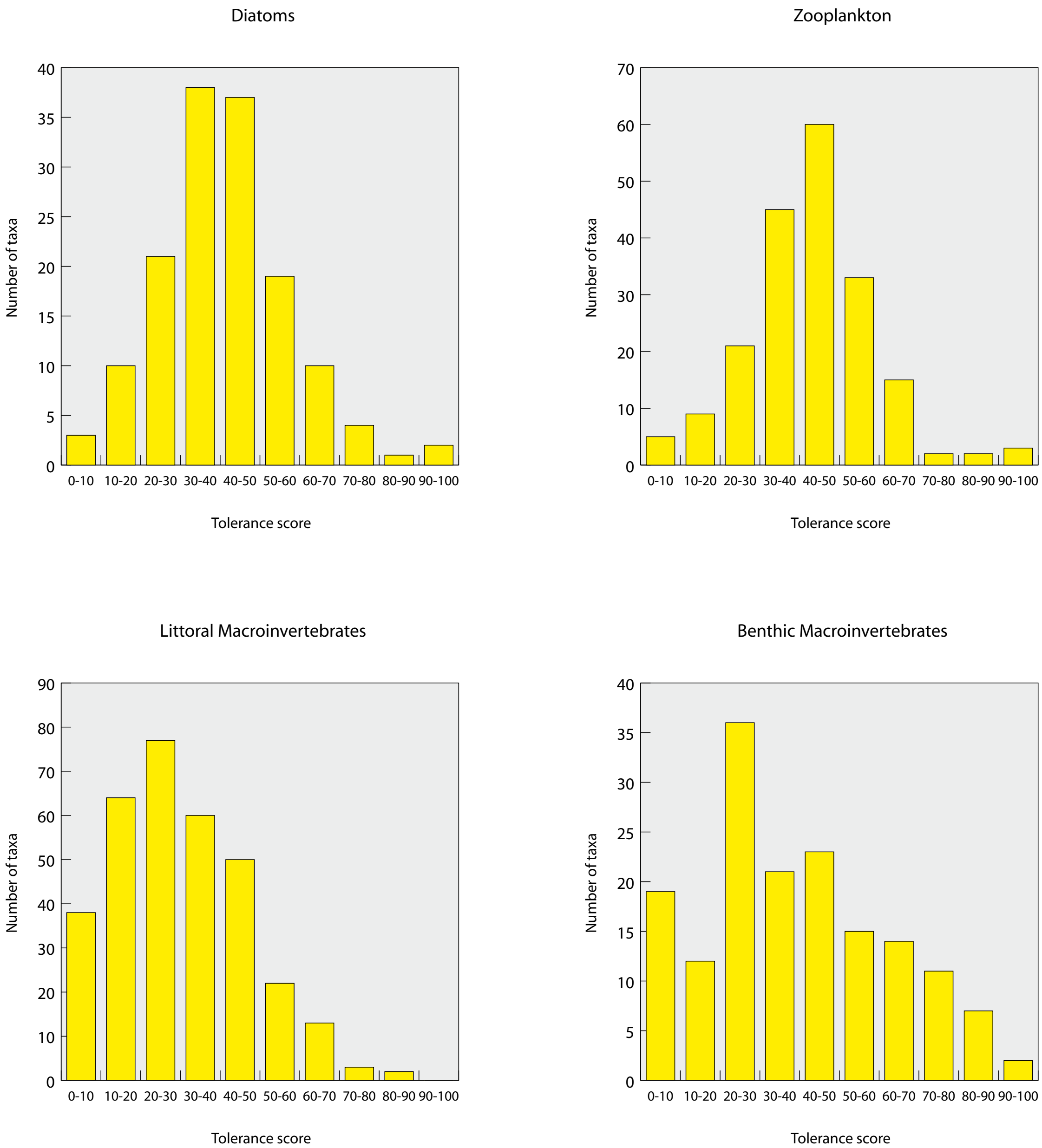


Figure 9.1. Tolerance score of diatoms, zooplankton, and littoral and benthic macroinvertebrates based on 57 sampling events at 43 sites, 2004–2006.

9.3 Variability of ATSPT values over the three sampling years

ATSPT values varied among for four biological indicator groups examined (Table 9.2). However, the values of each group were similar for collections made during different years at the same site (Table 9.3).

Table 9.2. *ATSPT values for the four indicator groups at all the sites sampled in 2004, 2005 and 2006.*

Yera	Site	Diatoms	Zooplankton	Littoral Macroinvertebrates (sweep samples)	Benthic Macroinvertebrate
2004	LNO	29	23	27	22
2004	LPB	36	33	29	32
2004	LVT	42	39	35	31
2004	LNG	34	39	35	36
2004	LKD	33	42	34	39
2004	LPS	38	40	33	37
2004	TMU	40	43	39	46
2004	TCH	43	40	35	43
2004	TSK	42	47	38	51
2004	TKO	41	40	29	35
2004	CPP	45	53	40	55
2004	CTU	42	49	45	52
2004	CPS	43	45	41	40
2004	CSS	37	43	33	39
2004	CSP	39	43	29	35
2004	CKT	34	41	32	34
2004	VTC	41	50	47	62
2004	VCD	45	49	44	57
2004	VKT	42	44	37	45
2004	VSP	37	41	27	38
2005	LOU	29	22	20	33
2005	LPB	38	41	34	33
2005	LNK	33	34	29	32
2005	LMH	39	43	34	34
2005	LMX	39	42	36	35
2005	TMI	42	43	35	36
2005	TMC	40	43	32	35
2005	TKO	40	42	34	32
2005	LKU	35	35	29	36
2005	LKL	35	34	31	35
2005	CMR	33	37	36	38
2005	CSJ	33	38	31	35
2005	CKM	33	39	32	34
2005	CSU	36	38	34	36
2005	CSS	36	36	34	36
2005	CSP	28	40	28	38
2006	CPP	51	51	46	52
2006	CBS	44	52	42	53
2006	CNL	40	49	38	52
2006	CTU	49	49	45	53
2006	CSN	44	48	45	47
2006	CSK	45	48	47	47
2006	CPT	45	50	45	46
2006	CKT	39	40	31	31
2006	CMR	35	41	32	45
2006	CSJ	36	39	28	32
2006	CKM	37	39	32	35
2006	CSP	36	39	27	30
2006	CSU	39	41	28	39
2006	VSS	41	42	34	34
2006	VSR	41	39	31	40
2006	VTR	45	53	47	59
2006	VCT	49	54	46	65
2006	VLX	52	49	47	58
2006	VCL	50	51	44	54
2006	VTC	47	50	50	57
2006	VCD	50	49	52	55

Table 9.3. *Sites for which multiple year comparisons of the ATSPT values could be made.*

Diatoms			
Site	2004	2005	2006
LPB	36	38	-
CPP	45	-	51
CTU	42	-	49
CSS	37	36	-
CSP	39	28	36
CKT	34	-	39
CMR	-	33	35
CSJ	-	33	36
CKM	-	33	37
CSU	-	36	39
TKO	41	40	-
VTC	41	-	47
VCD	45	-	50

Zooplankton			
Site	2004	2005	2006
LPB	33	41	-
CPP	53	-	51
CTU	49	-	49
CSS	43	36	-
CSP	43	40	39
CKT	41	-	40
CMR	-	37	41
CSJ	-	38	39
CKM	-	39	39
CSU	-	38	41
TKO	41	42	-
VTC	50	-	50
VCD	49	-	49

Littoral Macroinvertebrates			
Site	2004	2005	2006
LPB	29	34	
CPP	40		46
CTU	45		45
CSS	33	34	
CSP	29	28	27
CKT	32		31
CMR		36	32
CSJ		31	28
CKM		32	32
CSU		34	28
TKO	29	34	
VTC	47		50
VCD	44		52

Benthic Macroinvertebrates			
Site	2004	2005	2006
LPB	32	33	-
CPP	55	-	52
CTU	52	-	53
CSS	39	36	-
CSP	35	38	30
CKT	34	-	31
CMR	-	38	45
CSJ	-	35	32
CKM	-	34	35
CSU	-	36	39
TKO	35	32	-
VTC	62	-	57
VCD	57	-	55

9.4 Rating of sampling sites

Each site was rated in one of five classes according to the ATSPTs of the four biological assemblages. The average and variability (standard deviation) of ATSPT at designated reference sites were used as benchmarks from which to rate other sites. Reference sites were defined as those with very little or no disturbance, and included sites on the Nam Ou in Lao PDR, the Sre Pok and Se Kong in Cambodia, and the Mekong at Kampi, also in Cambodia.

Each ATSPT value was scaled in relation to reference data by subtracting the reference mean for the same assemblage and dividing the difference by the reference standard deviation. The result is the number of standard deviations by which a site falls above the reference mean. In statistical terms, the more standard deviations a site lies above the reference mean, the less likely it is to be 'equivalent to reference' in terms of the tolerance of the biota. For example, if a site has a value of two standard deviations above the reference mean it only has a 4% chance of being of reference status.

The greatest scaled value of the four biological indicator groups was used to rate each site as follows:

Class A: < 2 standard deviations above reference

Class B: 2−4 standard deviations above reference

Class C: 4−6 standard deviations above reference

Class D: 6−8 standard deviations above reference

Class E: > 8 standard deviations above reference.

Class A represents the lowest level of stress to the biological community (most ecologically healthy condition) and class E the highest level of stress.

Most sites rated in classes A and B (Figure 9.2) indicating relatively low stress. Only two sites rated in class D and no site rated in the highest stress class (Class E). This indicates that, in general, the Mekong River and its major tributaries are not severely polluted.

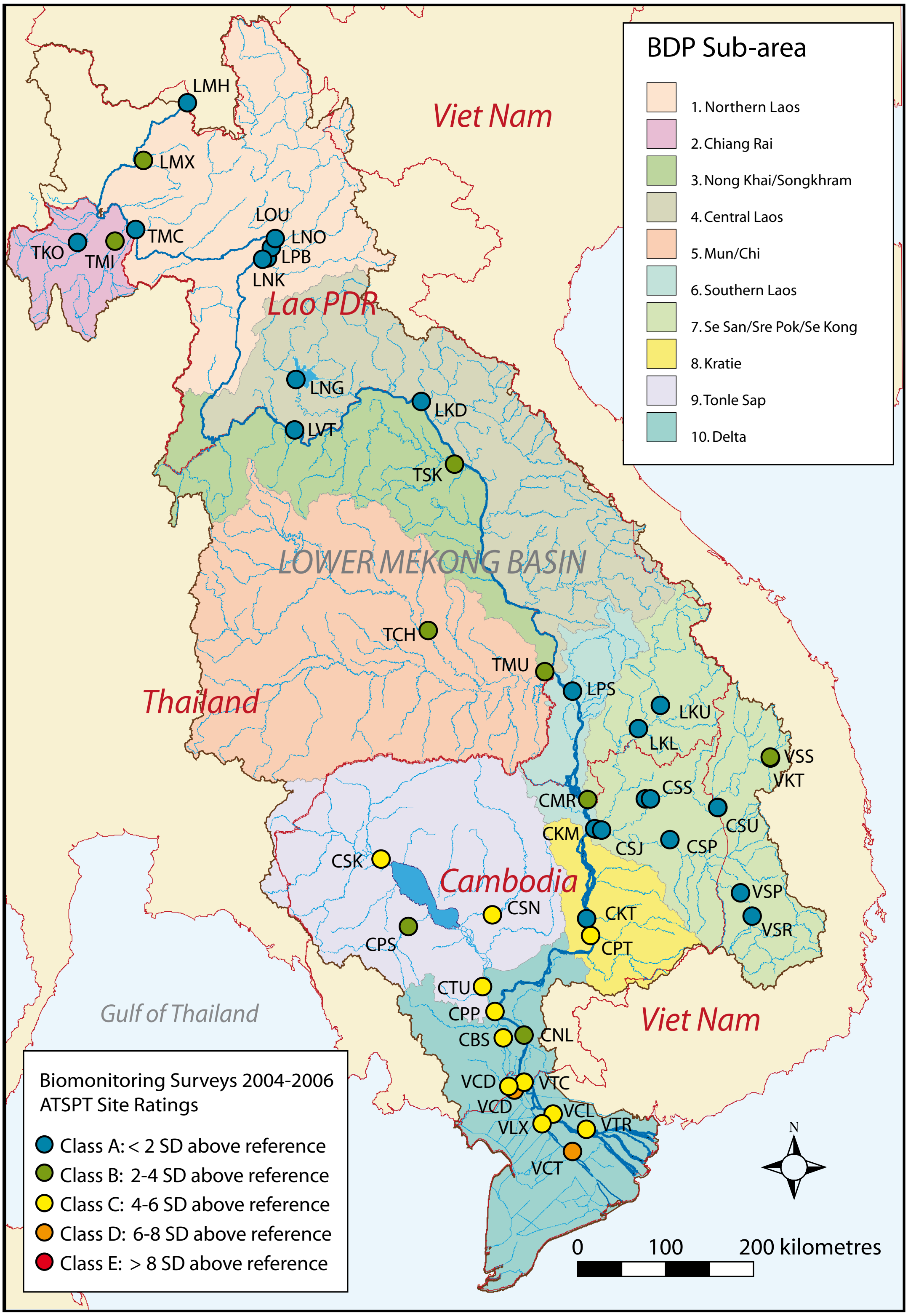


Figure 9.2. Site ratings based on ATSPT values at 57 samples from 43 sites visited during, the 2004–2006 biomonitoring surveys. Class A represents the lowest level of stress to the biological community (most healthy ecological condition) and Class E the highest level of stress. Note no sites had stress levels in Class E.

10. General conclusions

This 2006 report covers the third year of a four-year assessment of the ecological health of the Lower Mekong River (2004 – 2007). This assessment was preceded by an initial testing of alternative sampling methods in 2003. Data analysis in each year of the programme has emphasised different issues and has progressively improved our capacity to interpret the data collected for diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. In 2004, a major component of the analysis was to compare both the biological variability within the individual sites and the biological variability among sites. This analysis confirmed that within-site variability is comparatively low and that the sampling effort used in the programme is sufficient to characterize each site adequately. The 2005 analysis then focused on testing the performance of assessment metrics developed and widely used elsewhere to describe community structure (species richness, abundance, a species diversity index, and a dominance index) when these approaches were applied to data from the Mekong River system. In many cases these metrics did not perform very well. In the 2006 programme, the emphasis was on developing values for each taxon (which included organisms identified to species, genus or family) representing tolerance to stress, which are specifically applicable to the Mekong River system. In addition, the other metrics were re-tested with the larger data set that was available following the 2006 sampling.

Some clear relationships were found between the original metrics and the Average Site Disturbance Score calculated for each of the 57 sampling events that occurred at 43 sites during the 2004, 2005, and 2006 field seasons. For example, statistically significant correlations ($p<0.05$) were found for all four metrics (richness, abundance, diversity, and dominance) in the case of littoral macroinvertebrates and for one metric (diversity) in the case of zooplankton. In contrast, no statistically significant relationships were found for any of the original metrics in the case of diatoms or benthic macroinvertebrates. Although these metrics have been used in assessments of river health and water quality in other countries, their applicability for evaluating the ecological health of the lower Mekong River appears limited. One problem with these metrics is that they can all vary considerably in response to natural factors such as inter-site differences in habitat features that strongly influence the structure and composition of the communities being examined.

In contrast to these metrics, the tolerance values obtained showed much promise for developing an appropriate analytical tool for biological monitoring of the lower Mekong River. The Average Tolerance Score Per Taxon (ATSPT) showed a strong correlation with the Average Site Disturbance Score for each group of organisms. However, this is not an independent test because the Site Disturbance Scores were used in the derivation of tolerance values. However, the ATSPT was significantly related to the measured water-quality data for all four groups, which does provide an independent, objective test. Further testing of the ATSPT was scheduled for the 2007 biomonitoring programme.

A trend of increasing ATSPT values (suggesting increasing environmental stress) in a downstream direction was evident for the four biological groups examined (Table 10.1). Furthermore, the tributaries generally had scores that are indicative of a less stressed assemblage than the mainstream of the lower Mekong River. However, only a few sites were considered to have a highly stressed biota, and no site was evaluated as being indicative of extremely stressed conditions. Because some sites were sampled in more than one year, a comparison can be made between the average Site Disturbance Scores and the ATSPT values for the different biological assemblages and years. In this analysis, the average Site Disturbance Scores were similar and sometimes the same from year to year, and the biological assemblages showed far more similarities than differences (Table 10.1). In many cases, ATSPT values were the same or only slightly different between years. This indicates that the tolerance values can be used to produce consistent data.

Table 10.1. *Sites, Average Site Disturbance Scores, and ATSPT scores for which collections have been made for multiple years.*

No.	Site	Site Disturbance Score			ATSPT mean											
					Diatoms			Zooplankton			Littoral Macroinvertebrates			Benthic Macroinvertebrates		
		2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
1	CKM		1.50	1.19		33	37		39	39		32	32		34	35
2	CKT	1.25		1.14	34		39	41		40	32		31	34		31
3	CMR		1.75	1.42		33	35		37	41		36	32		38	45
4	CPP	2.88		2.89	45		51	53		51	40		46	55		52
5	CSJ		1.50	1.25		33	36		38	39		31	28		35	32
6	CSP	1.25	1.13	1.11	39	28	36	43	40	39	29	28	27	35	38	30
7	CSS	1.75	1.75		37	36		43	36		33	34		39	36	
8	CSU		2.13	1.75		36	39		38	41		34	28		36	39
9	CTU	2.13		2.04	42		49	49		49	45		45	52		53
10	LNO	1.00	1.00		29	29		23	22		27	20		22	33	
11	LPB	1.28	1.69		36	38		33	41		29	34		32	32	
12	TKO	1.88	1.86		40	41		40	42		29	34		35	32	
13	VCD	2.69		2.31	45		50	49		49	44		52	57		55
14	VTC	2.50		2.28	41		47	50		50	47		50	62		57

In conclusion, the field and laboratory procedures are performing well, and the tolerance values determined from the 2006 data analysis clearly can serve as a basis for a long-term monitoring programme to evaluate ecological health. The final phase of development and application of methods for data interpretation and reporting was scheduled for 2007–08.

11. References

Barbour, M.T., Gerritsen, J., Snyder, J. & J.B. Stribling (1999*) Rapid bioassessment protocols for use in streams and wadable rivers: periphyton, benthic macroinvertebrates and fish.* US Environmental Protection Agency, Washington D.C.

Bonada, N., Prat, N., Resh, V.H. & B. Statzner. (2006) Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annual Review of Entomology*, **51**, 495−523.

Campbell, I.C. (2007) Perceptions, data, and river management: Lessons from the Mekong River. *Water Resources Research*, **43** W02407, 13 pp

Chessman, B.C., Growns, J.E. & A.R. Kotlash, (1997). Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL biotic index: application to the Hunter River system, New South Wales. *Marine and Freshwater Research*, **48**, 159−172.

Cimdins, P., Druvietis, I., Liepa, R., Parele, E., Urtane L. & A. Urtans (1995) *A Latvian catalogue of indicator species of freshwater saprobity*. Latvian Academy of Sciences.

Crivelli, A.J. & G. Catsadorakis (1997) *The zooplankton of Lake Prespa*. Kluwer Academic Publishers.

Dang, N.T, Thai, T.B. & V.M. Pham (1980) *Classification of freshwater invertebrate zoology in North Viet Nam.* Science and Technology Publisher.

De Pauw, N., Damme, D.V & B. De Vaate (1996) Integrated training program for implementation of the recommended trans—national monitoring strategy for the Danube River Basin: Manual for macroinvertebrate identification and water quality assessment. CEC PHASE/TACIS project.

De Zwart, D. & R.C. Trivedi (1994) Manual on integrated water quality evaluation. National Institute of Public Health and Environmental Protection, Bilthoven, the Netherlands.

Deeley, D.M. & E.I. Paling (1999) Assessing the ecological health of estuaries in Australia. LWRRDC Occasional Paper 17/99 (Urban Subprogram, Report No. 10).

Doan, C. (2000) *The studies of biodiversity in Dong Thap Muoi Wetlands for the sustainable socio−economic development*. The Institute of Tropical Biology, HCMC.

Eiji, T. (1993) *An illustrated guide to fresh water zooplankton*. Togai University.

Foged, N. (1971) *Freshwater diatoms in Thailand*. Publisher, Lehre.

Foged, N. (1975) *Some littoral diatoms from the coast of Tanzania*. Odense, Lehre.

Hynes, H.B.N. (1970) *The ecology of running waters*. University of Toronto Press, Toronto.

Krammer, K. & H. Lange-Bertalot (1986) Bacillariophyceae. Teil 1. Naviculaceae. Süßwasserflora von Mitteleuropa, Bd. 2. Gustav Fisher Verlag, Stuttgart.

Krammer, K. & H. Lange-Bertalot (1988) Bacillariophyceae. Teil 2. Epithemiaceae, Surirellaceae. Süßwasserflora von Mitteleuropa, Bd.2. Gustav Fisher Verlag, Stuttgart.

Krammer, K. & H. Lange-Bertalot (1991a) Bacillariophyceae. Teil 3. Centrales, Fragilariaceae, Eunotiaceae. Süßwasserflora von Mitteleuropa , Bd.2. Gustav Fisher Verlag , Stuttgart.

Krammer, K. & H. Lange-Bertalot (1991b) Bacillariophyceae. Teil 4. Achnanthaceae. Kritische Ergänzungen zu Navicula. Süßwasserflora von Mitteleuropa, Bd.2. Gustav Fisher Verlag , Stuttgart.

Kudo, R.R. (1963) *Protozoology*. 4th edn. Charles C. Thomas.

Le, T. & V.M. Pham (2002) The studies of aquatic flora and fauna in canals and river system of Vinh Long Province for planning the aquaculture. The Institute of Environment and Sustainable Development.

Merritt, R.W. & K.W. Cummins (1996) *An introduction to the aquatic insects of North America*. 3rd edition. Kendall Hunt, Dubuque.

MRC (2005) Integrated water quality management report No. 1. Mekong River Commission, Vientiane.

MRC (2006) Biomonitoring of the lower Mekong River and selected tributaries. *MRC Technical Paper* No. 13. Mekong River Commission, Vientiane.

MRC (2008) Biomonitoring of the lower Mekong River and selected tributaries, 2004–2007. *MRC Technical Paper* No. 20. Mekong River Commission, Vientiane.

MRC (in press) Report on the 2005 biomonitoring survey of the lower Mekong River and selected tributaries. *MRC Technical Paper*. Mekong River Commission, Vientiane.

Mustow, S.E. (1997) Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score. *Hydrobiologia*, **479**,191–229.

Nguyen, X.Q., Mai, D.Y., Pinder, C. & S. Tilling (2000) Biological surveillance of freshwaters using macroinvertebrates. *A practical manual and identification key for use in Vietnam*. Field Studies Council.

Patrick, R. (1939) A taxonomic and distribution study of some diatoms from Siam and the Federated Malay States. Proceedings of the Academy of Natural Sciences, Philadelphia, 88.

PCD (2004) Standard surface water quality for Thailand. Pollution Control Department, Ministry of Natural Resources and Environment, Thailand, Bangkok. (Available at http://www.pcd.go.th/info_serv/en_reg_std_water05.html#s3)

Peerapornpisal, Y., Pekthong, T., Waiyaka, P. & S. Promkutkaew (2000) Diversity of phytoplankton and benthic algae in Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai. *Siam Society*, **48**, 193–211.

Pfister, V.P. (1992) Phytobenthos communities from 2 Tyrolean mountain streams. Arbeitsgemeinschaft Limnologie , Telfs , Österreich.

Pinder, L.C.V. (1999) Biological surveillance of freshwaters using macroinvertebrates and its application in South East Asia. Proceedings of International Conference on Water Resources Management in Intermontane Basins. Chiang Mai University, Thailand

Resh, V.H. & J.K. Jackson (1993) Rapid assessment approaches to biomonitoring using benthic macroinvertebrates. pp. 195–233 In: D.M. Rosenberg & V.H. Resh (eds.). *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman and Hall, New York.

Rosenberg, D.M. & V.H. Resh (eds.) (1993) *Freshwater biomonitoring and benthic Macroinvertebrates*. Chapman and Hall, New York.

Sangpradub, N. & B. Boonsoong (2004) *Identification of freshwater invertebrates of the Mekong River and tributaries.* Faculty of Science, Applied Taxonomic Research Center, Khon Kaen University, Khon Kaen, Thailand. Report submitted to Mekong River Commission, Vientiane, Lao PDR.

Stiling, P. (2002) *Ecology: theories and applications* (4th edn). Prentice Hall International, New Jersey.

Thorne, R.S.J. & W.P. Williams (1997) *The response of benthic macroinvertebrates to pollution in developing countries*: a multimetric system of bioassessment. *Freshwater Biology*, **37**, 671–686.

Walley W.J. and H.A. Hawkes (1997) A computer-based development of the Biological Monitoring Working Party score system incorporating abundance rating, biotope type and indicator value. *Water Research*, **31** (2), 201–210.

Appendix 1.1. Diatoms species list and abundance

No.	Taxon	Sampling sites																				
		CPP	CTU	CKK	CNL	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VCT	VLX	VCL	VTC	VCD
1	*Achananthes exiqua* var. *constricta* (Torka) Hustedt													3	3							
2	*Achnanthes biasolettiana* Grunow															130	146					
3	*Achnanthes crenulata* Grunow											1					1					
4	*Achnanthes frequentissimun* (Lange-Bertalet) Lange-Bertalet									22		29			5	20						
5	*Achnanthes lanceolata* (Brébisson) Grunow			2				1	67	66	30		2		2	6	29					
6	*Achnanthes lanceolata* sp. *rostrala* (Oestrup) Hustedt											21			1						1	
7	*Achnanthes minutissima* Kützing										248		840	248	760			18				
8	*Achnanthes* sp.1												7						670		5	
9	*Amphora montana* Krasske				24	1									1							
10	*Amphora* sp.1												23									
11	*Aulacoseira granulata* Ehrenberg	2	1	13						9	60	5	9				19					2
12	*Aulacoseira muzzanensis* (Meister) Krammer										21											
13	*Bacillaria paradoxa* Gmelin			1					2			1	1									
14	*Caloneis silicula* (Ehrenberg) Cleve					1		1														
15	*Cocconeis pediculus* Ehrenberg			2				1	82	193	86	68	52			20						
16	*Cyclotella stelligera* Cleve				88	170					9	48	13	52			162	22	46		72	
17	*Cymbella japonica* Reichelt	1													41							
18	*Cymbella* sp.1				171		1	1	117	48	34	8			5							
19	*Cymbella* sp.2			7	249	33		30	66	24												

No.	Taxon	Sampling sites																				
		CPP	CTU	CKK	CNL	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VCT	VLX	VCL	VTC	VCD
20	*Cymbella tumida* (Brébisson) Van Heurck	4		1											7	4						1
21	*Cymbella turgidula* Grunow	8	4										3			26					15	
22	*Diploneis elliptica* (Kützing) Cleve				1					1	1											
23	*Encyonema silesiacum* (Bleisch) D.G. Mann			1				1			22		29		14							
24	*Encyonema* sp.1													77	50							
25	*Epithemia adnata* (Kützing) Brébisson										36	45										
26	*Fragilaria capucina* Desmazières	2		255	106	10	2	31			117	47		12	21		10			1	226	2
27	*Geissleria decussis* (Østrup) Lange-Bertalot&Metzeltin		1		6				4	28	20		21									
28	*Geissleria paludosa* (Hustedt) Lange-Bertalot&Metzeltin											2	5									
29	*Gomphonema augur* var. *turris* (Ehrenberg) Lange-Bertalet				3						1											
30	*Gomphonema clevei* Fricke										580	216	147		125	71	19					
31	*Gomphonema entolejum* Østrup										51	10			3							
32	*Gomphonema gracile* Ehrenberg	29	47	218	43	10		1	29			8	11		49	14	12		1	4	111	7
33	*Gomphonema parvulum* (Kützing) Grunow	65	39	380	138	90	51	218	44	1	9	51	42	24	34	4	12	13		32		
34	*Gyrosigma scalproides* (Rabenhorst) Cleve					1		1	1								1					1
35	*Gyrosigma spencerii* (Quekett) Griffith&Herfrey				1				1			1	4			1						
36	*Luticula goeppertiana* (Bleisch) D.G.Mann	594	246	78	105	81	116	3	8	10		12						3	108	28	415	136
37	*Luticula monita* (Hustedt) D.G.Mann	2	60																			
38	*Luticula mutica* (Kützing) D.G.Mann	16	0	3																		

No.	Taxon	Sampling sites																				
		CPP	CTU	CKK	CNL	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VCT	VLX	VCL	VTC	VCD
39	*Luticula nivalis* (Ehrenberg) D.G. Mann																	10	9	3		
40	*Meloseira varians* Agardh			1				4		2			2		1							3
41	*Navicula crytocephala* Kützing								20		9	13										
42	*Navicula crytotenella* Kützing	6	4	63	91	7	3	49	20	56	70		171	81		13	36	28		15		
43	*Navicula flabellate* MEIST									1	11	10										
44	*Navicula gastrum* (Ehrenberg) Kützing				10	2	1			8		1										
45	*Navicula radiosa* Kützing										2	24		10	11							
46	*Navicula symmetrica* Patrick	211	175	64				44		16	19	97	33	174	276	173	26	27	71	34	24	74
47	*Navicula viridula* var. *germainii* (Wallace) Lange-Bertalot	5	1																	39		
48	*Navicula viridula* var. *rostellata* (Kützing) Cleve			1		111	4	30	8		1		8	1		6			14			17
49	*Neidium binodis* (Ehrenberg) Hustedt										1											
50	*Neidium dubium* (Ehrenberg) Cleve											1										
51	*Neidium gracille* Hustedt var. *aequalis* Hustedt							1														
52	*Nitszchia obtusa* W. Smith	1																				
53	*Nitzschia calida* Grunow											2										
54	*Nitzschia clausii* Hantzsch	975	499	472	188	29	69		57								58	136	676	169	283	588
55	*Nitzschia dissipata* (Kützing) Grunow															34						
56	*Nitzschia frustulum* Kützing											2										205
57	*Nitzschia levidensis* (W.Smith)Grunow				1																	

No.	Taxon	Sampling sites																				
		CPP	CTU	CKK	CNL	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VCT	VLX	VCL	VTC	VCD
58	*Nitzschia littoralis* Grunow																			11		
59	*Nitzschia palea* (Kützing) W. Smith	177	17	14	266	486	285	1010	105	61	19	428	43	14			10	20			88	258
60	*Nitzschia pseudofonticola* Hustedt																	121	20	184		
61	*Nitzschia* sp.1																		4	3		
62	*Nitzschia subacicularis* Hustedt							2	1		16	2					1			2		
63	*Pinnularia braunii* (Grunow) Cleve	2				2											1					
64	*Pinnularia divergens* var. *linearis* Østrup														3							
65	*Pinnularia microstauron* Ehrenberg							59														
66	*Pleurosigma salinarum* Grunow								1		1											
67	*Pleurosira laevis* (Ehrenberg) Compère								1													
68	*Rhopalodia gibberula* Ehrenberg O. Müller							1	88	2	107	222										
69	*Sellaphora amoena* Lange-Bertalot										7	2	1									
70	*Sellaphora gibbula* Lange-Bertalot										1	3	1		2							
71	*Sellaphora popula* (Kützing) Mereschkowsky					104			7	91		54	2		4	2						
72	*Surirella angusta* Kützing				2	2		1			1	2	2		3	2						
73	*Surirella roba* Leclercq														3	1						
74	*Surirella splendida* Krammer							1				2	3								1	
75	*Synedra ulna* (Nitzsch) Ehrenberg				7				1		1	6		5	115	7	2			3		
76	*Synedra ulna* var. *aequalis* (Kützing) Hustedt												97									

Appendix 1.2. Diatoms tolerance score

Order	Family	Species	Tolerance score	Total samples
Centrales	Coscinodiscineae	*Cyclotella meneghiniana* Kützing	44	12
Centrales	Coscinodiscineae	*Cyclotella stelligera* Cleve	45	99
Centrales	Melosiraceae	*Aulacoseira granulata* Ehrenberg	47	67
Centrales	Melosiraceae	*Aulacoseira muzzanensis* (Meister)Krammer	51	18
Centrales	Melosiraceae	*Meloseira varians* Agardh	45	68
Centrales	Thalassiosiraceae	*Thalassiosira* sp.1	19	12
Pennales	Achnanthaceae	*Achnanthes biasolettiana* Grunow	50	41
Pennales	Achnanthaceae	*Achnanthes crenulata* Grunow	46	17
Pennales	Achnanthaceae	*Achananthes exiqua* var. *constricta* (Torka) Hustedt	44	2
Pennales	Achnanthaceae	*Achnanthes frequentissimun* (Lange-Bertalet) Lange-Bertalet	35	36
Pennales	Achnanthaceae	*Achnanthes inflata* (Kützing) Grunow	47	1
Pennales	Achnanthaceae	*Achnanthes lanceolata* (Brébisson) Grunow	33	174
Pennales	Achnanthaceae	*Achnanthes lanceolata* sp. *rostrala* (Oestrup) Hustedt	37	28
Pennales	Achnanthaceae	*Achnanthes minutissima* Kützing	33	222
Pennales	Achnanthaceae	*Achnanthes oblongella* Østrup	37	9
Pennales	Achnanthaceae	*Achnanthes* sp.1	49	67
Pennales	Achnanthaceae	*Achnanthes* sp.2	61	4
Pennales	Achnanthaceae	*Achnanthes* sp.3	39	1
Pennales	Achnanthaceae	*Cocconeis pediculus* Ehrenberg	17	31
Pennales	Achnanthaceae	*Cocconeis placentula* Ehrenberg	33	241
Pennales	Bacillariaceae	*Bacillaria paradoxa* Gmelin	33	23
Pennales	Bacillariaceae	*Hantzschia amphioxys* (Ehrenberg) Grunow	63	3
Pennales	Bacillariaceae	*Hantzschia elongata* (Hantzsch) Grunow	38	2
Pennales	Bacillariaceae	*Nitzschia calida* Grunow	27	2
Pennales	Bacillariaceae	*Nitzschia clausii* Hantzsch	59	173
Pennales	Bacillariaceae	*Nitzschia coarctata* Grunow	56	2
Pennales	Bacillariaceae	*Nitzschia dissipata* (Kützing) Grunow	37	77
Pennales	Bacillariaceae	*Nitzschia frustulum* Kützing	59	9
Pennales	Bacillariaceae	*Nitzschia levidensis* (W.Smith)Grunow	41	11
Pennales	Bacillariaceae	*Nitzschia levidensis* var. *salinarum* Grunow	44	1
Pennales	Bacillariaceae	*Nitzschia littoralis* Grunow	45	1
Pennales	Bacillariaceae	*Nitszchia obtusa* W. Smith	65	9
Pennales	Bacillariaceae	*Nitzschia palea* (Kützing) W. Smith	42	302
Pennales	Bacillariaceae	*Nitzschia perminuta* (Grunow) Peragalle	41	8
Pennales	Bacillariaceae	*Nitzschia pseudofonticola* Hustedt	66	23
Pennales	Bacillariaceae	*Nitzschia reversa* W. Smith	39	3
Pennales	Bacillariaceae	*Nitzschia sigma* (Kützing) W. Smith	21	1
Pennales	Bacillariaceae	*Nitzschia subacicularis* Hustedt	45	22
Pennales	Bacillariaceae	*Nitzschia* sp.1	55	7
Pennales	Bacillariaceae	*Nitzschia* sp.2	6	7
Pennales	Epithemiaceae	*Epithemia adnata* (Kützing) Brébisson	20	72
Pennales	Epithemiaceae	*Rhopalodia contorta* Hustedt	44	1
Pennales	Epithemiaceae	*Rhopalodia gibba* (Ehrenberg) O. Müller var. gibba	15	18

Order	Family	Species	Tolerance score	Total samples
Pennales	Epithemiaceae	*Rhopalodia gibberula* Ehrenberg O. Müller	25	76
Pennales	Fragilariaceae	*Fragilaria bidens* Heiberg	40	9
Pennales	Fragilariaceae	*Fragilaria capucina* Desmazières	39	152
Pennales	Fragilariaceae	*Fragilaria leptostauron* (Ehrenberg) Hustedt	56	1
Pennales	Fragilariaceae	*Fragilaria tenera* (W. Smith) Lange-Bertalet	25	7
Pennales	Fragilariaceae	*Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot	21	9
Pennales	Fragilariaceae	*Synedra lanceolata* (Kützing) Reichardt	43	5
Pennales	Fragilariaceae	*Synedra ulna* var. *aequalis* (Kützing) Hustedt	34	117
Pennales	Fragilariaceae	*Synedra ulna* (Nitzsch) Ehrenberg	39	218
Pennales	Naviculaceae	*Luticula goeppertiana* (Bleisch) D.G.Mann	57	100
Pennales	Naviculaceae	*Luticula monita* (Hustedt) D.G.Mann	64	6
Pennales	Naviculaceae	*Luticula mutica* (Kützing) D.G.Mann	81	6
Pennales	Naviculaceae	*Luticula nivalis* (Ehrenberg) D.G. Mann	57	8
Pennales	Naviculaceae	*Luticula* sp.1	44	9
Pennales	Naviculaceae	*Amphora montana* Krasske	39	76
Pennales	Naviculaceae	*Amphora* sp.1	40	6
Pennales	Naviculaceae	*Amphora* sp.2	56	2
Pennales	Naviculaceae	*Cymbella cistula* (Ehrenberg) Kirchner	12	28
Pennales	Naviculaceae	*Cymbella helmckei* Krammer	23	3
Pennales	Naviculaceae	*Cymbella japonica* Reichelt	53	30
Pennales	Naviculaceae	*Cymbella tumida* (Brébisson) Van Heurck	48	117
Pennales	Naviculaceae	*Cymbella turgidula* Grunow	40	180
Pennales	Naviculaceae	*Cymbella* sp.1	37	89
Pennales	Naviculaceae	*Cymbella* sp.2	28	64
Pennales	Naviculaceae	*Diatoma vulgaris* Bory	18	10
Pennales	Naviculaceae	*Diploneis elliptica* (Kützing) Cleve	15	17
Pennales	Naviculaceae	*Diploneis oblongella* (Naegeli) Cleve	21	1
Pennales	Naviculaceae	*Diploneis puella* (Schumann) Cleve	26	13
Pennales	Naviculaceae	*Encyonema silesiacum* (Bleisch) D.G. Mann	32	70
Pennales	Naviculaceae	*Encyonema vulgare* Krammer	43	2
Pennales	Naviculaceae	*Encyonema* sp.1	37	69
Pennales	Naviculaceae	*Encyonema* sp.2	36	31
Pennales	Naviculaceae	*Encyonema* sp.3	43	30
Pennales	Naviculaceae	*Encyonema* sp.4	43	26
Pennales	Naviculaceae	*Enocyonopsis leei* var. *leei* Lange-Bertalet	37	5
Pennales	Naviculaceae	*Encyonopsis subminuta* Krammer&Reichardt	31	37
Pennales	Naviculaceae	*Eunotia minor* (Kützing) Grunow	56	1
Pennales	Naviculaceae	*Eunotia pectinalis* var. *undulata* (Ralf) Rabenhorst	56	1
Pennales	Naviculaceae	*Frustularia vulgaris* (Brébisson) Lange-Bertalet	54	2
Pennales	Naviculaceae	*Geissleria decussis* (Østrup) Lange-Bertalot&Metzeltin	25	35
Pennales	Naviculaceae	*Geissleria paludosa* (Hustedt) Lange-Bertalot&Metzeltin	28	25
Pennales	Naviculaceae	*Gomphonema augur* var. *turris* (Ehrenberg) Lange-Bertalet	36	3
Pennales	Naviculaceae	*Gomphonema clevei* Fricke	32	85
Pennales	Naviculaceae	*Gomphonema entolejum* Østrup	29	63
Pennales	Naviculaceae	*Gomphonema gracile* Ehrenberg	46	127

Order	Family	Species	Tolerance score	Total samples
Pennales	Naviculaceae	*Gomphonema parvulum* (Kützing) Grunow	46	225
Pennales	Naviculaceae	*Gomphonema truncatum* Ehrenberg	24	5
Pennales	Naviculaceae	*Gomphonema* sp.1	40	58
Pennales	Naviculaceae	*Gomphonema* sp.2	39	24
Pennales	Naviculaceae	*Gomphonema* sp.3	60	10
Pennales	Naviculaceae	*Gomphonema* sp.4	57	15
Pennales	Naviculaceae	*Gyrosigma scalproides* (Rabenhorst) Cleve	44	31
Pennales	Naviculaceae	*Gyrosigma spencerii* (Quekett) Griffith&Herfrey	28	35
Pennales	Naviculaceae	*Navicula affine* (Ehrenberg) Pfitzer	75	2
Pennales	Naviculaceae	*Navicula antonii* Lange-Bertalot	56	3
Pennales	Naviculaceae	*Navicula catarata-rheni* Lange-Bertalot	43	10
Pennales	Naviculaceae	*Navicula constans* Hustedt	43	1
Pennales	Naviculaceae	*Navicula crytocephala* Kützing	20	10
Pennales	Naviculaceae	*Navicula crytotenella* Kützing	35	164
Pennales	Naviculaceae	*Navicula flabellate* MEIST	15	7
Pennales	Naviculaceae	*Navicula gastrum* (Ehrenberg) Kützing	37	19
Pennales	Naviculaceae	*Navicula symmetrica* Patrick	44	247
Pennales	Naviculaceae	*Navicula radiosa* Kützing	30	49
Pennales	Naviculaceae	*Navicula viridula* var. *germainii* (Wallace) Lange-Bertalot	37	82
Pennales	Naviculaceae	*Navicula viridula* var.*linearis* Hustedt	4	9
Pennales	Naviculaceae	*Navicula viridula* var. *rostellata* (Kützing) Cleve	44	124
Pennales	Naviculaceae	*Navicula viridula* (Kützing) Ehrenberg var. *viridula*	33	8
Pennales	Naviculaceae	*Navicula* sp.1	53	8
Pennales	Naviculaceae	*Navicula* sp.2	49	52
Pennales	Naviculaceae	*Navicula* sp.3	47	8
Pennales	Naviculaceae	*Neidium binodis* (Ehrenberg) Hustedt	34	7
Pennales	Naviculaceae	*Neidium dubium* (Ehrenberg) Cleve	23	3
Pennales	Naviculaceae	*Neidium gracille* Hustedt var. *aequalis* Hustedt	67	1
Pennales	Naviculaceae	*Neidium* sp.1	56	1
Pennales	Naviculaceae	*Pleurosigma salinarum* Grunow	11	6
Pennales	Naviculaceae	*Sellaphora amoena* Lange-Bertalot	40	17
Pennales	Naviculaceae	*Sellaphora illustris* Lange-Bertalot	61	6
Pennales	Naviculaceae	*Sellaphora gibbula* Lange-Bertalot	28	46
Pennales	Naviculaceae	*Sellaphora popula* (Kützing) Mereschkowsky	30	73
Pennales	Naviculaceae	*Stauroneis anceps* Ehrenberg	29	5
Pennales	Pinnulariaceae	*Caloneis bacillum* (Grunow) Cleve	43	3
Pennales	Pinnulariaceae	*Caloneis silicula* (Ehrenberg) Cleve	58	2
Pennales	Pinnulariaceae	*Caloneis lauta* Carter&Bailey	75	1
Pennales	Pinnulariaceae	*Caloneis* sp.1	38	5
Pennales	Pinnulariaceae	*Caloneis* sp.2	11	5
Pennales	Pinnulariaceae	*Pinnularia acrospharia* W. Smith	75	1
Pennales	Pinnulariaceae	*Pinnularia braunii* (Grunow) Cleve	63	11
Pennales	Pinnulariaceae	*Pinnularia divergens* var. *linearis* Østrup	21	1
Pennales	Pinnulariaceae	*Pinnularia graciloides* Hustedt	64	1
Pennales	Pinnulariaceae	*Pinnularia mesolepta* (Ehrenberg) W. Smith	39	5

Order	Family	Species	Tolerance score	Total samples
Pennales	Pinnulariaceae	*Pinnularia microstauron* Ehrenberg	71	10
Pennales	Pinnulariaceae	*Pinnularia subcapitata* Gregory	32	1
Pennales	Pinnulariaceae	*Pinnularia* sp.1	56	1
Pennales	Surirellaceae	*Cymatopleura solae* (Brébisson) W. Smith	21	1
Pennales	Surirellaceae	*Surirella angusta* Kützing	39	20
Pennales	Surirellaceae	*Surirella capronii* Brébisson	6	1
Pennales	Surirellaceae	*Surirella roba* Leclercq	45	10
Pennales	Surirellaceae	*Surirella splendida* Krammer	41	20
Pennales	Surirellaceae	*Surirella tenera* Grunow	44	1
Pennales	Triceratiaceae	*Pleurosira laevis* (Ehrenberg) Compère	27	9

Appendix 1.3. Diatom metrics

No.	Year	Site	Site disturbance score	Species richness	Abundance	Species diversity index	Dominance index	ATSPT values
1	2004	LNO	1.00	23	326	1.237	0.631	29
2	2004	LPB	1.28	26	388	2.073	0.363	36
3	2004	LVT	1.78	29	562	1.746	0.561	42
4	2004	LNG	1.50	21	354	1.674	0.540	34
5	2004	LKD	1.43	33	372	1.734	0.576	33
6	2004	LPS	1.57	23	343	2.123	0.269	38
7	2004	TMU	1.71	23	346	1.410	0.577	40
8	2004	TCH	1.86	29	306	1.798	0.542	43
9	2004	TSK	2.13	41	318	2.160	0.336	42
10	2004	TKO	1.88	52	372	2.486	0.302	41
11	2004	CPP	2.88	16	197	1.226	0.518	45
12	2004	CTU	2.13	22	227	2.332	0.179	42
13	2004	CPS	2.22	18	231	2.107	0.140	43
14	2004	CSS	1.75	19	214	1.801	0.496	37
15	2004	CSP	1.25	18	144	1.961	0.282	39
16	2004	CKT	1.25	32	318	2.542	0.203	34
17	2004	VTC	2.50	37	239	2.537	0.252	41
18	2004	VCD	2.69	24	326	2.397	0.219	45
19	2004	VSS	2.29	27	318	2.098	0.383	42
20	2004	VSP	1.29	34	359	2.214	0.269	37
21	2005	LOU	1.00	21	257	2.246	0.317	29
22	2005	LPB	1.69	16	305	2.058	0.283	38
23	2005	LNK	1.38	15	276	2.282	0.262	33
24	2005	LMH	1.94	25	154	2.534	0.273	39
25	2005	LMX	1.94	24	129	2.239	0.273	39
26	2005	TMI	2.25	22	196	2.313	0.231	42
27	2005	TMC	1.64	22	229	2.031	0.251	40
28	2005	TKO	1.86	18	227	1.984	0.241	40
29	2005	LKU	1.13	20	209	1.935	0.369	35
30	2005	LKL	1.50	14	219	1.376	0.666	35
31	2005	CMR	1.75	21	206	1.093	0.521	33
32	2005	CSJ	1.50	24	214	1.020	0.563	33
33	2005	CKM	1.5ß	20	191	1.837	0.399	33
34	2005	CSU	2.13	19	268	1.573	0.514	36
35	2005	CSS	1.75	21	231	1.559	0.514	36
36	2005	CSP	1.13	23	232	1.388	0.569	28
37	2006	CPP	2.89	19	377	1.478	0.417	51
38	2006	CBS (CKL)	2.19	19	311	1.884	0.304	49
39	2006	CNL	1.97	22	314	2.421	0.233	44
40	2006	CTU	2.04	13	219	1.607	0.433	40
41	2006	CSN	2.00	19	221	1.775	0.427	44
42	2006	CSK	2.00	13	107	1.528	0.462	45

No.	Year	Site	Site disturbance score	Species richness	Abundance	Species diversity index	Dominance index	ATSPT values
43	2006	CPT	2.33	24	268	1.176	0.698	45
44	2006	CKT	1.14	26	134	2.516	0.159	39
45	2006	CMR	1.42	28	217	2.645	0.151	35
46	2006	CSJ	1.25	35	314	2.366	0.337	36
47	2006	CKM	1.19	38	250	2.466	0.298	37
48	2006	CSP	1.11	30	308	1.611	0.592	36
49	2006	CSU (CUS)	1.75	14	140	1.655	0.460	39
50	2006	VSS	2.00	25	334	1.575	0.571	41
51	2006	VSR (VSP)	2.00	31	161	2.264	0.221	41
52	2006	VTR (VVL)	2.44	21	100	2.201	0.280	45
53	2006	VCT	2.64	13	72	1.663	0.460	49
54	2006	VLX	2.69	18	317	1.532	0.393	52
55	2006	VCL	1.91	23	180	1.623	0.535	50
56	2006	VTC	2.28	19	234	1.856	0.321	47
57	2006	VCD	2.31	19	280	1.608	0.410	50

Appendix 2.1. Zooplankton species list and abundance

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Phylum Arthropoda																					
	Class Crustacea																					
	Subclass Copepoda																					
	Order Clanoida																					
	Family Pseudodiaptomidae																					
1	*Pseudodiaptomus beieri* Brehm	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	3	6	26	3	1	6
2	*Schmackeria bulbosa* Shen et Tai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
	Family Diaptomidae																					
3	*Vietodiaptomus hatinhensis* Dang	0	0	1	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	*Eodiaptomus draconisignivomi* Brehm	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	*Neodiaptomus visnu* (Brehm)	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	1
6	*Neodiaptomus botulifer* (Kiefer)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Order Cyclopoida																					
	Family Cyclopidae																					
7	*Ectocyclops phaleratus* (Koch)	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0
8	*Microcyclops varicans* (Sars)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	*Mesocyclops leuckarti* (Claus)	0	24	1	1	2	10	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	*Thermocyclops hyalinus* (Rehberg)	5	37	2	4	75	87	201	1	4	0	2	0	17	0	0	1	1	7	2	2	1
11	*Thermocyclops taihokuensis* (Harada)	0	0	0	1	1	3	1	0	0	0	0	0	8	0	0	0	0	0	0	0	0
	Order Harpacticoida																					
	Family Parastenocaridae																					
12	*Parastenocaris* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Subclass Ostracoda																					
	Order Podocopida																					
	Family Cypridae																					
13	*Heterocypris anomala* Klie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
	Subclass Branchiopoda																					
	Order Cladocera																					
	Family Bosminidae																					
14	*Bosmina longirostris* (O. F. Muller)	0	5	4	0	0	0	0	1	0	4	0	1	8	0	0	0	0	2	0	0	0

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
15	*Bosmina coregoni* Baird	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	*Bosminopsis deitersi* Richard	0	5	45	0	155	45	708	0	1	2	0	6	2	0	0	0	0	0	0	7	2
	Family Sididae																					
17	*Diaphanosoma sarsi* Richard	0	5	0	0	11	4	1	1	0	1	0	0	0	0	0	0	0	2	0	1	0
18	*Diaphanosoma paucispinosum* Brehm	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Family Daphniidae																					
19	*Moinodaphnia macleayii* (King)	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	*Ceriodaphnia rigaudi* Richard	0	3	1	0	0	0	3	0	0	0	1	0	2	0	0	0	0	0	0	0	0
	Family Chydoridae																					
21	*Disparalona rostrata* (Koch)	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0
22	*Leydigia acanthocercoides* (Fischer)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0
23	*Biapertura intermedia* (Sars)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Phylum Aschelminthes																					
	Class Eurotatorea																					
	Family Philodinidae																					
24	*Trichotria tetractis* (Ehrenberg)	0	0	0	0	0	0	0	0	0	1	0	0	22	18	0	0	0	0	0	0	0
25	*Rotaria neptunia* (Ehrenberg)	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	1	1	0	0	0
26	*Philodina roseola* (Ehrenberg)	0	2	3	0	0	29	18	3	1	0	3	1	57	22	1	1	5	2	0	1	7
27	*Philodina megalotrocha* (Ehrenberg)	0	0	0	0	0	9	15	0	0	0	0	0	0	0	0	0	0	0	0	0	2
28	*Philodina citrina* Ehrenberg	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
29	*Philodina* sp.	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
	Family Notommatidae																					
30	*Notommata aurita* (O.F.Muller)	0	0	0	0	0	0	0	0	0	0	0	0	2	7	0	0	0	0	0	0	0
31	*Cephalodella exigna* (Gosse)	0	0	0	0	0	27	0	0	0	12	0	9	1	0	0	0	0	0	0	0	0
32	*Cephalodella catellina* (O.F.Muller)	0	0	0	0	0	0	0	0	0	0	0	0	31	8	0	0	0	0	0	0	0
33	*Cephalodella gibba* Ehrenberg	0	0	0	0	0	0	0	0	1	0	0	5	0	0	0	0	0	0	0	0	0
34	*Scaridium longicaudum* (Muller)	0	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0	0	0	0	0
	Family Trichocercidae																					
34	*Diurella similis* (Wierzejski)	1	6	3	5	8	46	66	0	0	0	0	0	0	0	0	0	0	0	1	0	0
35	*Diurella tigris* (Muller)	0	0	0	0	0	17	17	0	0	1	0	0	1	2	0	0	0	0	0	0	0

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
34	*Diurella weberi* Jennings	0	0	0	0	3	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	*Trichocerca cylindrica* (Imhof)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	*Trichocerca capucina* (Wiersejski et Zacharias)	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
37	*Trichocerca rattus rattus* Muller	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
38	*Trichocerca pusilla* Jennigns	0	16	9	0	3	216	187	0	0	5	0	6	0	0	0	0	0	0	0	1	0
	Family Synchaetidae																					
40	*Polyarthra vulgaris* Carlin	4	40	65	13	170	825	4513	0	2	8	5	62	3	0	0	2	1	52	62	41	15
41	*Polyarthra mira* Voigt	0	1048	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	*Ploesoma hudsoni* (Imhof)	0	0	1	0	39	0	0	0	0	0	0	0	1	0	0	0	0	0	7	0	0
	Family Testudinellidae																					
43	*Testudinella patina* (Hermann)	0	0	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
44	*Pompholyx complanata* Gosse	0	0	0	0	0	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
45	*Pompholyx sulcata* Hudson	0	0	0	0	0	0	0	0	0	6	1	1	13	2	0	0	0	3	0	0	0
	Family Asplanchnidae																					
46	*Asplanchna sieboldi* (Leydig)	0	0	0	0	0	0	148	0	0	0	0	0	0	0	0	0	2	1	0	0	1
47	*Asplanchnopus multiceps* (Schrank)	2	20	0	0	0	31	660	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Family Gastropodidae																					
48	*Ascomorpha ecaudis* Perty	0	0	0	0	0	24	423	0	0	16	6	26	4	3	0	0	0	0	0	0	0
49	*Ascomorpha ovalis* (Carlin)	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Family Lecanidae																					
50	*Lecane leontina* (Turner)	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
51	*Lecane luna* (Muller)	0	0	0	0	0	17	10	0	0	1	0	0	26	14	0	0	0	0	0	0	0
52	*Lecane curvicornis* (Murray)	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
53	*Lecane hastata* (Murray)	0	0	0	0	1	0	10	0	0	0	1	0	1	0	0	0	0	0	0	0	0
54	*Lecane pusilla* Harring	0	0	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0	0	0	0	0
55	*Lecane ungulata* (Ehrenberg)	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
56	*Monostyla bulla* (Gosse)	0	0	0	0	0	7	2	1	0	1	0	0	15	1	0	0	0	0	0	0	1
57	*Monostyla crenata* Harring	0	0	0	0	0	2	2	0	0	0	0	0	3	5	0	0	0	0	0	0	0
58	*Monostyla lunaris* Ehrenberg	0	0	0	0	0	3	3	0	0	0	1	0	28	2	0	0	0	0	0	0	0
59	*Monostyla quadridentata* Ehrenberg	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Family Mytilinidae																					
60	*Mytilina ventralis* (Ehrenberg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Family Euchlanidae																					
61	*Euchlanis dilatata* Ehrenberg	0	0	0	0	0	0	8	1	1	1	0	0	6	12	0	0	0	0	0	0	0
62	*Diplois daviesiae* Gosse	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1
63	*Dipleuchlanis propatula* (Gosse)	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	*Eudactylota eudactylota* Gosse	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Family Brachionidae																					
65	*Brachionus angularis* Gosse	0	23	185	0	105	1056	5	0	0	13	0	0	0	0	0	1	0	1	41	6	0
66	*Brachionus urceus* (Linnaeus)	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	*Brachionus calyciflorus* cf. *calicyflorus* Pallas	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
68	*Brachionus calyciflorus* cf. *anuaeiformis* (Brehm)	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	*Brachionus caudatus* Apstein	0	5	1	0	8	44	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
70	*Brachionus forficula forficula* Wierzejski	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
71	*Brachionus falcatus* Zacharias	0	38	31	0	4	471	13	0	0	0	0	0	0	0	0	0	0	0	9	1	0
72	*Brachionus quadridentatus* var. *quadridentatus* Hermann	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
73	*Brachionus plicatilis* Muller	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0
74	*Schizocerca diversicornis* Daday	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	*Platyias quadricornis* Ehrenberg	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	*Platyias patulus patulus* (Muller)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	*Keratella valga tropica* (Apstein)	0	1	6	1	34	39	11	0	0	3	0	0	0	0	0	0	0	2	6	6	0
78	*Keratella cochlearis cochlearis* (Gosse)	0	3	92	1	6	6	0	3	0	54	15	15	25	0	0	0	0	0	7	9	0
79	*Keratella cochlearis tecta* Gosse	0	0	0	0	1	42	754	2	0	4	0	0	8	0	0	0	0	0	0	0	0
80	*Keratella cochlearis hispida* Lauterborn	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	*Anuraeopsis fissa* (Gosse)	0	0	0	0	0	201	43	0	0	3	0	0	0	0	0	0	0	0	0	0	0
	Family Filiniidae																					
82	*Filinia longiseta* (Ehrenberg)	0	12	1	0	42	272	23	0	0	4	0	0	0	0	0	0	0	0	2	2	0
83	*Filinia brachiata* (Rousselet)	2	0	0	0	6	0	244	0	0	1	0	0	0	0	0	0	0	0	1	0	0

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
84	*Tetramastix opoliensis* Zacharias	0	5	0	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	3	0	0
	Family Hexathridae																					
85	*Hexathra mira* (Hudson)	0	198	34	0	1	0	8	0	0	0	2	1	0	0	0	3	43	54	42	19	5
	Phylum Sarcomastigophora																					
	Class Lobosea																					
	Family Arcellidae																					
84	*Arcella vulgaris* Ehrenberg	6	0	2	2	1	38	59	13	6	8	5	5	23	41	8	0	1	6	2	1	3
85	*Arcella conica* Deflante	0	0	0	0	0	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	*Arcella hemisphaerica* Perty	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Family Centropyxidae																					
87	*Centropyxis aculeata* Stein	1	0	0	0	0	5	1	13	2	2	5	1	23	23	17	2	5	5	5	0	2
	Family Diffugiidae																					
88	*Difflugia elegans* Penard	1	0	157	4	0	15	0	9	11	0	0	0	2	1	0	4	19	12	44	91	15
89	*Difflugia urceolata* Carter	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	6	0
90	*Difflugia corona* Wallich	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
91	*Diffugia lobostoma* Leidy	0	0	0	0	2	13	0	8	3	0	2	4	5	0	3	0	0	0	0	0	0
92	*Difflugia acuminata* Ehrenberg	0	0	0	0	0	0	0	0	0	1	0	0	8	1	1	0	0	0	1	0	1
93	*Difflugia piriformis* Ehrenberg	0	0	0	0	0	0	7	6	2	0	0	0	0	0	1	0	0	1	0	1	1
94	*Difflugia globulosa* Dujardin	0	0	0	0	0	0	0	0	0	0	0	12	12	5	2	0	2	14	3	0	0
95	*Difflugia tuberculatus* (Wallich)	0	0	0	0	13	20	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	*Diflugia lanceolata* Penard	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0
97	*Diflugia* sp.	0	0	0	0	0	0	161	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	*Lesquereusia spiralis* (Ehrenberg)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0
	Class Filosea																					
	Family Euglyphidae																					
99	*Euglypha alveorata* Dujardin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
	Class Phytomastigophora																					
	Family Peridiniidae																					
100	*Ceratium* spp	0	0	0	0	4	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
	Family Volvocidae																					
101	*Pleodorina californica* Shaw	7	74	7	3	0	0	0	0	0	0	0	0	1	0	0	1	3	20	13	0	1

No.	Taxon	Sampling Sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Larva																					
102	*Nauplius copepoda*	242	879	69	160	173	626	375	4	31	8	2	2	133	4	3	21	51	220	72	34	217
103	Bivalvia	3	0	12	3	0	0	0	8	5	7	5	49	0	1	0	2	3	6	49	2	3
104	Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	15	2	1	0	0
105	Chironomidae - Diptera	0	0	0	0	0	1	0	3	1	3	2	2	4	0	1	0	0	0	0	0	0

Appendix 2.2. Zooplankton tolerance score

Class	Family	Taxon	Tolerance score	Total samples
Crustacea	Pseudodiaptomidae	*Pseudodiaptomus beieri* Brehm	68	14
Crustacea	Pseudodiaptomidae	*Schmackeria bulbosa* Shen et Tai	59	3
Crustacea	Diaptomidae	*Allodiaptomus calcarus* Shen et Tai	23	4
Crustacea	Diaptomidae	*Allodiaptomus raoi* Kiefer	94	1
Crustacea	Diaptomidae	*Allodiaptomus* sp.	49	3
Crustacea	Diaptomidae	*Eodiaptomus draconisignivomi* Brehm	82	3
Crustacea	Diaptomidae	*Vietodiaptomus hatinhensis* Dang	50	4
Crustacea	Diaptomidae	*Neodiaptomus visnu* (Brehm)	59	7
Crustacea	Diaptomidae	*Neodiaptomus botulifer* (Kiefer)	45	4
Crustacea	Cyclopidae	*Ectocyclops phaleratus* (Koch)	47	12
Crustacea	Cyclopidae	*Paracyclops fimbriatus* (Fischer)	38	1
Crustacea	Cyclopidae	*Microcyclops varicans* (Sars)	51	17
Crustacea	Cyclopidae	*Microcyclops* sp.	39	3
Crustacea	Cyclopidae	*Mesocyclops leuckarti* (Claus)	54	23
Crustacea	Cyclopidae	*Thermocyclops hyalinus* (Rehberg)	49	55
Crustacea	Cyclopidae	*Thermocyclops taihokuensis* (Harada)	39	41
Crustacea	Cyclopidae	*Thermocyclops* sp.	36	1
Crustacea	Canthocamptidae	*Canthocamptus staphylinus* Jurine	16	2
Crustacea	Canthocamptidae	*Elaphoidella* sp.	30	3
Crustacea	Canthocamptidae	*Epactophanes* sp.	56	1
Crustacea	Parastenocaridae	*Parastenocaris* sp.	54	10
Crustacea	Cypridae	*Heterocypris anomala* Klie	68	5
Crustacea	Cypridae	*Heterocypris* sp.	28	2
Crustacea	Cypridae	*Cypris* sp.	43	1
Crustacea	Cypridae	*Candona* sp.	19	1
Crustacea	Bosminidae	*Bosmina longirostris* (O. F. Muller)	37	36
Crustacea	Bosminidae	*Bosmina coregoni* Baird	40	23
Crustacea	Bosminidae	*Bosminopsis deitersi* Richard	47	61
Crustacea	Sididae	*Diaphanosoma sarsi* Richard	54	20
Crustacea	Sididae	*Diaphanosoma paucispinosum* Brehm	45	3
Crustacea	Macrothricidae	*Macrothrix spinosa* King	43	3
Crustacea	Macrothricidae	*Macrothrix* sp.	43	2
Crustacea	Daphniidae	*Moina* sp.	43	2
Crustacea	Daphniidae	*Daphnia lumholtzi* Sars	25	2
Crustacea	Daphniidae	*Daphnia* cf. *galeata* Sars	47	2
Crustacea	Daphniidae	*Moinodaphnia macleayii* (King)	64	3
Crustacea	Daphniidae	*Ceriodaphnia rigaudi* Richard	40	11
Crustacea	Daphniidae	*Ceriodaphnia laticaudata* O. F. Muller	25	8
Crustacea	Daphniidae	*Ceriodaphnia cornuta* Sars	36	1
Crustacea	Chydoridae	*Chydorus sphaericus sphaericus* (O. F. Muller)	29	6
Crustacea	Chydoridae	*Chydorus barroisi barroisi* (Richard)	25	1
Crustacea	Chydoridae	*Chydorus* sp.	43	1
Crustacea	Chydoridae	*Alonella excisa* (Fischer)	48	3

Class	Family	Taxon	Tolerance score	Total samples
Crustacea	Chydoridae	*Disparalona rostrata* (Koch)	45	15
Crustacea	Chydoridae	*Pleuroxus hamatus hamatus* Birge	44	3
Crustacea	Chydoridae	*Pleuroxus similis* Varva	43	2
Crustacea	Chydoridae	*Leydigia acanthocercoides* (Fischer)	39	8
Crustacea	Chydoridae	*Alona rectangula* Sars	43	9
Crustacea	Chydoridae	*Alona davidi* Richard	44	5
Crustacea	Chydoridae	*Biapertura karua* (King)	47	4
Crustacea	Chydoridae	*Biapertura intermedia* (Sars)	50	5
Eurotatorea	Philodinidae	*Trichotria tetractis* (Ehrenberg)	41	28
Eurotatorea	Philodinidae	*Rotaria rotaria* (Pallas)	39	2
Eurotatorea	Philodinidae	*Rotaria neptunia* (Ehrenberg)	71	4
Eurotatorea	Philodinidae	*Philodina roseola* (Ehrenberg)	48	48
Eurotatorea	Philodinidae	*Philodina megalotrocha* (Ehrenberg)	59	7
Eurotatorea	Philodinidae	*Philodina citrina* Ehrenberg	13	2
Eurotatorea	Philodinidae	*Philodina* sp.	33	15
Eurotatorea	Notommatidae	*Monomata* sp.	43	1
Eurotatorea	Notommatidae	*Notommata aurita* (O.F.Muller)	43	15
Eurotatorea	Notommatidae	*Notommata* sp.	44	1
Eurotatorea	Notommatidae	*Cephalodella compacta* Wiszniewski	0	4
Eurotatorea	Notommatidae	*Cephalodella catellina* (O.F.Muller)	34	13
Eurotatorea	Notommatidae	*Cephalodella exigna* (Gosse)	23	13
Eurotatorea	Notommatidae	*Cephalodella gibba* Ehrenberg	21	3
Eurotatorea	Notommatidae	*Cephalodella auriculata* (O.F.Muler)	94	1
Eurotatorea	Notommatidae	*Cephalodella* sp.	17	6
Eurotatorea	Notommatidae	*Scaridium longicaudum* (Muller)	44	11
Eurotatorea	Trichocercidae	*Diurella similis* (Wierzejski)	57	28
Eurotatorea	Trichocercidae	*Diurella tigris* (Muller)	52	18
Eurotatorea	Trichocercidae	*Diurella weberi* Jennings	63	4
Eurotatorea	Trichocercidae	*Diurrella tenuior* (Goose)	0	2
Eurotatorea	Trichocercidae	*Diurella brachyura* (Gosse)	43	4
Eurotatorea	Trichocercidae	*Trichocerca gracilis* (Tessin)	56	12
Eurotatorea	Trichocercidae	*Trichocerca cylindrica* (Imhof)	40	3
Eurotatorea	Trichocercidae	*Trichocerca capucina* (Wiersejski et Zacharias)	66	7
Eurotatorea	Trichocercidae	*Trichocerca longiseta* (Schrank)	60	2
Eurotatorea	Trichocercidae	*Trichocerca rattus* minor Fad	36	1
Eurotatorea	Trichocercidae	*Trichocerca rattus rattus* Muller	64	7
Eurotatorea	Trichocercidae	*Trichocerca pusilla* Jennigns	46	30
Eurotatorea	Trichocercidae	*Trichocerca bicristata* (Gosse)	39	1
Eurotatorea	Synchaetidae	*Polyarthra vulgaris* Carlin	47	95
Eurotatorea	Synchaetidae	*Polyarthra mira* Voigt	54	6
Eurotatorea	Synchaetidae	*Ploesoma hudsoni* (Imhof)	49	19
Eurotatorea	Testudinellidae	*Testudinella patina* (Hermann)	47	5
Eurotatorea	Testudinellidae	*Testudinella mucronata* (Gosse)	43	3
Eurotatorea	Testudinellidae	*Testudinella* sp.	0	2
Eurotatorea	Testudinellidae	*Pompholyx complanata* Gosse	32	15

Class	Family	Taxon	Tolerance score	Total samples
Eurotatorea	Testudinellidae	*Pompholyx sulcata* Hudson	32	32
Eurotatorea	Asplanchnidae	*Asplanchna sieboldi* (Leydig)	52	26
Eurotatorea	Asplanchnidae	*Asplanchna girodi* de Guerne	35	5
Eurotatorea	Asplanchnidae	*Asplanchna priodonta* Gosse	45	5
Eurotatorea	Asplanchnidae	*Asplanchnopus multiceps* (Schrank)	69	13
Eurotatorea	Gastropodidae	*Ascomorpha ecaudis* Perty	34	53
Eurotatorea	Gastropodidae	*Ascomorpha agilis* Zach	12	3
Eurotatorea	Gastropodidae	*Ascomorpha ovalis* Perty	56	4
Eurotatorea	Gastropodidae	*Ascomorpha* sp.	30	10
Eurotatorea	Lecanidae	*Lecane leontina* (Turner)	27	6
Eurotatorea	Lecanidae	*Lecane luna* (Muller)	42	40
Eurotatorea	Lecanidae	*Lecane curvicornis* (Murray)	40	8
Eurotatorea	Lecanidae	*Lecane hastata* (Murray)	48	11
Eurotatorea	Lecanidae	*Lecane pusilla* Harring	42	6
Eurotatorea	Lecanidae	*Lecane ungulata* (Ehrenberg)	38	2
Eurotatorea	Lecanidae	*Lecane ludwigii* (Eckstein)	36	1
Eurotatorea	Lecanidae	*Lecane hornemanni* (Ehrenberg)	36	1
Eurotatorea	Lecanidae	*Lecane signifera ploenensis* (Voigt)	39	4
Eurotatorea	Lecanidae	*Lecane* sp.	43	1
Eurotatorea	Lecanidae	*Monostyla bulla* (Gosse)	33	32
Eurotatorea	Lecanidae	*Monostyla crenata* Harring	50	9
Eurotatorea	Lecanidae	*Monostyla lunaris* Ehrenberg	41	27
Eurotatorea	Lecanidae	*Monostyla quadridentata* Ehrenberg	67	1
Eurotatorea	Lecanidae	*Monostyla closterocerca* Schmarda	25	2
Eurotatorea	Proalidae	*Proales decipiens* (Ehrenberg)	56	1
Eurotatorea	Mytilinidae	*Mytilina ventralis* (Ehrenberg)	36	9
Eurotatorea	Mytilinidae	*Mytilina compressa* (Gosse)	14	1
Eurotatorea	Colurellidae	*Lepadella patella* (Muller)	34	9
Eurotatorea	Colurellidae	*Lepadella* sp.	29	1
Eurotatorea	Colurellidae	*Colurella uncinata* (O.F.Muller)	38	1
Eurotatorea	Euchlanidae	*Euchlanis dilatata* Ehrenberg	44	25
Eurotatorea	Euchlanidae	*Euchlanis* sp.	39	2
Eurotatorea	Euchlanidae	*Diplois daviesiae* Gosse	42	14
Eurotatorea	Euchlanidae	*Dipleuchlanis propatula* (Gosse)	55	4
Eurotatorea	Euchlanidae	*Eudactylota eudactylota* Gosse	67	2
Eurotatorea	Brachionidae	*Brachionus angularis* Gosse	54	49
Eurotatorea	Brachionidae	*Brachionus urceus* (Linnaeus)	54	5
Eurotatorea	Brachionidae	*Brachionus* cf. *urceus* (Linnaeus)	43	3
Eurotatorea	Brachionidae	*Brachionus calyciflorus* cf. *calicyflorus* Pallas	62	14
Eurotatorea	Brachionidae	*Brachionus calyciflorus* cf. *anuaeiformis* (Brehm)	59	3
Eurotatorea	Brachionidae	*Brachionus caudatus* Apstein	52	14
Eurotatorea	Brachionidae	*Brachionus forficula forficula* Wierzejski	70	2
Eurotatorea	Brachionidae	*Brachionus falcatus* Zacharias	55	19
Eurotatorea	Brachionidae	*Brachionus quadridentatus* var. *quadridentatus* Hermann	49	6

Class	Family	Taxon	Tolerance score	Total samples
Eurotatorea	Brachionidae	*Brachionus plicatilis* Muller	82	2
Eurotatorea	Brachionidae	*Schizocerca diversicornis* Daday	68	5
Eurotatorea	Brachionidae	*Platyias quadricornis* Ehrenberg	50	3
Eurotatorea	Brachionidae	*Platyias patulus patulus* (Muller)	53	7
Eurotatorea	Brachionidae	*Keratella valga tropica* (Apstein)	50	58
Eurotatorea	Brachionidae	*Keratella cochlearis cochlearis* (Gosse)	40	92
Eurotatorea	Brachionidae	*Keratella cochlearis tecta* Gosse	48	40
Eurotatorea	Brachionidae	*Keratella cochlearis hispida* Lauterborn	43	5
Eurotatorea	Brachionidae	*Keratella irregularis* (Lauterborn)	24	4
Eurotatorea	Brachionidae	*Keratella quadrata* (O.F.Muller)	46	8
Eurotatorea	Brachionidae	*Anuraeopsis fissa* (Gosse)	35	19
Eurotatorea	Brachionidae	*Anuraeopsis* sp.	60	6
Eurotatorea	Brachionidae	*Macrochaetus subquadritus* Petry	25	5
Eurotatorea	Flosculariidae	*Sinantheria socialis* (Linnaeus)	36	1
Eurotatorea	Filiniidae	*Filinia longiseta* (Ehrenberg)	45	27
Eurotatorea	Filiniidae	*Filinia longiseta* var. *passa* (O. F. Muller)	41	2
Eurotatorea	Filiniidae	*Filinia brachiata* (Rousselet)	55	13
Eurotatorea	Filiniidae	*Tetramastix opoliensis* Zacharias	54	10
Eurotatorea	Hexathridae	*Hexathra mira* (Hudson)	56	47
Ciliata	Epistylidae	*Epistylis plicatilis* Ehrenberg	47	2
Ciliata	Epistylidae	*Epistylis* sp.	38	1
Ciliata	Vorticellidae	*Vorticella* sp.	47	1
Lobosea	Arcellidae	*Arcella vulgaris* Ehrenberg	38	122
Lobosea	Arcellidae	*Arcella discoides* Ehrenberg	27	10
Lobosea	Arcellidae	*Arcella hemisphaerica* Perty	32	21
Lobosea	Arcellidae	*Arcella gibbosa* Penard	56	1
Lobosea	Arcellidae	*Arcella conica* Deflante	60	5
Lobosea	Arcellidae	*Arcella* sp.	42	11
Lobosea	Centropyxidae	*Centropyxis aculeata* Stein	40	79
Lobosea	Centropyxidae	*Centropyxis constricta* Ehrenberg	29	12
Lobosea	Diffugiidae	*Protocucurbitella coroniformis* Gauthier-Lie'vre & Thomas	32	9
Lobosea	Diffugiidae	*Protocucurbitella* sp.	46	4
Lobosea	Diffugiidae	*Pseudodifflugia gracilis* Schlumberger	8	10
Lobosea	Diffugiidae	*Pseudodifflugia fascicularis* Penard	11	8
Lobosea	Diffugiidae	*Difflugia elegans* Penard	51	71
Lobosea	Diffugiidae	*Difflugia urceolata* Carter	52	29
Lobosea	Diffugiidae	*Difflugia corona* Wallich	49	15
Lobosea	Diffugiidae	*Diffugia lobostoma* Leidy	31	56
Lobosea	Diffugiidae	*Difflugia acuminata* Ehrenberg	35	24
Lobosea	Diffugiidae	*Difflugia piriformis* Ehrenberg	36	21
Lobosea	Diffugiidae	*Difflugia globulosa* Dujardin	35	39
Lobosea	Diffugiidae	*Diflugia scalpellum* Penard	0	1
Lobosea	Diffugiidae	*Difflugia molesta* Penard	19	2
Lobosea	Diffugiidae	*Difflugia lanceolata* Penard	22	11
Lobosea	Diffugiidae	*Difflugia amphora* Leidy	25	1

Class	Family	Taxon	Tolerance score	Total samples
Lobosea	Diffugiidae	*Difflugia tuberculatus* (Wallich)	49	11
Lobosea	Diffugiidae	*Diflugia* sp.	40	5
Lobosea	Diffugiidae	*Pontigulasia bigibbosa* Penard	25	1
Lobosea	Diffugiidae	*Lesquereusia spiralis* (Ehrenberg)	35	3
Filosea	Euglyphidae	*Euglypha alveorata* Dujardin	40	18
Filosea	Euglyphidae	*Euglypha laevis* Ehrenberg	37	6
Filosea	Euglyphidae	*Euglypha* sp.	13	1
Phytomastigophora	Peridiniidae	*Ceratium* spp	30	26
Phytomastigophora	Euglenidae	*Euglena acus* Ehrenberg	57	4
Phytomastigophora	Euglenidae	*Phacus longicauda* (Ehrenberg)	34	7
Phytomastigophora	Volvocidae	*Pleodorina californica* Shaw	61	44
Phytomastigophora	Volvocidae	*Volvox spermatosphaera* Powers	94	1
Larvae		*Nauplius copepoda*	43	158
Larvae		Bivalvia	43	65
Larvae		Gastropoda	74	8
Larvae		Chironomidae - Diptera	28	48
Larvae		Ephemeroptera	28	20
Larvae		*Hydra carina*	32	6

Appendix 2.3. Zooplankton metrics

No.	Year	Site	Site disturbance score	Species richness	Abundance	Abundance (log)	Species diversity index	Dominance index	ATSPT value
1	2004	LNO	1.00	16	172	2.236	1.564	0.546	23
2	2004	LPB	1.28	18	547	2.738	0.578	0.104	33
3	2004	LVT	1.78	17	72	1.857	2.39	0.75	39
4	2004	LNG	1.50	28	1194	3.077	1.965	0.576	39
5	2004	LKD	1.43	13	53	1.724	2.181	0.773	42
6	2004	LPS	1.57	31	681	2.833	1.289	0.306	40
7	2004	TMU	1.71	61	3982	3.600	1.424	0.508	43
8	2004	TCH	1.86	28	2252	3.353	1.296	0.332	40
9	2004	TSK	2.13	18	1739	3.240	1.621	0.576	47
10	2004	TKO	1.88	22	160	2.204	2.42	0.75	40
11	2004	CPP	2.88	34	954	2.980	1.717	0.431	53
12	2004	CTU	2.13	30	2234	3.349	1.004	0.497	49
13	2004	CPS	2.22	30	576	2.760	1.714	0.39	45
14	2004	CSS	1.75	26	150	2.176	2.632	0.76	43
15	2004	CSP	1.25	20	67	1.826	2.646	0.776	43
16	2004	CKT	1.25	24	106	2.025	2.798	0.858	41
17	2004	VTC	2.50	35	1378	3.139	2.25	0.732	50
18	2004	VCD	2.69	25	1090	3.037	1.833	0.601	49
19	2004	VKT	2.29	19	194	2.288	2.024	0.603	44
20	2004	VSP	1.29	21	80	1.903	2.573	0.712	41
21	2005	LOU	1.00	16	64	1.806	2.093	0.578	22
22	2005	LPB	1.69	23	77	1.886	2.708	0.818	41
23	2005	LNK	1.38	29	169	2.228	2.92	0.846	34
24	2005	LMH	1.94	24	332	2.521	1.534	0.379	43
25	2005	LMX	1.94	27	228	2.358	2.091	0.508	42
26	2005	TMI	2.25	29	541	2.733	2.191	0.622	43
27	2005	TMC	1.64	23	485	2.686	1.153	0.237	43
28	2005	TKO	1.86	43	435	2.638	2.572	0.714	42
29	2005	LKU	1.13	18	152	2.182	1.925	0.539	35
30	2005	LKL	1.50	24	67	1.826	2.886	0.835	34
31	2005	CMR	1.75	23	118	2.072	2.25	0.567	37
32	2005	CSJ	1.50	23	356	2.551	1.826	0.62	38
33	2005	CKM	1.50	19	235	2.371	1.947	0.638	39
34	2005	CSU	2.13	20	42	1.623	2.77	0.857	38
35	2005	CSS	1.75	19	103	2.013	2.487	0.796	36
36	2005	CSP	1.13	16	259	2.413	1.935	0.656	40
37	2006	CPP	2.89	12	275	2.439	0.626	0.12	51
38	2006	CBS (CKL)	2.19	28	2532	3.403	1.652	0.587	52
39	2006	CNL	1.97	25	796	2.901	2.308	0.768	49
40	2006	CTU	2.04	13	199	2.299	0.909	0.196	49
41	2006	CSN	2.00	28	890	2.949	2.338	0.806	48
42	2006	CSK	2.00	44	4293	3.633	2.385	0.755	48

No.	Year	Site	Site disturbance score	Species richness	Abundance	Abundance (log)	Species diversity index	Dominance index	ATSPT value
43	2006	CPT	2.33	52	8895	3.949	1.97	0.493	50
44	2006	CKT	1.14	19	81	1.908	2.559	0.84	40
45	2006	CMR	1.42	16	73	1.863	2.035	0.576	41
46	2006	CSJ	1.25	30	185	2.267	2.732	0.709	39
47	2006	CKM	1.19	18	63	1.799	2.566	0.762	39
48	2006	CSP	1.11	20	210	2.322	2.169	0.705	39
49	2006	CSU (CUS)	1.75	41	527	2.722	2.912	0.748	41
50	2006	VSS	2.00	23	179	2.253	2.533	0.771	42
51	2006	VSR (VSP)	2.00	14	45	1.653	2.066	0.623	39
52	2006	VTR (VVL)	2.44	14	62	1.792	1.931	0.662	53
53	2006	VCT	2.64	19	166	2.220	2.081	0.693	54
54	2006	VLX	2.69	25	445	2.648	1.885	0.506	49
55	2006	VCL	1.91	26	381	2.581	2.413	0.812	51
56	2006	VCT	2.28	24	237	2.375	2.057	0.617	50
57	2006	VCD	2.31	24	291	2.464	1.229	0.255	49

Appendix 3.1. Littoral macroinvertebrates species list and abundance

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
1	*Haustorus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	*Scaphusa* sp	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	*Indoplanorbis* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	*Carbaidae* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	*Laccophilus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	*Rhantus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	*Cleptelmis* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	*Lara* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	*Macronychus* sp	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
10	*Optioservus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	*Georyssus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	*Gyretes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	*Exnochrus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	*Lampyridae* sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
15	*Psephenus* sp	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
16	*Scritidae* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	*Isotomidae* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	*Caridina* sp	0	1	0	0	3	37	0	3	84	0	0	0	0	1	0	43	15	25	17	0	0
19	*Macrobrachium dienbienphuensis*	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
20	*Macrobrachium eriocheirum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	*Macrobrachium lanchesteri*	5	2	1	0	0	11	0	8	20	2	0	0	0	1	0	0	0	0	0	0	0
22	*Macrobrachium mieni*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	*Macrobrachium thai*	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
24	*Macrobrachium yui*	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0
25	*Parathelphusidae* sp	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0
26	Decaopda unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
27	*Canaceoides* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	*Bezzia* sp	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0	0	0	0	0	0

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
29	*Culicoides* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	*Dasyhelea* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	*Ablabesmyia* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0
32	*Chironomus* sp	0	0	10	0	0	0	0	5	0	5	1	3	2	7	51	0	1	0	8	0	0
33	*Rhaphium canpestre*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	*Simulium fenestratum*	0	0	0	0	0	0	0	0	0	22	0	1	0	0	0	0	0	0	0	0	0
35	*Simulium inthanonense*	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
36	*Tabaninae* sp	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
37	*Antocha* sp	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0
38	*Limnophila* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0
39	*Pedicia* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
40	*Baetiella* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
41	*Baetis* sp	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
42	*Centroptilum* sp	0	0	0	0	0	0	0	1	0	2	3	1	3	0	0	0	0	0	0	0	0
43	*Cloeon* sp	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0
44	*Gratia narumonae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	*Heterocloeon* sp	0	0	0	0	0	0	0	1	3	37	4	3	59	0	8	0	0	0	0	0	0
46	*Platybaetis* sp	0	0	0	0	0	0	0	0	0	3	0	0	0	10	28	0	0	0	0	0	0
47	*Caenoculis* sp	0	3	5	0	0	0	0	3	0	0	7	3	0	9	0	0	0	0	0	0	0
48	*Caenodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
49	*Ephacerella commondema*	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0
50	*Eatonigenia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
51	*Ephemera* sp	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
52	*Cinygmina* sp	0	0	0	0	0	0	0	0	0	9	5	1	0	0	2	0	0	0	0	0	0
53	*Thalerosphyrus* sp	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
54	*Isonychia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	*Choroterpes* sp	0	0	0	0	0	0	0	2	0	8	1	20	0	5	1	0	0	0	0	0	0
56	*Choroterpides* sp	0	0	0	0	0	0	0	0	0	8	0	53	1	5	0	0	0	0	0	0	0
57	*Habrophlebiodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	*Potamanthellus caenodes*	0	0	0	0	0	0	0	0	0	9	0	4	0	2	0	0	0	0	0	0	0

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
59	*Potamanthellus edmundsi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	*Anthopotamus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	*Potamanthus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	*Rhoenanthus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
63	*Prosopistoma annamese*	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0	0	0	0	0	0	0
64	*Prosopistoma sinensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	*Prosopistoma wouterae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	*Aphelocheirus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	*Cryptobates japonicus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	*Limnogonus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	*Naboandelus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	*Ptilomera tigrina*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
71	*Rheumatobates* sp	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
72	*Tanagogonus* sp	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
73	*Trepobates* sp	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
74	*Ventidius* sp	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0
75	*Hebrus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	*Micronecta* sp	0	88	4	0	53	13	0	4	6	0	5	0	70	0	11	24	6	3	15	55	3
77	*Limnocoris* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
78	*Cercotmetus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	*Ranatra* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	*Nychia suppho*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	*Paraplea* sp	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
82	*Baptista* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	*Chenevelia* sp	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
84	*Microvelia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	*Rhagovelia* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	0	10	0	0	0	0	0	0
86	*Euphobia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	*Peltrophila confusalis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
88	*Protohermes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	*Assimineidae* sp	0	1	12	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0
90	*Bithynia* sp	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
91	*Walttebledia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	*Hubendickia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	*Hydrorissoia* sp	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0
94	*Jullienia* sp	0	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0	0
95	*Kareliania* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	*Lacunopsis* sp	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
97	*Neotricula* sp	0	0	14	0	0	0	0	0	40	3	2	0	0	0	0	0	0	0	0	0	0
98	*Pachydrobia brevis*	0	0	0	0	0	0	0	0	22	0	1	0	0	0	0	0	0	0	0	0	0
99	*Paraprososthenia* sp	0	0	8	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
100	*Rehderiella* sp	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
101	*Pila pesmi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102	*Pila scutata*	0	0	0	0	5	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0
103	*Stenothyra* sp*1*	0	2	5	0	0	0	0	25	33	7	0	3	0	0	0	0	0	0	0	0	0
104	*Stenothyra* sp2	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
105	*Ademietta housei*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106	*Brotia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	*Unknown*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	*Filopaludina martensi*	0	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	*Filopaludina polygramma*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110	*Indiopoma* sp	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
111	*Mekongia* sp	0	0	0	0	83	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	*Sinotaia* sp	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
113	*Limnoperna* sp	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
114	*Nematoda*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
115	*Clea helena*	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	0	0
116	*Amphipterygidae* sp	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
117	*Calopterygidae* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
118	*Chlorocyphynae* sp	0	0	0	0	0	0	0	0	0	2	1	1	0	1	0	0	0	0	0	0	0
119	*Corduliinae* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
120	*Amphylla williamsoni*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	*Gomphus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
122	*Octogomphus* sp	0	0	0	0	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	0
123	*Ophiogomphus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
124	*Progomphus* sp	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
125	*Plathemis* sp	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
126	*Protoneura* sp	0	10	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	1	0	0	0
127	*Oligochaeta*	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0
128	*Peltoperla* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
129	*Neoperla* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	10	0	0	0	0	0	0	0
130	*Polychaeta* sp*1*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
131	*Polychaeta* sp*2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
132	S*phaeromatida* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0
133	*Ganonema extensum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
134	*Diseudopsis* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
135	*Seudoneureclipsis* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
136	*Ecnomus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
137	*Glososoma* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
138	*Goera* sp	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
139	*Amphisyche* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140	*Hydromanicus* sp	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
141	*Hydropsyche* sp	0	0	0	0	0	0	0	0	0	24	0	33	0	5	0	0	0	0	0	0	0

No.	Taxon	Sampling sites																				
		CPP	CKL	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSP	VVL	VTC	VLX	VCL	VCT	VCD
142	*Macrostemum* sp	0	0	0	0	0	0	0	0	0	41	0	28	0	1	0	0	0	0	0	0	0
143	*Pseudoleptonema* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
144	*Trichomacronema* sp	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
145	*Hydroptila* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
146	*Mayatrichia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
147	*Orthotrichia* sp	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
148	*Ceraclea* sp	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
149	*Leptocerus* sp	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
150	*Ocetis* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
151	*Sitodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
152	*Trianodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
153	*Cryptochia* sp	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
154	*Pedomoecus* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	*Molannodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
156	*Chimarra* sp	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
157	*Dolophilodes* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
158	*Tinodes* sp	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
159	*Fattigia* sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	*Stenopsyche siamensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
161	*Ensidens ingallsianus*	0	8	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	*Physunio cambodiensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
163	*Physunio eximinus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
164	*Scabies crispata*	0	0	6	0	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0
165	*Corbicula* sp	0	1	21	3	7	0	2	0	0	2	0	19	3	2	2	1	0	0	4	0	0

Appendix 3.2. Littoral macroinvertebrates tolerance scores

Order	Family	Species	Tolerance score	Total samples
Amphipoda	Haustoridae	*Haustorus* sp.	77	8
Arcoida	Arcidae	*Scaphusa* sp.	50	8
Basommatophora	Planorbidae	*Indoplanorbis* sp.	11	3
Coleoptera	Psephenidae	*Acneus* sp.	15	3
Coleoptera	Salpingidae	*Aegialites* sp.	40	2
Coleoptera	Elmidae	*Ancyronyx* sp.	24	3
Coleoptera	Carbaidae	*Carbaidae* sp.	13	1
Coleoptera	Elmidae	*Cleptelmis* sp.	13	32
Coleoptera	Hydrophilidae	*Derallus* sp.	52	2
Coleoptera	Gyrinidae	*Dineutus* sp.	7	2
Coleoptera	Chrysomelidae	*Donacia* sp.	25	3
Coleoptera	Dytiscidae	*Dytiscidae* sp.	63	1
Coleoptera	Scirtidae	*Elodes* sp.	13	2
Coleoptera	Hydrophilidae	*Exnochrus* sp.	40	3
Coleoptera	Georyssidae	*Georyssus* sp.	48	2
Coleoptera	Gyrinidae	*Gyretes* sp.	49	3
Coleoptera	Gyrinidae	*Gyrinidae* sp.	47	4
Coleoptera	Haliplidae	*Haliplus* sp.	56	1
Coleoptera	Carbaidae	*Harpalus* sp.	25	1
Coleoptera	Hydrophilidae	*Helechares* sp.	31	2
Coleoptera	Heteroceridae	*Heteroceridae* sp.	64	1
Coleoptera	Elmidae	*Heterolimnius* sp.	16	15
Coleoptera	Hydrophilidae	*Hydrobius* sp.	42	2
Coleoptera	Hydrophilidae	*Hydrochara* sp.	13	5
Coleoptera	Hydropchidae	*Hydrochus* sp.	0	2
Coleoptera	Hydroscaphidae	*Hydroscapha* sp.	32	2
Coleoptera	Dytiscidae	*Hydrovatus* sp.	25	1
Coleoptera	Dytiscidae	*Laccophilus* sp.	26	21
Coleoptera	Lampyridae	*Lampyrinae* sp.	11	10
Coleoptera	Elmidae	*Lara* sp.	32	4
Coleoptera	Elmidae	*Macronychus* sp.	34	13
Coleoptera	Mysidae	*Neomysid* sp.	84	1
Coleoptera	Elmidae	*Optioservus* sp.	13	1
Coleoptera	Elmidae	*Ordobrevia* sp.	47	3
Coleoptera	Elmidae	*Oulimnius* sp.	25	10
Coleoptera	Hydrophilidae	*Paracymus* sp.	30	2
Coleoptera	Haliplidae	*Peltodytes* sp.	26	3
Coleoptera	Psephenidae	*Psephenus* sp.	12	12
Coleoptera	Dytiscidae	*Rhantus* sp.	32	10
Coleoptera	Scritidae	*Scritidae* sp.	13	1
Coleoptera	Staphilinidae	*Staphilinidae*	47	1
Coleoptera	Elmidae	*Stenelmis* sp.	31	3

Order	Family	Species	Tolerance score	Total samples
Coleoptera	Staphilinidae	*Thinopinus* sp.	56	2
Collembola	Isotomidae	*Isotomidae* sp.	65	1
Collembola	Isotomidae	*Isotomurus tricolor*	29	3
Decapoda	Atyidae	*Caridina* sp.	53	111
Decapoda	Palaemonidae	*Macrobrachium dienbienphuensis*	6	2
Decapoda	Palaemonidae	*Macrobrachium eriocheirum*	50	3
Decapoda	Palaemonidae	*Macrobrachium hirsutimanus*	26	1
Decapoda	Palaemonidae	*Macrobrachium lanchesteri*	35	18
Decapoda	Palaemonidae	*Macrobrachium mieni*	27	187
Decapoda	Palaemonidae	*Macrobrachium pilimanus*	20	18
Decapoda	Palaemonidae	*Macrobrachium rosenbergii*	31	20
Decapoda	Palaemonidae	*Macrobrachium thai*	77	3
Decapoda	Palaemonidae	*Macrobrachium yui*	32	6
Decapoda	Parathelphusidae	*Parathelphusidae* sp.	27	9
Decapoda	Potamonidae	*Potamon* sp.	13	20
Decapoda	Unknown	*Unknown*	59	2
Diptera	Chironomidae	*Ablabesmyia* sp.	30	45
Diptera	Culicidae	*Anophelinae* sp.	38	2
Diptera	Tipulidae	*Antocha* sp.	30	13
Diptera	Athericidae	*Atherix* sp.	42	8
Diptera	Ceratopogonidae	*Bezzia* sp.	37	46
Diptera	Blephariceridae	*Blephariceridae* sp.	56	1
Diptera	Canacidae	*Canaceoides* sp.	5	4
Diptera	Chaoboridae	*Chaoborus* sp.	53	4
Diptera	Chironomidae	*Chironomus* sp.	36	214
Diptera	Culicidae	*Culicidae*	11	6
Diptera	Ceratopogonidae	*Culicoides* sp.	51	7
Diptera	Ceratopogonidae	*Dasyhelea* sp.	37	4
Diptera	Empididae	*Empidinae* sp.	31	13
Diptera	Tipulidae	*Limnophila* sp.	28	32
Diptera	Sciomyzidae	*Nanocladius* sp.	22	7
Diptera	Stratiomyidae	*Odontomyia* sp.	0	1
Diptera	Tipulidae	*Pedicia* sp.	32	4
Diptera	Tipulidae	*Pilaria* sp.	63	3
Diptera	Psychodidae	*Psychoda* sp.	25	1
Diptera	Dolichopodidae	*Rhaphium canpestre*	65	1
Diptera	Dolichopodidae	*Rhaphium* sp.	32	1
Diptera	Ceratopogonidae	*Sciomyzid* sp.	14	1
Diptera	Sciomyzidae	*Sepadon* sp.	43	1
Diptera	Simulidae	*Simulium fenestratum*	16	12
Diptera	Simulidae	*Simulium inthanonense*	11	2
Diptera	Tabanidae	*Tabaninae* sp.	13	1
Diptera	Tanyderidae	*Tanyderinae* sp.	43	1
Diptera	Chironomidae	*Thaumalea* sp.	31	13
Diptera	Tipulidae	*Tipula* sp.	39	6
Ephemeroptera	Ephemeridae	*Afromera siamensis*	43	1

Order	Family	Species	Tolerance score	Total samples
Ephemeroptera	Potamanthidae	*Anthopotamus* sp.	50	1
Ephemeroptera	Anthropleidae	*Arthroplea* sp.	14	1
Ephemeroptera	Heptageniidae	*Asionurus* sp.	19	15
Ephemeroptera	Baetidae	*Baetiella* sp.	26	62
Ephemeroptera	Baetidae	*Baetis* sp.	32	98
Ephemeroptera	Caenidea	*Caenis* sp.	44	21
Ephemeroptera	Caenidea	*Caenoculis* sp.	32	87
Ephemeroptera	Caenidea	*Caenodes* sp.	25	41
Ephemeroptera	Baetidae	*Centroptilum* sp.	26	85
Ephemeroptera	Caenidae	*Cercobrachys* sp.	35	3
Ephemeroptera	Leptophlebiidae	*Choroterpes* sp.	22	89
Ephemeroptera	Leptophlebiidae	*Choroterpides*	21	55
Ephemeroptera	Heptageniidae	*Cinygmina* sp.	25	93
Ephemeroptera	Baetidae	*Cloeon* sp.	34	48
Ephemeroptera	Ephemerellidae	*Crinitella* sp.	15	11
Ephemeroptera	Ephemeridae	*Eatonigenia* sp.	43	7
Ephemeroptera	Ephemerellidae	*Ephacerella commodema*	24	18
Ephemeroptera	Ephemeridae	*Ephemera* sp.	26	36
Ephemeroptera	Baetidae	*Gratia narumonae*	41	10
Ephemeroptera	Leptophlebiidae	*Habrophlebiodes* sp.	13	1
Ephemeroptera	Baetidae	*Heterocloeon* sp.	23	44
Ephemeroptera	Isonycheiridae	*Isonycheirus* sp.	20	9
Ephemeroptera	Isonychidae	*Isonychia* sp.	50	2
Ephemeroptera	Heptageniidae	*Leucrocuta* sp.	14	3
Ephemeroptera	Palingeniidae	*Palingenea* sp.	43	1
Ephemeroptera	Baetidae	*Platybaetis* sp.	35	85
Ephemeroptera	Neoephmeridae	*Potamanthellus caenodes*	19	30
Ephemeroptera	Neoephemeridae	*Potamanthellus edmundsi*	18	17
Ephemeroptera	Neoephmeridae	*Potamanthus formosus*	0	2
Ephemeroptera	Potamanthidae	*Potamanthus* sp.	21	12
Ephemeroptera	Prosopistomatidae	*Prosopistoma annamense*	21	29
Ephemeroptera	Prosopistomatidae	*Prosopistoma sinensis*	13	2
Ephemeroptera	Prosopistomatidae	*Prosopistoma wouterae*	9	2
Ephemeroptera	Potamanthidae	*Rhoenanthus obscurus*	14	8
Ephemeroptera	Potamanthidae	*Rhoenanthus* sp.	50	2
Ephemeroptera	Teloganosidae	*Teloganodes* sp.	15	7
Ephemeroptera	Heptageniidae	*Thaler*sp.*hyrus* sp.	20	18
Ephemeroptera	Epemerellidae	*Uracanthella* sp.	17	13
Hemiptera	Notonectidae	*Anisops* sp.	49	6
Hemiptera	Aphelocheiridae	*Aphelocheirus* sp.	18	20
Hemiptera	Notonectidae	*Aphelonecta* sp.	41	2
Hemiptera	Veliidae	*Baptista* sp.	5	2
Hemiptera	Belostomatidae	*Belostoma* sp.	47	1
Hemiptera	Nepidae	*Cercometus* sp.	51	4
Hemiptera	Veliidae	*Chenevelia stridulans*	31	4
Hemiptera	Gerridae	*Cryptobates japonicus*	12	14

Order	Family	Species	Tolerance score	Total samples
Hemiptera	Gerridae	*Cryptobates* sp.	26	3
Hemiptera	Hebridae	*Hebrus* sp.	35	2
Hemiptera	Platycnemidae	*Heleocoris* sp.	0	1
Hemiptera	Nepidae	*Laccotrephes* sp.	43	1
Hemiptera	Naucoridae	*Limnocoris* sp.	50	1
Hemiptera	Gerridae	*Limnogonus* sp.	20	2
Hemiptera	Macroveliidae	*Macrovelia* sp.	36	2
Hemiptera	Mesoveliidae	*Mesovelia* sp.	33	9
Hemiptera	Gerridae	*Metrocoris* sp.	19	8
Hemiptera	Micronectidae	*Micronecta* sp.	42	207
Hemiptera	Veliidae	*Microvelia* sp.	65	1
Hemiptera	Gerridae	*Naboandelus* sp.	72	1
Hemiptera	Naucoridae	*Naucoris scutellaris*	19	9
Hemiptera	Gerridae	*Noegerris parvurus*	32	22
Hemiptera	Notonectidae	*Nychia suppho*	35	9
Hemiptera	Pleidae	*Paraplea* sp.	21	7
Hemiptera	Veliidae	*Perittopus* sp.	36	1
Hemiptera	Pleidae	*Plea* sp.	28	8
Hemiptera	Gerridae	*Ptilomera tigrina*	14	16
Hemiptera	Nepidae	*Ranatra* sp.	36	9
Hemiptera	Veliidae	*Rhagovelia* sp.	14	18
Hemiptera	Gerridae	*Rheumatobates* sp.	50	1
Hemiptera	Gerridae	*Rheumatogonus intermedius*	12	6
Hemiptera	Saldidae	*Saldidae* sp.	43	1
Hemiptera	Corixidae	*Sigara* sp.	32	8
Hemiptera	Naucoridae	*Stenicoris* sp.	13	1
Hemiptera	Veliidae	*Strongyvelia* sp.	13	2
Hemiptera	Gerridae	*Tanagogonus* sp.	8	2
Hemiptera	Gerridae	*Tenagogonus* sp.	0	1
Hemiptera	Gerridae	*Tinaggonus* sp.	25	3
Hemiptera	Gerridae	*Trepobates* sp.	33	3
Hemiptera	Veliidae	*Trochopus* sp.	56	1
Hemiptera	Gerridae	*Ventidius* sp.	28	25
Hymenoptera	Trichogrammatidae	*Hydrophilita aquivolans*	47	1
Isopoda	Sp.haeromatidae	Sp.*haeromatid* sp.	42	33
Lepidoptera	Noctuidae	*Archanara* sp.	0	1
Lepidoptera	Grambidae	*Elophila* sp.	25	1
Lepidoptera	Crambidae	*Euphobia* sp.	50	1
Lepidoptera	Pyralidae	*Peltrophila confusalis*	28	2
Lepidoptera	Pyralidae	*Petrophila* sp.	25	4
Lepidoptera	Cossidae	*Prionoxystus* sp.	45	2
Megaloptera	Corydalidae	*Corydalus* sp.	6	3
Megaloptera	Corydalidae	*Protohermes* sp.	28	2
Mesogastropoda	Thiaridae	*Ademietta housei*	52	3
Mesogastropoda	Assimineidae	*Assimineidae*	37	9
Mesogastropoda	Bithyniidae	*Bithynia* sp.	27	64

Order	Family	Species	Tolerance score	Total samples
Mesogastropoda	Bithyniidae	*Bithynia walttebledia*	11	4
Mesogastropoda	Thiaridae	*Brotia* sp.	38	4
Mesogastropoda	Fairbankiidae	*Fairbankid* sp.	14	2
Mesogastropoda	Viviparidae	*Filopaludina martensi*	38	10
Mesogastropoda	Viviparidae	*Filopaludina munensis*	41	8
Mesogastropoda	Viviparidae	*Filopaludina polygramma*	38	38
Mesogastropoda	Hydrobiidae	*Hubendickia* sp.	21	3
Mesogastropoda	Hydrobiidae	*Hydrorissoia* sp.	21	3
Mesogastropoda	Viviparidae	*Indiopoma* sp.	69	6
Mesogastropoda	Hydrobiidae	*Jullienia* sp.	31	7
Mesogastropoda	Hydrobiidae	*Kareliania* sp.	21	1
Mesogastropoda	Hydrobiidae	*Lacunopsis* sp.	22	14
Mesogastropoda	Lymnaeidae	*Lymnaea* sp.	40	14
Mesogastropoda	Viviparidae	*Mekongia* sp.	41	31
Mesogastropoda	Thiaridae	*Melanodes tuberculata*	50	6
Mesogastropoda	Hydrobiidae	*Neotricula* sp.	28	17
Mesogastropoda	Hydrobiidae	*Pachydrobia brevis*	18	4
Mesogastropoda	Hydrobiidae	*Pachydrobiella* sp.	34	14
Mesogastropoda	Ampullariidae	*Pamacea* sp.	4	3
Mesogastropoda	Thiaridae	*Paracrostoma* sp.	16	2
Mesogastropoda	Hydrobiidae	*Paraprososthenia* sp.	39	7
Mesogastropoda	Pilidae	*Pila pesmi*	65	1
Mesogastropoda	Pilidae	*Pila scutata*	50	9
Mesogastropoda	Ampullariidae	*Pila* sp.	43	5
Mesogastropoda	Hydrobiidae	*Rehderiella* sp.	16	7
Mesogastropoda	Hydrobiidae	*Rehderiellinae* sp.	22	6
Mesogastropoda	Viviparidae	*Sinotaia* sp.	37	21
Mesogastropoda	Viviparidae	Species of Viviparidae?	63	3
Mesogastropoda	Stenothyridae	*Stenothyra* sp.	29	87
Mesogastropoda	Stenothyridae	*Stenothyra* sp.1	40	22
Mesogastropoda	Stenothyridae	*Stenothyra* sp.2	10	5
Mesogastropoda	Thiaridae	*Tarebia granifera*	37	4
Mesogastropoda	Bithyniidae	*Walttebledia* sp.	50	1
Mytiloida	Mytilidae	*Limnoperna siamensis*	56	7
Mytiloida	Mytilidae	*Limnoperna* sp.	51	6
Nematoda	Nematoda	*Nematoda* sp.	13	3
Neogastropoda	Buccidae	*Clea helena*	36	58
Odonata	Coenagrionidae	*Acanthagrion* sp.	41	2
Odonata	Aeshnidae	*Aeshna* sp.	38	3
Odonata	Amphipterygidae	*Amphipterygidae* sp.	4	3
Odonata	Amphipterygidae	*Amphipteryx* sp.	14	6
Odonata	Gomphidae	*Amphylla williamsoni*	63	5
Odonata	Gomphidae	*Aphylla williamsoni*	34	6
Odonata	Lestidae	*Archilestes* sp.	43	1
Odonata	Coenagrionidae	*Argia* sp.	27	9

Order	Family	Species	Tolerance score	Total samples
Odonata	Libellulidae	*Brechmorhoga* sp.	56	1
Odonata	Calopterygidae	*Calopterygidae* sp.	50	1
Odonata	Calopterygidae	*Calopteryx maculata*	17	4
Odonata	Chlorocyphidae	*Chlorocyphidae* sp.	31	8
Odonata	Corduliidae	*Corduliinae* sp.	30	9
Odonata	Gomphidae	*Dromogomphus* sp.	19	20
Odonata	Coenagrionidae	*Enallagma civile*	28	5
Odonata	Libellulidae	*Epicordulia princeps*	25	1
Odonata	Gomphidae	*Erpetogomphus* sp.	3	6
Odonata	Euphaeidae	*Euphaeidae* sp.	36	9
Odonata	Gomphidae	*Gomphus* sp.	41	4
Odonata	Aeshnidae	*Gynacantha* sp.	14	3
Odonata	Gomphidae	*Hagenius brevistylus*	14	1
Odonata	Calopterygidae	*Hetaerina titia*	0	2
Odonata	Libellulidae	*Macrothemis*	27	9
Odonata	Gomphidae	*Meglogomphus* sp.	84	1
Odonata	Gomphidae	*Octogomphus* sp.	19	28
Odonata	Gomphidae	*Ophiogomphus* sp.	35	40
Odonata	Libellulidae	*Plathemis* sp.	24	62
Odonata	Platycnemidae	*Platycnemidae* sp.	56	1
Odonata	Gomphidae	*Progomphus* sp.	20	16
Odonata	Protoneuridae	*Protoneura* sp.	39	44
Odonata	Gomphidae	*Stylogomphus albistylus*	19	1
Odonata	Aeshnidae	*Triacanthagyna trifida*	14	3
Oligochaeta	Oligochaeta	*Oligochaeta* sp.	40	60
Plecoptera	Peltoperidae	*Crytoperla* sp.	13	7
Plecoptera	Peridae	*Eccoptura xanthenes*	23	19
Plecoptera	Perlidae	*Etrocorema* sp.	16	35
Plecoptera	Neoperidae	*Neoperla* sp.	23	33
Plecoptera	Peltoperidae	*Peltoperla* sp.	24	2
Plecoptera	Perlidae	*Phanoperla* sp.	0	3
Polychaeta	Polychaeta	*Polychaeta* sp.1	65	23
Polychaeta	Polychaeta	*Polychaeta* sp.2	38	1
Trichoptera	Hydroptilidae	*Agraylea* sp.	18	3
Trichoptera	Hydropsychidae	*Amphisyche* sp.	5	1
Trichoptera	Calamoceridae	*Anisocentropus brevi*	38	4
Trichoptera	Hydropsychidae	*Arctopsyche* sp.	9	6
Trichoptera	Leptoceridae	*Ceraclea* sp.	8	3
Trichoptera	Philopotamidae	*Chimarra* sp.	28	25
Trichoptera	Limnephilidae	*Cryptochia* sp.	24	5
Trichoptera	Diseudopsidae	*Diseudopsis* sp.	8	2
Trichoptera	Philopotamidae	*Dolophilodes* sp.	52	7
Trichoptera	Ecnomidae	*Ecnomus* sp.	5	1
Trichoptera	Branchycentridae	*Eobrachycentrus* sp.	36	2
Trichoptera	Sericostomatidae	*Fattigia*	21	6
Trichoptera	Calamoceridae	*Ganonema extensum*	41	5

Order	Family	Species	Tolerance score	Total samples
Trichoptera	Glossosomatidae	*Glossosoma* sp.	9	2
Trichoptera	Goeridae	*Goera* sp.	22	5
Trichoptera	Limnephilidae	*Goerita* sp.	29	17
Trichoptera	Helichopsychidae	*Helichopsyche* sp.	0	2
Trichoptera	Calamoceridae	*Heteroplecton* sp.	56	2
Trichoptera	Hydropsychidae	*Hydatonicus* sp.	6	4
Trichoptera	Hydropsychidae	*Hydromanicus* sp.	24	5
Trichoptera	Hydropsychidae	*Hydropsyche bettni*	21	4
Trichoptera	Hydropsychidae	*Hydropsyche* sp.	21	38
Trichoptera	Hydroptilidae	*Hydroptila* sp.	19	8
Trichoptera	Hydroptilidae	*Ithytrichia* sp.	25	1
Trichoptera	Leptoceridae	*Leptocerus* sp.	21	16
Trichoptera	Limnephilidae	*Limnephilus*	27	2
Trichoptera	Hydropsychidae	*Macrostemum* sp.	13	26
Trichoptera	Limnephilidae	*Madeophylax* sp.	35	3
Trichoptera	Hydroptilidae	*Mayatrichia* sp.	10	1
Trichoptera	Branchycentridae	*Micrasema* sp.	24	13
Trichoptera	Molannidae	*Molannodes* sp.	8	2
Trichoptera	Limnephilidae	*Moselyana comosa*	13	2
Trichoptera	Polycentropodidae	*Neureclipsis* sp.	33	10
Trichoptera	Polycentropodidae	*Nyctiophylax* sp.	53	5
Trichoptera	Leptoceridae	*Ocetis* sp.	18	3
Trichoptera	Leptoceridae	*Oecetis* sp.	23	9
Trichoptera	Helichopsychidae	*Orthotrichia* sp.	23	16
Trichoptera	Limnephilidae	*Pedomoecus* sp.	37	3
Trichoptera	Peltoperidae	*Peltoperlopsis* sp.	24	3
Trichoptera	Polycentropodidae	*Polycentropus* sp.	24	9
Trichoptera	Hydropsychidae	*Polymorphanisus* sp.	11	6
Trichoptera	Odontoceridae	*Pseudogoera* sp.	25	1
Trichoptera	Hydropsychidae	*Pseudoleptonema* sp.	6	3
Trichoptera	Diseudopsidae	*Pseudoneureclipsis* sp.	20	5
Trichoptera	Limnephilidae	*Pseudostenophylax* sp.	13	7
Trichoptera	Phryganeidae	*Ptilostomis* sp.	56	2
Trichoptera	Rhyacophilidae	*Rhyacophila* sp.	6	1
Trichoptera	Sericostomatidae	*Sericostoma* sp.	25	2
Trichoptera	Leptoceridae	*Setodes* sp.	21	11
Trichoptera	Diseudopsidae	*Seudoneureclipsis* sp.	7	6
Trichoptera	Leptoceridae	*Sitodes* sp.	10	1
Trichoptera	Stenopsychidae	*Stenopsyche siamensis*	50	1
Trichoptera	Psychomyiidae	*Tinodes* sp.	5	1
Trichoptera	Leptoceridae	*Triaenodes* sp.	35	3
Trichoptera	Hydropsychidae	*Trichomacronema* sp.	6	2
Trichoptera	Philopotamidae	*Wormaldia* sp.	0	1
Unioroida	Amblemidae	*Ensidens ingallsianus*	56	7
Unioroida	Amblemidae	*Ensidens* sp.	29	5
Unioroida	Amblemidae	*Physunio cambodiensis*	59	1

Order	Family	Species	Tolerance score	Total samples
Unioroida	Amblemidae	*Physunio eximinus*	59	1
Unioroida	Amblemidae	*Physunio* sp.	13	1
Unioroida	Amblemidae	*Pilsbryoconcha exilis*	6	1
Unioroida	Amblemidae	*Scabies crispata*	61	8
Unioroida	Amblemidae	*Scabies* sp.	41	19
Veneroida	Corbiculidae	*Corbicula* sp.	45	46

Appendix 3.3. Littoral macroinvertebrates metrics

No.	Year	Site	Site disturbance score	Species richness	Abundance	Species diversity index	Dominance index	Littoral sweep ATSPT values
1	2004	LNO	1.00	42	2390	0.867	0.207	27
2	2004	LPB	1.28	14	670	0.473	0.724	29
3	2004	LVT	1.78	15	151	0.779	0.384	35
4	2004	LNG	1.50	27	1975	0.744	0.433	35
5	2004	LKD	1.43	25	442	1.099	0.204	34
6	2004	LPS	1.57	13	880	0.527	0.661	33
7	2004	TMU	1.71	15	301	0.721	0.372	39
8	2004	TCH	1.86	28	170	1.152	0.176	35
9	2004	TSK	2.13	26	1105	0.270	0.890	38
10	2004	TKO	1.88	16	117	0.738	0.470	29
11	2004	CPP	2.88	7	36	0.827	0.194	40
12	2004	CTU	2.13	24	369	0.801	0.444	41
13	2004	CPS	2.22	53	1807	0.845	0.334	29
14	2004	CSS	1.75	10	43	0.826	0.256	45
15	2004	CSP	1.25	39	695	1.016	0.414	33
16	2004	CKT	1.25	35	988	0.834	0.383	32
17	2004	VTC	2.50	54	894	1.210	0.282	47
18	2004	VCD	2.69	19	119	0.935	0.378	37
19	2004	VSS	2.29	17	454	0.597	0.553	44
20	2004	VSP	1.29	17	9759	0.161	0.924	27
21	2005	LOU	1.00	18	1176	2.929	0.209	34
22	2005	LPB	1.69	59	811	1.725	0.342	20
23	2005	LNK	1.38	46	7614	1.169	0.508	29
24	2005	LMH	1.94	22	108	2.072	0.306	34
25	2005	LMX	1.94	27	217	2.077	0.406	36
26	2005	TMI	2.25	52	1650	1.701	0.468	35
27	2005	TMC	1.64	62	855	1.893	0.295	32
28	2005	TKO	1.86	22	708	1.591	0.435	34
29	2005	LKU	1.13	23	1638	2.773	0.245	29
30	2005	LKL	1.50	36	1587	3.300	0.101	31
31	2005	CMR	1.75	12	1656	1.951	0.281	36
32	2005	CSJ	1.50	57	1283	2.857	0.175	31
33	2005	CKM	1.50	63	1096	3.124	0.177	32
34	2005	CSU	2.13	89	894	2.671	0.449	34
35	2005	CSS	1.75	66	632	3.137	0.222	34
36	2005	CSP	1.13	73	2317	3.428	0.143	28
37	2006	CPP	2.89	7	55	1.299	0.545	46
38	2006	CBS	2.19	24	817	1.443	0.671	42
39	2006	CNL	1.97	18	828	2.211	0.314	38
40	2006	CTU	2.04	12	50	2.001	0.380	45
41	2006	CSN	2.00	15	627	1.336	0.636	45
42	2006	CSK	2.00	9	461	1.093	0.557	47

No.	Year	Site	Site disturbance score	Species richness	Abundance	Species diversity index	Dominance index	Littoral sweep ATSPT values
43	2006	CPT	2.33	19	231	2.313	0.255	45
44	2006	CKT	1.14	37	795	2.302	0.367	31
45	2006	CMR	1.42	28	2062	2.198	0.373	32
46	2006	CSJ	1.25	59	705	3.162	0.133	28
47	2006	CKM	1.19	53	465	3.268	0.123	32
48	2006	CSP	1.11	73	1157	3.238	0.160	27
49	2006	CSU	1.75	66	1149	1.186	0.480	28
50	2006	VSS	2.00	53	564	2.843	0.289	34
51	2006	VSR	2.00	48	690	2.269	0.284	31
52	2006	VTR	2.44	16	269	1.700	0.353	47
53	2006	VCT	2.64	8	121	0.978	0.694	46
54	2006	VLX	2.69	14	148	0.959	0.797	47
55	2006	VCL	1.91	15	196	1.741	0.418	44
56	2006	VTC	2.28	3	114	0.240	0.947	50
57	2006	VCD	2.31	16	75	1.607	0.587	52

Appendix 4.1. Benthic macroinvertebrates species list and abundance

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Phylum Annelida																					
	Class Polychaeta																					
	Order Neveimorpha																					
	Family Nephthydidae																					
1	*Nephthys polybranchia* (Southern)																19					
	Family Nereidae																					
2	*Namalycastis abiuma* Muller																		18			30
3	*Neanthes caudata* (Delle Chiaje)																	4				
	Order Spiomorpha																					
	Family Ariciidae																					
4	*Scoloplos* sp.																2					
	Family Spionidae																					
5	*Prionospio* sp.																		19			
6	*Polydora* sp.																3					
	Class Oligochaeta																					
	Family Naididae																					
7	Genus sp.					7			16		7		10	4	1							
	Family Tubificidae																					
8	*Limnodrilus hoffmeisteri* Claparede	18	2	6	17	3	25	27	7	54							56	21	81	27	26	6
9	*Branchiura sowerbyi* Beddard	15	19	19	57		51	36		12				2		11	8	2	19	19	3	33
	Phylum Mollusca																					
	Class Gastropoda																					
	Order ARCHAEOGASTROPODA																					
	Family Neritidae																					
10	*Neritina rubida* (Pease)								5													
	Order Mesogastropoda																					
	Family Stenothyiidae																					

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
11	*Stenothyra mcmulleni* Brandt	2		1					6													
12	*Stenothyra koratensis holosculpta* Brandt	21	1						4	13									10		9	2
13	*Stenothyra koratensis koratensis* Brandt	1																				
14	*Stenothyra* sp.																		2			
	Family Hydrobiidae																					
15	*Pachydrobia* sp.										1		2						4			18
16	*Hubendickia crooki* Brandt									175												
17	*Hubendickia* sp.											1										
18	*Hydrorissoia* sp.									12												
19	*Paraprososthnia* sp.									75												
20	*Jullienia acuta* Poirier								6													
	Family Viviparidae																					
21	*Filopaludian (Filopaludina) filosa* (Reeve)	1				3		4														
22	*Filopaludina (Filopaludina) doliaris* (Gould)				1		1															
23	*Mekongia swainsoni breueri* (Kobelt)						3															
24	*Mekongia swainsoni flavida* n. subsp.		7			43																
	Family Bythiniidae																					
25	*Bithynia* sp.		3				6		60				1						3		6	
26	*Wattebledia siamensis* (Moellendorff)												1									
	Family Fluminicolidae																					
27	Genus sp.										2	3										
	Family Thiaridae																					
28	*Sermyla tornatella* (Lea)	1	5		5	2											4	1	10			4
29	*Melanoides tuberculatus* (Muller)				1														2			1

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Family Assimineidae																					
30	*Cyclotropis* sp.																40					
	Class Bivalvia																					
	Order Arcoida																					
	Family Arcidae																					
31	*Scaphula pinna* Benson																1	2				
	Order Mytiloida																					
	Family Mytilidae																					
32	*Limnoperna siamensis* (Morelet)		3	9	8												3		6	10		2
	Order Veneroida																					
	Family Dreissenidae																					
33	*Sinomytilus harmandi* (Rochebrune)	2	42	11	9												22	1	15	21		
	Family Corbiculidae																					
34	*Corbicula lamarckiana* Prime							2														
35	*Corbicula leviuscula* Prime				41										1							
36	*Corbicula tenuis* Clessin	5	26	8	406	11		10	5		1	6	9	30		35	4	3	56	13	14	2
37	*Corbicula baudoni* Morlet				27			1											1		9	1
38	*Corbicula moreteliana* Prime		11																2		2	
39	*Corbicula cyreniformis* Prime		17		38			1													2	1
40	*Corbicula blandiana* Prime	1	21		2	6		1												8	5	
	Order Unionoida																					
	Family Amblemidae																					
41	*Ensidens ingallsianus ingallsianus* (Lea)		33				11															
42	*Pseudodon vondembuschianus ellipticus* (Conrad)						2															
43	*Pseudodon inoscularis cumingi* (Lea)						1															

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
44	*Pseudodon cambodjensis cambodjensis* (Petit)		2	1																		
45	*Uniandra contradens ascia* (Hanley)		12																		1	
46	*Pilbryoconcha lemeslei* (Morelet)							1														
47	*Pilsbryoconcha exilis exilis* (Lea)		1																			
48	*Scabies* sp.						1															
49	*Trapezoidens exolescens comptus* (Deshayes)		3																			
	Phylum Arthropoda																					
	Class Crustacea																					
	Order Amphipoda																					
	Family Gammaridae																					
50	*Melita* sp.	3		7													31	18	10	2		21
	Family Oedicerotidae																					
51	*Perioculodes* sp.																			4	104	
	Family Corophiidae																					
52	*Corophium* sp.																		8		66	
53	*Kamaka* sp.																	18				
54	*Grandidierella lignorum* Barnard			3													2	26		23	11	
55	*Grandidierella vietnamica* Dang																		2			54
	Order Isopoda																					
	Family Anthuridae																					
56	*Cyathura trucata* Dang	1		3	42													6			4	34
	Order Tanaidacea																					
	Family Apseudidae																					
57	*Apseudes vietnamensis* Dang																	3				
	Order Cumacea																					
58	Genus sp.																	1				

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Order Decapoda																					
	Family Palaemonidae																					
59	*Macrobrachium pilimanus* (De Man)			1		1																
	Family Alpheidae																					
60	*Alpheus bisincisus* (De Man)																	1				
	Class Insecta																					
	Order Ephemeroptera																					
	Family Baetidae																					
61	*Baetis* sp.	1																				
	Family Caenidae																					
62	*Caenis* sp.					13		15	1				6	2								
	Family Leptoplebiidae																					
63	*Leptophlebia* sp.												1									
64	*Traverella* sp.								2													
65	*Choroterpes* sp.													2								
	Family Ephemeridae																					
66	*Ephemera* sp.													1								
67	*Eatonigenia* sp.					74																
	Family Palingeniidae																					
68	*Pentagenia* sp.					182		103		2												
	Order Plecoptera																					
	Family Perlidae																					
69	*Perla* sp.												1									
	Order Odonata																					
	Family Gomphidae																					
70	*Dromogomphus* sp.	2			3	2		3					3	1								
71	*Octogomphus* sp.												2									
72	*Aphylla* sp.				1									1								

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Family Libellulidae																					
73	*Libellula* sp.								1													
	Order Hemiptera																					
	Family Naucoridae																					
74	*Naucoris* sp.								2													
	Order Coleoptera																					
	Family Elmidae																					
75	Genus sp.							3					5	4		3						
	Family Dytiscidae																					
76	Genus sp.												1									
	Order Trichoptera																					
	Family Rhyacophilidae																					
77	*Rhyacophila* sp.															2						
	Family Ecnomidae																					
78	*Economus* sp.											2						2				
	Family Philopotamidae																					
79	Genus sp.	11	4	29	43	2	2			5	1	2				79					2	8
	Order Lepidoptera																					
	Family Crambidae																					
80	Genus sp.								1													
	Order Diptera																					
	Family Heleidae																					
81	*Culicoides* sp.					5	3	22								2						
	Family Culicidae																					
82	*Chaoborus* sp.					2	2															
	Family Limoniidae																					
83	*Eriocera* sp.													21								
84	*Pedicia* sp.						2															

No.	Taxon	Sampling sites																				
		CPP	CBS	CNL	CTU	CSN	CSK	CPT	CKT	CMR	CSJ	CKM	CSP	CSU	VSS	VSR	VTR	VCT	VLX	VCL	VTC	VCD
	Family Chironomidae																					
85	*Ablabesmyia* sp.		6	3		2	39	26		3	2		15	8		77	2	2	5		1	50
86	*Chironomus* sp.	2			7									2	2		4				1	
87	*Microtendipes* sp.														14							
88	*Parachironomus* sp.																	4				
89	*Cryptochironomus* sp.									4		4	9	25		10	7	2	5	1	7	
90	*Goeldichironomus* sp.			12	8			4	7		3		20								2	
91	*Sergentia* sp.				8																	
92	*Cladopelma* sp.		35																67			68
93	*Smittia* sp.														7							
94	*Polypedilum* sp.	5	4	2			12				29	30	10	21	21	3	7		16	4		15
95	Pupa of Chironomidae		1	1								2		1	2				2			0
	Total species	17	22	16	19	16	15	16	14	10	8	8	16	15	7	9	17	18	23	11	19	19
	Individuals/sample	92	258	116	724	358	161	337	123	355	46	50	96	145	47	224	215	106	376	132	275	350

Appendix 4.2. Benthic macroinvertebrates tolerance scores

Order	Family	Taxon	Tolerance score	Total samples
Neveimorpha	Nephthydidae	*Nephthys polybranchia* (Southern)	72	6
Neveimorpha	Nereidae	*Namalycastis longicirris* (Takahasi)	94	2
Neveimorpha	Nereidae	*Namalycastis abiuma* Muller	74	28
Neveimorpha	Nereidae	*Neanthes caudata* (Delle Chiaje)	82	1
Spiomorpha	Ariciidae	*Scoloplos* sp.	72	2
Spiomorpha	Spionidae	*Prionospio* sp.	85	6
Spiomorpha	Spionidae	*Polydora* sp.	77	15
Oligochaeta	Naididae	*Pristina* sp.	8	3
Oligochaeta	Naididae	*Chaetogaster* sp.	0	1
Oligochaeta	Naididae	Genus sp.	26	104
Oligochaeta	Tubificidae	*Limnodrilus hoffmeisteri* Claparede	58	155
Oligochaeta	Tubificidae	*Branchiura sowerbyi* Beddard	52	167
Gastropoda	Family	Genus sp.	0	3
Archaeogastropoda	Neritidae	*Neritina rubida* (Pease)	43	14
Mesogastropda	Stenothyiidae	*Stenothyra mcmulleni* Brandt	27	34
Mesogastropda	Stenothyiidae	*Stenothyra koratensis holosculpta* Brandt	53	68
Mesogastropda	Stenothyiidae	*Stenothyra koratensis koratensis* Brandt	95	1
Mesogastropda	Stenothyiidae	*Stenothyra jiraponi* Brandt	25	1
Mesogastropda	Stenothyiidae	*Stenothyra labiata* Brandt	19	8
Mesogastropda	Stenothyiidae	*Stenothyra* sp.	57	2
Mesogastropda	Hydrobiidae	*Pachydrobia* sp.	41	26
Mesogastropda	Hydrobiidae	*Hubendickia crooki* Brandt	25	18
Mesogastropda	Hydrobiidae	*Hubendickia* sp.	28	2
Mesogastropda	Hydrobiidae	*Hydrorissoia* sp.	21	4
Mesogastropda	Hydrobiidae	*Paraprososthnia levayi* (Bavay)	38	9
Mesogastropda	Hydrobiidae	*Paraprososthnia* sp.	22	8
Mesogastropda	Hydrobiidae	*Jullienia acuta* Poirier	7	1
Mesogastropda	Viviparidae	*Filopaludian (Filopaludina) filosa* (Reeve)	49	7
Mesogastropda	Viviparidae	*Filopaludina (Filopaludina) doliaris* (Gould)	51	2
Mesogastropda	Viviparidae	*Mekongia swainsoni breueri* (Kobelt)	46	5
Mesogastropda	Viviparidae	*Mekongia swainsoni flavida* n. ssp.	60	22
Mesogastropda	Viviparidae	*Angulyara* sp.	52	8
Mesogastropda	Bythiniidae	*Bithynia* sp.	31	37
Mesogastropda	Bythiniidae	*Wattebledia siamensis* (Moellendorff)	5	1
Mesogastropda	Fluminicolidae	*Genus* sp.	11	4
Mesogastropda	Thiaridae	*Thiara scabra* (Muller)	27	4
Mesogastropda	Thiaridae	*Sermyla tornatella* (Lea)	57	48
Mesogastropda	Thiaridae	*Tarebia granifera* (Lamarck)	25	2
Mesogastropda	Thiaridae	*Melanoides tuberculatus* (Muller)	45	13
Mesogastropda	Assimineidae	*Cyclotropis* sp. (Assimineidae)	62	12
Neogastropoda	Pyramidellidae	*Morrisonietta spiralis* Brandt	29	3
Neogastropoda	Pyramidellidae	*Morrisonietta* sp.	38	5
Neogastropoda	Planorbidae	*Gyraulus* sp.	27	3
Neogastropoda	Lymnaeidae	*Lymnaea viridis* Quoy et Gaimard	19	1
Neogastropoda	Lymnaeidae	*Lymnaea* sp.	6	1
Arcoida	Arcidae	*Scaphula pinna* Benson	70	5
Mytiloida	Mytilidae	*Limnoperna siamensis* (Morelet)	64	23
Veneroida	Dreissenidae	*Sinomytilus harmandi* (Rochebrune)	64	28

Order	Family	Taxon	Tolerance score	Total samples
Veneroida	Corbiculidae	*Corbicula lamarckiana* Prime	34	51
Veneroida	Corbiculidae	*Corbicula leviuscula* Prime	55	23
Veneroida	Corbiculidae	*Corbicula tenuis* Clessin	46	247
Veneroida	Corbiculidae	*Corbicula baudoni* Morlet	69	23
Veneroida	Corbiculidae	*Corbicula moreteliana* Prime	67	26
Veneroida	Corbiculidae	*Corbicula cyreniformis* Prime	64	34
Veneroida	Corbiculidae	*Corbicula blandiana* Prime	55	76
Veneroida	Corbiculidae	*Corbicula arata* (Sowerby)	21	2
Veneroida	Pisidiidae	*Afropisidium clarkeanum* (Nevill)	24	3
Unionoida	Amblemidae	*Hyriopsis (Hyriopsis) bialatus* Simpson	43	1
Unionoida	Amblemidae	*Hyriopsis (Limnoscapha) desowitzi*	25	1
Unionoida	Amblemidae	*Ensidens ingallsianus ingallsianus* (Lea)	56	10
Unionoida	Amblemidae	*Pseudodon vondembuschianus ellipticus* (Conrad)	50	1
Unionoida	Amblemidae	*Pseudodon inoscularis cumingi* (Lea)	50	1
Unionoida	Amblemidae	*Pseudodon cambodjensis cambodjensis* (Petit)	56	3
Unionoida	Amblemidae	*Uniandra contradens ascia* (Hanley)	43	8
Unionoida	Amblemidae	*Uniandra* sp.	25	3
Unionoida	Amblemidae	*Pilsbryoconcha exilis compressa* (Martens)	43	2
Unionoida	Amblemidae	*Pilbryoconcha lemeslei* (Morelet)	76	2
Unionoida	Amblemidae	*Pilsbryoconcha exilis exilis* (Lea)	59	1
Unionoida	Amblemidae	*Physunio cambodiensis* (Lea)	29	4
Unionoida	Amblemidae	*Physunio micropterus* (Morelet)	84	1
Unionoida	Amblemidae	*Scabies* sp.	50	1
Unionoida	Amblemidae	*Trapezoidens exolescens comptus* (Deshayes)	59	3
Amphipoda	Gammaridae	*Melita* sp.	75	49
Amphipoda	Oedicerotidae	*Perioculodes* sp.	62	11
Amphipoda	Corophiidae	*Corophium* sp.	68	11
Amphipoda	Corophiidae	*Kamaka* sp.	79	18
Amphipoda	Corophiidae	*Grandidierella lignorum* Barnard	66	18
Amphipoda	Corophiidae	*Grandidierella vietnamica* Dang	75	20
Isopoda	Corallanidae	*Tachaea chinensis* Thielemann	6	1
Isopoda	Anthuridae	*Cyathura trucata* Dang	70	35
Tanaidacea	Apseudidae	*Apseudes vietnamensis* Dang	82	2
Cumacae	Family	Genus sp.	82	1
Decapoda	Palaemonidae	*Macrobrachium pilimanus* (De Man)	35	3
Decapoda	Atyidae	*Caridina nilotica* Roux	33	3
Decapoda	Atyidae	*Caridina* sp.	6	1
Decapoda	Alpheidae	*Alpheus bisincisus* (De Man)	82	1
Ephemeroptera	Baetidae	*Cloeon* sp.	20	13
Ephemeroptera	Baetidae	*Baetis* sp.	30	19
Ephemeroptera	Baetidae	*Centroptilum* sp.	23	11
Ephemeroptera	Caenidae	*Caenis* sp.	33	64
Ephemeroptera	Heptageniidae	*Heptagenia* sp.	29	3
Ephemeroptera	Heptageniidae	Genus sp.	0	1
Ephemeroptera	Heptageniidae	*Epeorus* sp.	0	1
Ephemeroptera	Leptoplebiidae	*Leptophlebia* sp.	27	10
Ephemeroptera	Leptoplebiidae	*Traverella* sp.	22	2
Ephemeroptera	Leptoplebiidae	*Choroterpes* sp.	19	2
Ephemeroptera	Ephemeridae	*Ephemera* sp.	30	48
Ephemeroptera	Ephemeridae	*Afromera* sp.	32	12
Ephemeroptera	Ephemeridae	*Hexagenia* sp.	61	1

Order	Family	Taxon	Tolerance score	Total samples
Ephemeroptera	Ephemeridae	*Eatonigenia* sp.	50	11
Ephemeroptera	Palingeniidae	*Pentagenia* sp.	46	55
Ephemeroptera	Palingeniidae	Genus sp.	33	13
Ephemeroptera	Potamanthidae	*Potamanthus* sp.	20	6
Ephemeroptera	Behningiidae	Genus sp.	64	1
Plecoptera	Perlidae	*Perla* sp.	22	10
Odonata	Agrionidae	*Agrion* sp.	6	1
Odonata	Aeschnidae	*Aeschna* sp.	0	1
Odonata	Calopterygidae	*Calopteryx* sp.	28	2
Odonata	Gomphidae	*Gomphus* sp.	32	33
Odonata	Gomphidae	*Dromogomphus* sp.	31	40
Odonata	Gomphidae	*Octogomphus* sp.	14	6
Odonata	Gomphidae	*Progomphus* sp.	22	5
Odonata	Gomphidae	*Aphylla* sp.	23	17
Odonata	Libellulidae	*Libellula* sp.	11	2
Odonata	Libellulidae	*Macromia* sp.	23	6
Hemiptera	Corixidae	*Corixa* sp.	36	9
Hemiptera	Naucoridae	*Naucoris* sp.	28	12
Coleoptera	Gerridae	Genus sp.	0	1
Coleoptera	Elmidae	*Heterlimnius* sp.	19	23
Coleoptera	Hygrobiidae	*Hyphydrus* sp.	13	2
Coleoptera	Dolichopodidae	*Hydrophorus* sp.	47	1
Coleoptera	Haplidae	Genus sp.	63	1
Coleoptera	Elmidae	Genus sp.	35	15
Coleoptera	Dytiscidae	Genus sp.	5	1
Coleoptera	Staphilinidae	*Bledius* sp.	44	1
Trichoptera	Rhyacophilidae	*Rhyacophila* sp.	17	3
Trichoptera	Hydroptilidae	*Oxyethira* sp.	25	1
Trichoptera	Hydroptilidae	*Agraylea* sp.	75	1
Trichoptera	Hydroptilidae	Genus sp.	43	1
Trichoptera	Ecnomidae	*Economus* sp.	29	16
Trichoptera	Psychomyiidae	Genus sp.	50	32
Trichoptera	Philopotamidae	Genus sp.	42	53
Trichoptera	Hydropsychidae	*Hydropsyche* sp.	25	5
Trichoptera	Hydropsychidae	*Macronema* sp.	19	1
Trichoptera	Sialidae	*Sialis* sp.	6	1
Trichoptera	Crambidae	Genus sp.	7	1
Trichoptera	Pyralidae	Genus sp.	0	2
Diptera	Heleidae	*Culicoides* sp.	39	71
Diptera	Chaoboridae	*Chaoborus* sp.	42	4
Diptera	Limoniidae	*Eriocera* sp.	29	40
Diptera	Limoniidae	*Pedicia* sp.	50	1
Diptera	Tipulidae	*Antoncha* sp.	31	9
Diptera	Tipulidae	Genus sp.	14	4
Diptera	Tabanidae	*Chrysops* sp.	0	1
Diptera	Tabanidae	*Tabanus* sp.	56	1
Diptera	Chironomidae	*Ablabesmyia* sp.	34	223
Diptera	Chironomidae	*Chironomus* sp.	44	52
Diptera	Chironomidae	*Tanytarsus* sp.	25	2
Diptera	Chironomidae	*Clinotanypus* sp.	24	14
Diptera	Chironomidae	*Procladius* sp.	0	5

Order	Family	Taxon	Tolerance score	Total samples
Diptera	Chironomidae	*Microtendipes* sp.	50	4
Diptera	Chironomidae	*Pseudochironomus* sp.	27	14
Diptera	Chironomidae	*Parachironomus* sp.	82	3
Diptera	Chironomidae	*Cryptochironomus* sp.	34	74
Diptera	Chironomidae	*Goeldichironomus* sp.	38	120
Diptera	Chironomidae	*Sergentia* sp.	46	23
Diptera	Chironomidae	*Cladopelma* sp.	71	28
Diptera	Chironomidae	*Smittia* sp.	21	23
Diptera	Chironomidae	*Polypedilum* sp.	35	254
Diptera	Chironomidae	Pupa	38	58

Appendix 4.3. Benthic macroinvertebrates metrics

No.	Year	Site	Site disturbance score	Species richness	Abundance (indvs./m^2)	Species diversity index	Dominance index	ATSPT value
1	2004	LNO	1.00	30	550	2.601	0.700	22
2	2004	LPB	1.28	13	250	1.993	0.642	32
3	2004	LVT	1.78	4	3	1.332	0.600	31
4	2004	LNG	1.50	22	420	2.067	0.552	32
5	2004	LKD	1.43	14	370	1.567	0.546	39
6	2004	LPS	1.57	24	580	2.358	0.730	37
7	2004	TMU	1.71	8	80	1.837	0.759	46
8	2004	TCH	1.86	18	200	1.665	0.422	43
9	2004	TSK	2.13	20	1,220	0.624	0.112	51
10	2004	TKO	1.88	19	310	1.857	0.521	35
11	2004	CPP	2.88	19	510	1.952	0.607	55
12	2004	CTU	2.13	22	460	1.918	0.647	52
13	2004	CPS	2.22	10	80	1.528	0.511	40
14	2004	CSS	1.75	14	30	2.023	0.721	39
15	2004	CSP	1.25	13	80	1.556	0.444	35
16	2004	CKT	1.25	10	70	1.139	0.303	34
17	2004	VTC	2.50	27	2,190	2.150	0.698	62
18	2004	VCD	2.69	30	430	2.539	0.638	57
19	2004	VSS	2.29	2	2	0.637	0.249	45
20	2004	VSP	1.29	19	770	1.084	0.249	38
21	2005	LOU	1.00	22	250	2.159	0.706	33
22	2005	LPB	1.69	10	60	1.887	0.652	33
23	2005	LNK	1.38	31	1020	2.131	0.676	32
24	2005	LMH	1.94	16	130	2.086	0.712	34
25	2005	LMX	1.94	14	40	2.382	0.786	35
26	2005	TMI	2.25	16	260	1.890	0.716	36
27	2005	TMC	1.64	12	180	1.694	0.504	35
28	2005	TKO	1.86	22	120	2.430	0.720	32
29	2005	LKU	1.13	24	160	2.502	0.725	37
30	2005	LKL	1.50	24	250	2.010	0.499	35
31	2005	CMR	1.75	19	200	1.957	0.513	38
32	2005	CSJ	1.50	11	30	1.958	0.615	35
33	2005	CKM	1.50	13	40	2.040	0.759	34
34	2005	CSU	2.13	22	230	2.299	0.669	36
35	2005	CSS	1.75	19	70	2.532	0.830	36
36	2005	CSP	1.13	32	250	2.682	0.813	38
37	2006	CPP	2.89	17	60	2.266	0.772	52
38	2006	CBS (CKL)	2.19	22	170	2.560	0.837	53
39	2006	CNL	1.97	16	80	2.324	0.750	52
40	2006	CTU	2.04	19	480	1.735	0.439	53
41	2006	CSN	2.00	16	240	1.598	0.492	47
42	2006	CSK	2.00	15	110	1.957	0.683	47

No.	Year	Site	Site disturbance score	Species richness	Abundance (indvs./m^2)	Species diversity index	Dominance index	ATSPT value
43	2006	CPT	2.33	16	220	1.711	0.640	46
44	2006	CKT	1.14	14	80	1.860	0.512	31
45	2006	CMR	1.42	10	240	1.494	0.507	45
46	2006	CSJ	1.25	8	30	1.278	0.370	32
47	2006	CKM	1.19	8	30	1.396	0.400	35
48	2006	CSP	1.11	16	60	2.366	0.792	30
49	2006	CSU (CUS)	1.75	15	100	1.920	0.793	39
50	2006	VSS	2.00	7	30	1.437	0.553	34
51	2006	VSR (VSP)	2.00	10	150	1.553	0.647	40
52	2006	VTR (VVL)	2.44	17	140	2.233	0.740	59
53	2006	VCT	2.64	18	70	2.308	0.755	65
54	2006	VLX	2.69	23	250	2.426	0.215	58
55	2006	VCL	1.91	11	90	2.107	0.795	54
56	2006	VTC	2.28	19	180	2.003	0.622	57
57	2006	VCD	2.31	18	230	2.347	0.806	55

Other papers in the MRC Technical Paper series:

MRC Technical Paper No. 1 Status of the Mekong *Pangasianodon hypophthalmus* resources with special reference to the stock shared between Cambodia and Viet Nam.

MRC Technical Paper No. 2 Status of Pangasiid aquaculture in Viet Nam.

MRC Technical Paper No. 3 Mekong giant fish species: on their biology and management.

MRC Technical Paper No. 4 Deep pools as dry season fish habitats in the Mekong Basin.

MRC Technical Paper No. 5 Financial analysis and risk assessment of selected aquaculture and fishery activities in the Mekong Basin.

MRC Technical Paper No. 6 Fisheries in the Lower Mekong Basin: status and perspectives.

MRC Technical Paper No. 7 Freshwater aquaculture in the Lower Mekong Basin.

MRC Technical Paper No. 8 Fish migrations of the Lower Mekong Basin: implications for development, planning and environmental management.

MRC Technical Paper No. 9 The impacts of introductions and stocking of exotic species in the Mekong Basin and polices for their control.

MRC Technical Paper No. 10 Distribution and ecology of some important riverine fish species of the Mekong River Basin.

MRC Technical Paper No. 11 Hydro-acoustic survey of deep pools in the Mekong River of southern Lao PDR and northern Cambodia.

MRC Technical Paper No. 12 Tagging Fish - a case study from the Tonle Sap, Cambodia.

MRC Technical Paper No. 13 Biomonitoring of the lower Mekong River and selected tributaries.

MRC Technical Paper No. 14 Fish Migration Triggers in the Mekong River and other freshwater tropical systems.

MRC Technical Paper No. 15 Diagnostic study of water quality in the Lower Mekong Basin.

MRC Technical Paper No. 16 Fish Consumption and the Yield of Fish and Other Aquatic Animals from the Lower Mekong River Basin.

MRC Technical Paper No. 17 Socio-economics of the fisheries of the lower Songkhram River Basin, northeast Thailand.

MRC Technical Paper No. 18 Yield and value of the wild fishery of rice fields in Battambang Province, near Tonle Sap Lake, Cambodia.

MRC Technical Paper No. 19 An assessment of water quality in the Lower Mekong Basin.

MRC Technical Paper No. 20 Biomonitoring of the lower Mekong River and selected tributaries, 2004–2007

MRC Technical Paper No. 21 Flood situation report, August 2008.

Mekong River Commission
P.O.Box 6101,Vientiane 01000,
Lao PDR.Telephone: (856) 21 263 263 Facsimile: (856) 21 263 264
E-mail: mrcs@mrcmekong.org
Website: www.mrcmekong.org