Mekong River Commission

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

MRC Technical Paper No. 22

July 2009
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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.
Sampling sites and programme

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

Biomonitoring Survey 2005

Sampling site

BDP Sub-area

1. Northern Laos
2. Chiang Rai
3. Nong Khai/Songkhram
4. Central Laos
5. Mun/Chi
6. Southern Laos
7. Se San/Sre Pok/Se Kong
8. Kratie
9. Tonle Sap
10. Delta

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                                      |
|-------------------------------|------|-------|-------------------|-------------------|-----------|-----------|----------------|------------|-------------------------------------------------------------|
| Tonle Sap river at Phnom Penh Port | CPP  | 6/3/06| 491666 (E) 1280205 (N) | 66 460          | 6 460     | 7–8 12   | 5–6 Houses and docks | Houses and docks | Mud; sand; garbage; bamboo sticks; sewage discharge; urban runoff; rubbish disposal; spillage and leakage from docks |
| Bassac at Koh Khel            | CKL  | 7/3/06| 503327 (E) 1246641 (N) | 6 298           | 2 3 298   | 4 7      | 4–8 Villages and gardens; bananas | Villages and gardens | Sand; mud; water hyacinth; agricultural runoff; disposal of human and animal wastes |
| Mekong at Nak Loeung         | CNL  | 8/3/06| 528321 (E) 1250852 (N) | 6 1629          | 8–14 1629 | 3 15     | 4–12 Fields; few houses | Sand banks; fields; villages | Sand; a little mud; filamentous algae; agricultural runoff; disposal of human and animal wastes |
| Site                          | Code | Date      | Coordinates (UTM)               | GPS elevation (m) | Width (m) | Depth (m) | Land use cover                                                                 | Substratum                      | Potential human impacts                                      |
|------------------------------|------|-----------|---------------------------------|------------------|-----------|-----------|---------------------------------------------------------------------------------|---------------------|-------------------------------------------------------------|
| Tonle Sap river at Prek Kdam | CTU  | 9/3/06    | 478364 (E) 1307071 (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; L – Mud; debris; a little sand Human wastes; urban runoff; rubbish disposal; fish farming |
| Stoeng Sen                    | CSN  | 10/3/06   | 490998 (E) 1401845 (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 Agricultural runoff; disposal of human and animal wastes; bank erosion |
| Stoeng Sangke                 | CSK  | 11/3/06   | 348375 (E) 1465699 (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 | R – Mud; little 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)          |                  | 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 | 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 |
|-------------------------------------|------|----------|-------------------|------------------|-----------|-----------|----------------|------------|------------------------|
| 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 |
|                                     |      |          |                   |                  |           |           | L M R           |            |                        |                        | Bank erosion               |
|                                     |      |          |                   |                  |           |           | Left bank       |            |                        |                        | M – Sand; rock; algae     |
|                                     |      |          |                   |                  |           |           | Right bank      |            |                        |                        | L – Sand; rock; algae     |
|                                     |      |          |                   |                  |           |           | Littoral        |            |                        |                        |                        |
|                                     |      |          |                   |                  |           |           | Channel         |            |                        |                        |                        |
| 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 |
|                                     |      |          |                   |                  |           |           | L M R           |            |                        |                        | Disposal of human and animal wastes; livestock damage to banks; bank erosion |
|                                     |      |          |                   |                  |           |           | Left bank       |            |                        |                        | M – Sand; little debris   |
|                                     |      |          |                   |                  |           |           | Right bank      |            |                        |                        | L – Sand; debris           |
|                                     |      |          |                   |                  |           |           | Littoral        |            |                        |                        |                        |
|                                     |      |          |                   |                  |           |           | Channel         |            |                        |                        |                        |
| 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 |
|                                     |      |          |                   |                  |           |           | L M R           |            |                        |                        | Livestock damage to banks; bank erosion |
|                                     |      |          |                   |                  |           |           | Left bank       |            |                        |                        | M – Rock; cobbles; sand   |
|                                     |      |          |                   |                  |           |           | Right bank      |            |                        |                        | L – Sand; rock; little debris |
|                                     |      |          |                   |                  |           |           | Littoral        |            |                        |                        |                        |
|                                     |      |          |                   |                  |           |           | Channel         |            |                        |                        |                        |
| Lower Se Kong                       | CKM  | 16/3/06  | 615508 (E) 1500032 (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 | Livestock damage to banks; bank erosion |
|                                     |      |          |                   |                  |           |           | L M R           |            |                        |                        | M – Rock                  |
|                                     |      |          |                   |                  |           |           | Left bank       |            |                        |                        | L – Sand; mud; debris     |
|                                     |      |          |                   |                  |           |           | Right bank      |            |                        |                        |                        |
|                                     |      |          |                   |                  |           |           | Littoral        |            |                        |                        |                        |
|                                     |      |          |                   |                  |           |           | Channel         |            |                        |                        |                        |
| Site                  | Code | Date    | Coordinates (UTM)                  | GPS elevation (m) | Width (m) | Depth (m) | Land use cover                                      | Substratum                                      | Potential human impacts                                      |
|----------------------|------|---------|------------------------------------|-------------------|-----------|-----------|---------------------------------------------------|--------------------------------------------------|-------------------------------------------------------------|
| Lumphat              | CSP  | 18/3/06 | 717424 (E) 1490804 (N)             | 98-102            | 200       | 1.7 2.8   | Forest, small scale agriculture; ferry crossing   | Bedrock and cobble, with many small channels     | Some agricultural influences and small boat traffic; sewage from village |
| Pam Pi (Se San at border) | CUS  | 19/3/06 | 764506 (E) 1526065 (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                                                           |
| Upper Se San VSS     | 20/3/06 | 180527 (E) 180585 (E) 1588158 (N) | 527               | 167       | 0.5       | 1.5       | Bamboo bush; banana fields; island with farming in centre of site | Sand extraction; banana; housing                 | Cobble and gravel                                           |
| Upper Sre Pok VSP    | 21/3/06 | 817329 (E) 817731 (E) 1396950 (N) | 298-312           | 93-106   | 2         | 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                           |

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| Site            | Code | Date     | Coordinates (UTM) | GPS elevation (m) | Width (m) | Depth (m) | Land use cover                      | Substratum                  | Potential human impacts            |
|-----------------|------|----------|-------------------|------------------|-----------|-----------|------------------------------------|----------------------------|------------------------------------|
| Vinh Long       | VVL  | 23/3/06  | 603976 (E) 1135759 (N) | 603576 (E) 1134724 (N) | 4-9       | 1064-1070 | 5.2          | Housing; fish farms; water hyacinth | Mud; debris                  | Navigation; sand collection; agriculture; sewage; erosion; fishing |
|                 |      |          |                    |                  |           |           | 4.8          | Few trees; agriculture of cashew and fruit crops |                            | M – Sand                           |
|                 |      |          |                    |                  |           |           | 2           |                                | M – Sand; organic material     |                                    |
|                 |      |          |                    |                  |           |           |             |                                | L – Mud; organic debris        |                                    |
| Can Tho (Bassac)| VCT  | 24/3/06  | 588365 (E) 1110673 (N) | 587117 (E) 1110902 (N) | 7-10      | 872       | 3.2          | Agricultural; fruit trees         | Hard mud                      | Navigation; bridge construction; sewage treatment plant construction |
|                 |      |          |                    |                  |           |           | 6.9          |                                | M – Sand; mud; some organic matter |                                    |
|                 |      |          |                    |                  |           |           | 3           |                                | L – Clay; sand; mud; some organic matter |                                    |
| Long Xuyen      | VLX  | 25/3/06  | 551878 (E) 1143546 (N) | 551925 (E) 1144518 (N) | 7         | 662       | 6.9-7        | Navigation; Agriculture along bank; Eroding shoreline; Banana; mango; papaya; cassava Construction of bridge; Increasing siltation; Very strong flow; Sewage and waste from factories | Mud from erosion | R – Mud; clay; organic material; debris | Agriculture; construction; bank erosion |
|                 |      |          |                    |                  |           |           | 7.2-7.7     |                                | M – Soil                        |                                    |
|                 |      |          |                    |                  |           |           | 7.2-7.4     |                                | L – Mud; soil; clay            |                                    |
| Site     | Code | Date     | Coordinates (UTM)                  | GPS elevation (m) | Width (m) | Depth (m) | Land use cover | Substratum | Potential human impacts |
|----------|------|----------|-----------------------------------|-------------------|-----------|-----------|----------------|------------|------------------------|
|          |      |          |                                   |                   |           |           |                |            |                        |
|          |      |          |                                   |                   |           |           |                |            |                        |
|          |      |          |                                   |                   |           |           |                |            |                        |
| Cao Lanh | VCL  | 26/3/06  | 563807 (E) 564116 (E)             | 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 Navigation especially on the right bank; erosion on right bank (from agriculture and navigation) |
| Tan Cha  | VTC  | 27/3/06  | 524259 (E) 524706 (E)             | 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 Agriculture; navigation; domestic waste |
| Cha Doc  | VCD  | 28/3/06  | 510969 (E) 510829 (E)             | 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 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 example1 on the calculations is given in figure 3.1.

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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     |
| Taxon A   | 1     | 196   | 8     | 1     | 149   | 45    | 1     | 18    | 7     |
| Taxon B   | 2     | 1     | 1     | 2     | 1     | 2     | 3     | 2     |       |
| Taxon C   | 2     | 1     | 3     | 1     | 1     | 5     | 42    | 38    | 78    |

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.

**Example Calculation**
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.

- **Step 1:** Calculation of SDS for each site
  - Eight participants gave the following scores:
  - for Site 1: 1, 1, 1, 1, 1, 1, 1, 1
  - for Site 2: 1, 1, 2, 1, 1, 1, 2
  - for Site 3: 1, 1, 2, 1, 2, 2, 2, 3
  - for Site 4: 3, 3, 3, 3, 3, 2, 3, 3

  \[
  \text{SDS1} = \frac{1+1+1+1+1+1+1+1}{8} = 1.00 \\
  \text{SDS2} = \frac{1+1+2+1+1+1+1+2}{8} = 1.25 \\
  \text{SDS3} = \frac{1+1+2+1+2+2+2+3}{8} = 1.75 \\
  \text{SDS4} = \frac{3+3+3+3+3+2+3+3}{8} = 2.88
  \]

  This is calculated as the average of the SDSs for all samples in which the particular taxon was collected.

**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.

- **Step 2:** Calculation of the Tolerance Score for each taxon
  - Taxon A was found in: 1, 3, 2, 3 samples from Sites 1, 2, 3, 4 respectively.
  - Taxon B was found in: 2, 3, 3, 0 samples from Sites 1, 2, 3, 4 respectively.
  - Taxon C was found in: 2, 2, 2, 3 samples from Sites 1, 2, 3, 4 respectively.

  The tolerance score of taxon A would be:
  \[
  \frac{(1.00*1+1.25*3+1.75*2+2.88*3)}{(1+3+2+3)} = 1.88
  \]

  The tolerance score of taxon B would be:
  \[
  \frac{(1.00*2+1.25*2+1.75*3+2.88*0)}{(2+2+3+0)} = 1.38
  \]

  The tolerance score of taxon C would be:
  \[
  \frac{(1.00*2+1.25*2+1.75*2+2.88*3)}{(2+2+2+3)} = 1.85
  \]

**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.

- **Step 3:** Re-scaling of Tolerance Scores
  - 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) = \((1.88-1.00)\times50 = 43.75\)

  Re-scaling of Tolerance Score (taxon B) = \((1.38-1.00)\times50 = 18.75\)

  Re-scaling of Tolerance Score (taxon C) = \((1.85-1.00)\times50 = 43.36\)

**Step 4:** Calculation of the Average Tolerance Score Per Taxon for each individual sample from a site

- **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
    \[
    \frac{(43.75*0+18.75*1+42.36*0)/(0+1+0)} = 18.75 \\
    \frac{(43.75*0+18.75*1+42.36*1)/(0+1+1)} = 30.56
    \]
  - Site 1, sample 3: taxa A, C were found
    \[
    \frac{(43.75*1+18.75*0+42.36*1)/(1+0+1)} = 43.06 \\
    \frac{(43.75*1+18.75*1+42.36*0)/(1+1+1)} = 34.95
    \]
  - Site 2, sample 2: taxa A, B were found
    \[
    \frac{(43.75*1+18.75*1+42.36*1)/(1+1+1)} = 34.95 \\
    \frac{(43.75*1+18.75*0+42.36*0)/(0+1+1)} = 31.25
    \]
  - Site 3, sample 1: taxa A, B, C were found
    \[
    \frac{(43.75*1+18.75*1+42.36*0)/(1+1+0)} = 43.06 \\
    \frac{(43.75*1+18.75*0+42.36*1)/(0+1+1)} = 39.50
    \]

- **Step 5:** Calculation of the mean Average Tolerance Score Per Taxon for each site

  \[
  \text{ATSPT for Site 1} = \frac{18.75+30.56+43.06}{3} = 30.79 \\
  \text{ATSPT for Site 2} = \frac{34.95+31.25+43.06}{3} = 33.72 \\
  \text{ATSPT for Site 3} = \frac{34.95+31.25+30.56}{3} = 32.25 \\
  \text{ATSPT for Site 4} = \frac{43.06+43.06+43.06}{3} = 43.06
  \]

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 29.6°C (±1.4°C). 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.](image)

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 cm², 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 cm² 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 (H₂SO₄, HCl or HNO₃) was added and the tubes were heated in a boiler (70–80 °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:
\[ H' = \sum_{i=1}^{s} p_i \log(p_i) \]

where \( p_i \) 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):

\[ D = 1 - \frac{N_{\text{max}}}{N} \]

where \( N_{\text{max}} \) 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 cm² 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/cm² at the 2006 sites (Table 5.1). The highest abundance occurred at site CPP (377 cells/cm²), 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/cm²).

Table 5.1. Diatom metrics for 2006.

| Site | No. of species | Density (cell/cm²) |
|------|----------------|-------------------|
| 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.

![ATSPT Regression](image)

**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
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 R² 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 (ATSP) was calculated for each sample, and then averaged over all samples in each sampling event for 2004–2006. The ATSP 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), Eurotatoria, Protozoa and larvae (Table 6.1). Eurotatoria had the most taxa (30 genera and 12 families comprising 58.7% of the total zooplankton taxa collected). The Brachionidae (Eurotatoria), Difflugiidae (Protozoa) and Lecanidae (Eurotatoria) 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).

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

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

Eurotatoria, 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), *Polycarpa vulgaris* (Eurotatoria: Synchaetidae), *Philodina roseola* (Eurotatoria: Philodinidae), and *Thermocyclops hyalinus* (Crustacea: Cyclopidae) also had a wide distribution and occurred at 16–19 sites. The fauna was dominated by the Eurotatoria (families Synchaetidae, Brachionidae, Hexathridae) and Protozoa (families Arcellidae, Centropyxidae, Diffugidae).

**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 Eurotatareata 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 | 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 Diffugidae (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](image)

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
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](image)

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\textsuperscript{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 | Accella | Basommatophora | Coleoptera | Decapoda | Diptera | Ephemeroptera | Hemiptera | Lepidoptera | Megaloptera | Mysida | Nematoda | Nostocystidea | Odonata | Oligochaeta | Polychaeta | Plecoptera | Sphaeromatidae | Trichoptera | Uncaria | Venerida | Total taxa |
|------|-----------|---------|----------------|------------|----------|---------|---------------|-----------|-------------|-------------|--------|----------|---------------|---------|-------------|-----------|-------------|----------------|--------------|---------|--------|-----------|
| CPP  | 0         | 0       | 0              | 3          | 0        | 0       | 1             | 0         | 0           | 0           | 0      | 0        | 0              | 0       | 0           | 0         | 0           | 0              | 1            | 0       | 0      | 7         |
| CBS  | 0         | 1       | 0              | 0          | 2        | 2       | 2             | 0         | 0           | 4           | 1      | 0        | 1              | 0       | 1           | 2         | 1           | 0              | 1            | 4       | 1      | 24        |
| CNL  | 0         | 0       | 0              | 0          | 2        | 2       | 2             | 1          | 0           | 7           | 1      | 0        | 0              | 0       | 0           | 0         | 0           | 0              | 1            | 1       | 1      | 18        |
| CTU  | 0         | 1       | 0              | 0          | 2        | 1       | 0             | 1          | 0           | 4           | 0      | 0        | 1              | 0       | 0           | 1         | 0           | 1              | 0            | 0       | 1      | 12        |
| CSN  | 0         | 0       | 0              | 0          | 2        | 1       | 0             | 1          | 0           | 5           | 1      | 0        | 1              | 1       | 1           | 0         | 0           | 0              | 1            | 1       | 5      | 15        |
| CSK  | 0         | 0       | 0              | 0          | 3        | 1       | 0             | 1          | 0           | 4           | 0      | 0        | 0              | 0       | 0           | 0         | 0           | 0              | 0            | 0       | 0      | 9         |
| CPT  | 0         | 0       | 0              | 0          | 2        | 2       | 0             | 2          | 0           | 6           | 0      | 0        | 1              | 2       | 1           | 0         | 0           | 0              | 2            | 1       | 1      | 19        |
| CKT* | 0         | 0       | 1              | 1          | 0        | 4       | 3             | 8          | 3           | 0           | 8      | 0        | 1              | 3       | 1           | 0         | 0           | 3              | 0            | 1       | 3      | 37        |
| CMR* | 0         | 0       | 1              | 1          | 0        | 5       | 2             | 3          | 2           | 0           | 11     | 0        | 0              | 1       | 0           | 1         | 0           | 0              | 1            | 0       | 0      | 28        |
| CSJ* | 0         | 0       | 0              | 5          | 0        | 2       | 5             | 15         | 5           | 0           | 7      | 0        | 1              | 1       | 6           | 1         | 1           | 0              | 9            | 0       | 1      | 59        |
| CKM* | 0         | 0       | 0              | 1          | 0        | 6       | 3             | 13         | 4           | 1           | 0      | 7        | 0              | 0       | 4           | 0         | 1           | 0              | 12           | 1       | 0      | 53        |
| CSP* | 0         | 0       | 0              | 7          | 0        | 4       | 8             | 14         | 7           | 1           | 1      | 2        | 0              | 0       | 6           | 1         | 2           | 0              | 19           | 0       | 1      | 73        |
| CSU* | 0         | 0       | 0              | 3          | 0        | 2       | 1             | 11         | 7           | 1           | 0      | 0        | 0              | 0       | 1           | 0         | 1           | 0              | 4            | 0       | 1      | 33        |
| VSS* | 0         | 0       | 0              | 2          | 0        | 3       | 5             | 15         | 6           | 2           | 1      | 0        | 0              | 0       | 6           | 1         | 1           | 0              | 10           | 0       | 1      | 53        |
| VSR* | 0         | 0       | 0              | 4          | 0        | 2       | 4             | 13         | 11          | 0           | 0      | 1        | 0              | 0       | 1           | 5         | 0           | 0              | 6            | 0       | 1      | 48        |
| VTR  | 0         | 1       | 0              | 0          | 4       | 0       | 1             | 0          | 2           | 0           | 0      | 4        | 0              | 0       | 1           | 1         | 0           | 0              | 1            | 0       | 0      | 16        |
| VCT  | 0         | 1       | 0              | 0          | 1       | 1       | 0             | 2          | 0           | 0           | 0      | 0        | 0              | 0       | 1           | 0         | 1           | 0              | 0            | 0       | 8      | 8         |
| VLX  | 1         | 0       | 0              | 0          | 2       | 1       | 1             | 1          | 0           | 0           | 2      | 0        | 0              | 1       | 2           | 1         | 0           | 0              | 1            | 0       | 1      | 14        |
| VCL  | 0         | 0       | 0              | 0          | 2       | 1       | 2             | 0          | 0           | 3           | 1      | 0        | 1              | 0       | 1           | 0         | 1           | 0              | 1            | 0       | 1      | 15        |
| VTC  | 0         | 0       | 0              | 0          | 2       | 0       | 0             | 1          | 0           | 0           | 0      | 0        | 0              | 0       | 0           | 0         | 0           | 0              | 0            | 0       | 3      | 3         |
| VCD  | 0         | 0       | 0              | 0          | 1       | 1       | 3             | 1          | 2           | 0           | 3      | 0        | 0              | 1       | 1           | 1         | 0           | 1              | 0            | 0       | 0      | 16        |

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.
Littoral macroinvertebrates

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 | Ascocerida | Bristlemayida | Collembola | Coleoptera | Decapoda | Diptera | Ephemeroptera | Hemiptera | Heteroptera | Hydroptilida | Megaloptera | Mesogastropoda | Mollusca | Nematoda | Neogastropoda | Nematode | Notonectida | Odonata | Polyphemida | Pycroderida | Sphaeromatidae | Trichoptera | Urobrachida | Venerida | Zoarcida | Total |
|------|-----------|------------|--------------|------------|------------|----------|---------|----------------|-----------|-------------|------------|-------------|----------------|-----------|-------------|---------------|---------|-------------|----------|-------------|------------|----------------|-------------|-------------|--------|---------------|-------|
| CPP  | 0         | 0          | 0            | 0          | 0          | 47       | 0       | 0              | 0         | 0           | 0          | 0           | 0               | 0         | 0           | 0              | 0       | 0           | 0        | 0           | 0          | 0              | 0         | 0           | 0      | 0             | 55     |
| CBS  | 0         | 6          | 0            | 0          | 68         | 10       | 66      | 561            | 0         | 0           | 46         | 2           | 0               | 4         | 422         | 10             | 0       | 0           | 2         | 0           | 18         | 2             | 82       |
| CNL  | 0         | 0          | 0            | 0          | 12         | 21       | 110     | 50             | 0         | 0           | 543        | 3           | 0               | 0         | 0           | 0              | 0       | 0           | 2         | 8           | 69         | 828           |
| CTU  | 0         | 1          | 0            | 0          | 24         | 2        | 0       | 1              | 0         | 0           | 7          | 0           | 3               | 0         | 0           | 4              | 4       | 0           | 0         | 0           | 8          | 54             |
| CSN  | 0         | 0          | 0            | 0          | 36         | 18       | 0       | 89             | 0         | 0           | 427        | 1           | 0               | 1         | 11          | 1              | 0       | 0           | 0         | 11          | 42         | 627           |
| CSK  | 0         | 0          | 0            | 0          | 388        | 1        | 0       | 63             | 0         | 0           | 9          | 0           | 0               | 0         | 0           | 0              | 0       | 0           | 0         | 0           | 0          | 461           |
| CPT  | 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          | 50         | 34       | 77      | 18             | 0         | 5           | 514        | 0           | 0               | 5         | 21          | 16             | 0       | 0           | 8         | 0           | 2         | 795           |
| CMK  | 0         | 0          | 82           | 2          | 0          | 942      | 3       | 20             | 25        | 0           | 947        | 0           | 0               | 2         | 0           | 11             | 0       | 0           | 1         | 0           | 0         | 2062          |
| CSJ  | 0         | 0          | 0            | 19         | 0          | 14       | 39      | 268            | 13        | 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           | 40         | 0           | 0               | 7         | 0           | 1              | 0       | 0           | 5         | 0           | 51         | 1              | 465      |
| CSP  | 0         | 0          | 0            | 19         | 0          | 13       | 116     | 507            | 95        | 1           | 116         | 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               | 1         | 0           | 1              | 0       | 1           | 1         | 1           | 8          | 0              | 4690     |
| VSS  | 0         | 0          | 0            | 7          | 0          | 17       | 106     | 289            | 15        | 3           | 1           | 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               | 1         | 13          | 0              | 0       | 0           | 0         | 22          | 0         | 9              | 690      |
| VTR  | 0         | 3          | 0            | 0          | 101        | 11       | 0       | 96             | 0         | 0           | 11         | 0           | 0               | 26        | 1           | 0              | 0       | 4           | 0         | 4           | 0         | 0              | 16       |
| VCT  | 0         | 1          | 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          | 119        | 7        | 1       | 7              | 0         | 0           | 2          | 0           | 1               | 4         | 1           | 0              | 0       | 2           | 0         | 0           | 2         | 0              | 148      |
| VCL  | 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          | 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               | 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.](image)

**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).
Littoral macroinvertebrates

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](image)

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 m². 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 r² 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.

| 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        | 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, Tubificidae); 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/m². As with numbers of taxa, the highest abundances occurred at sites with muddy and debris substrata such as CTU (480 indiv./m²), while the lowest abundances occurred at sites with sandy and rocky substrata, such as sites CSJ, CKM and VSS (30 indiv./m²) (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| 10-100 | 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 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](image1.png)  
**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](image2.png)  
**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.

|                  | 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.
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).

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

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

| Year | 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 | VLY   | 52      | 49          | 42                                          | 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.

| Site | Diatoms 2004 | Diatoms 2005 | Diatoms 2006 | Zooplankton 2004 | Zooplankton 2005 | Zooplankton 2006 |
|------|--------------|--------------|--------------|------------------|------------------|------------------|
| LPB  | 36           | 38           | -            | LPB              | 33               | 41               |
| CPP  | 45           | -            | 51           | CPP              | 53               | -                |
| CTU  | 42           | -            | 49           | CTU              | 49               | -                |
| CSS  | 37           | 36           | -            | CSS              | 43               | 36               |
| CSP  | 39           | 28           | 36           | CSP              | 43               | 40               |
| CKT  | 34           | -            | 39           | CKT              | 41               | -                |
| CMR  | -            | 33           | 35           | CMR              | -                | 37               |
| CSJ  | -            | 33           | 36           | CSJ              | -                | 38               |
| CKM  | -            | 33           | 37           | CKM              | -                | 39               |
| CSU  | -            | 36           | 39           | CSU              | -                | 38               |
| TKO  | 41           | 40           | -            | TKO              | 41               | 42               |
| VTC  | 41           | -            | 47           | VTC              | 50               | -                |
| VCD  | 45           | -            | 50           | VCD              | 49               | -                |

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 | Diatoms | Zooplankton | Littoral Macroinvertebrates | Benthic Macroinvertebrates |
|-----|------|------------------------|---------|-------------|---------------------------|---------------------------|
|     |      |                        |         |             |                           |                           |
| 1   | CKM  | 1.50                   | 33      | 39          | 32                        | 34                        |
| 2   | CKT  | 1.25                   | 1.14    | 39          | 34                        | 32                        |
| 3   | CMR  | 1.75                   | 33      | 37          | 36                        | 38                        |
| 4   | CPP  | 2.88                   | 45      | 53          | 40                        | 55                        |
| 5   | CSJ  | 1.50                   | 33      | 38          | 31                        | 35                        |
| 6   | CSP  | 1.25                   | 39      | 43          | 29                        | 35                        |
| 7   | CSS  | 1.75                   | 37      | 43          | 33                        | 39                        |
| 8   | CSU  | 2.13                   | 36      | 38          | 34                        | 36                        |
| 9   | CTU  | 2.13                   | 42      | 49          | 45                        | 52                        |
| 10  | LNO  | 1.00                   | 29      | 23          | 27                        | 22                        |
| 11  | LPB  | 1.28                   | 36      | 33          | 29                        | 32                        |
| 12  | TKO  | 1.88                   | 40      | 40          | 29                        | 35                        |
| 13  | VCD  | 2.69                   | 45      | 49          | 44                        | 52                        |
| 14  | VTC  | 2.50                   | 41      | 50          | 47                        | 62                        |

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.
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### Appendix 1.1: Diatoms species list and abundance

| No. | Taxon | Sampling sites |
|-----|-------|----------------|
|     |       | CPP | CTU | CKK | CNL | CSN | SK | CPT | CKT | CMR | CSJ | CKM | CSP | CSU | VSS | VSP | VVL | VCT | VLX | VCL | VTC | VCD |
| 1   | *Achnanthes exqui*a 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 lanciscoleta* (Bérbisson) Grunow | 2   | 1   | 67  | 66  | 30  | 2   | 2   | 6   | 29 |
| 6   | *Achnanthes lanciscoleta* 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   |
| 10  | *Amphora* sp. 1 | 23  |     |
| 11  | *Aulacoseira* *granulata* Ehrenberg | 2   | 1   | 13  | 9   | 60  | 5   | 9   | 19  |
| 12  | *Aulacoseira* *mazzanensis* (Meister) Krammer | 21  |     |
| 13  | *Bacillaria paradoxa* Gmelin | 1   | 2   | 1   | 1   |
| 14  | *Caloneis* *silicula* (Ehrenberg) Cleve | 1   | 1   |
| 15  | *Cocconeis pediculatus* Ehrenberg | 2   | 1   | 82  | 193 | 86  | 68  | 52  |
| 16  | *Cyclotella* *siliculosa* Cleve | 88  | 170 |
| 17  | *Cymbella japonica* Reidhert | 1   |     | 41  |
| 18  | *Cymbella* sp. 1 | 171 | 1   | 1   | 117 | 48  | 34  |
| 19  | *Cymbella* sp. 2 | 7   | 249 | 33  | 30  | 66  | 24  |
| No. | Taxon                                                   | Sampling sites |
|-----|--------------------------------------------------------|----------------|
|     |                                                        | CPP | CTU | CKK | CNL | CSN | CKS | CPT | CKT | CMR | CSJ | CKM | CSP | CSU | VSS | VSP | VVL | VCT | VLC | VTC | VCD |
| 20  | *Cymbella tumida* (Brébisson) Van Heurck                |     |     |     |     |     | 4   | 1   | 7   | 4   | 1   | 1   |     |     |     |     |     |     |     |     |     |     |     |
| 21  | *Cymbella turgidula* Grunow                            | 8   | 4   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 22  | *Diploneis elliptica* (Kützing) Cleve                   |     | 1   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 23  | *Encyonema silesiacum* (Bleisch) D.G. Mann             |     | 1   | 1   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 24  | *Encyonema sp.1*                                       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 25  | *Epithemia adnata* (Kützing) Brébisson                 |     | 36  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 26  | *Fragilaria capucina* Désimierès                       |     | 2   | 255 | 106 | 10  | 2   | 31  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 27  | *Geitskera decastir* (Østrup) Lange-Bertalot & Metzeltin | 1   | 6   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 28  | *Geitskera paladona* (Hustedt) Lange-Bertalot & Metzeltin | 1   | 28  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 29  | *Gomphonema augur var. turris* (Ehrenberg) Lange-Bertalot & Metzeltin | 2   | 5   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 30  | *Gomphonema clevei* Fricke                             |     | 580 | 216 | 147 | 125 | 71  | 19  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 31  | *Gomphonema entoileum* Østrup                          |     | 51  | 10  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 32  | *Gomphonema gracile* Ehrenberg                         |     | 29  | 47  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 33  | *Gomphonema parvulum* (Kützing) Grunow                 |     | 65  | 39  | 380 | 138 | 90  | 51  | 218 | 44  | 19  | 51  | 42  | 24  | 34  | 4   | 12  | 13  | 1   |     |     |
| 34  | *Gyrosigma scalpriden* (Rabenhorst) Cleve              | 1   | 1   | 1   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 35  | *Gyrosigma spencerii* (Queckett) Griffith & Herfrey    | 1   | 1   | 1   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 36  | *Luticula goeppertiana* (Bleisch) D.G. Mann            | 594 | 246 | 78  | 105 | 81  | 116 | 3   | 8   | 10  | 12  |     |     |     |     |     |     |     |     |     |     |
| 37  | *Luticula montia* (Hustedt) D.G. Mann                  | 2   | 60  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 38  | *Luticula mutica* (Kützing) D.G. Mann                  | 16  | 0   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| No. | Taxon                                                   | Sampling sites |
|-----|--------------------------------------------------------|----------------|
| 39  | *Luticula nivalis* (Ehrenberg) D.G. Mann              |                |
| 40  | *Melosira varians* Agardh                            |                |
| 41  | *Navicula cryptocephala* Kützing                     |                |
| 42  | *Navicula cryotenella* Kützing                       |                |
| 43  | *Navicula flabellata* MEIST                           |                |
| 44  | *Navicula gastrum* (Ehrenberg) Kützing                |                |
| 45  | *Navicula radiosa* Kützing                            |                |
| 46  | *Navicula symmetrica* Patrick                        |                |
| 47  | *Navicula viridula var. germanii* Wallace Lange-Bertalot |                |
| 48  | *Navicula viridula var. rutilata* (Kützing) Cleve     |                |
| 49  | *Neidium binodis* (Ehrenberg) Hustedt                |                |
| 50  | *Neidium dubium* (Ehrenberg) Cleve                    |                |
| 51  | *Neidium gracile* Hustedt var. aequalis Hustedt      |                |
| 52  | *Nitzschia obtusa* W. Smith                          |                |
| 53  | *Nitzschia calida* Grunow                            |                |
| 54  | *Nitzschia clausii* Hantzsch                         |                |
| 55  | *Nitzschia distipula* (Kützing) Grunow                |                |
| 56  | *Nitzschia frustulam* Kützing                         |                |
| 57  | *Nitzschia levidensis* (W. Smith) Grunow             |                |

Appendix 1. Diatom data
| No. | Taxon                                      | Sampling sites |
|-----|--------------------------------------------|----------------|
| 58  | Nitzschia littoralis Grunow                | 11             |
| 59  | Nitzschia palea (Kützing) W. Smith         | 177 17 14 266 486 285 1010 105 19 428 43 14 10 20 88 258 |
| 60  | Nitzschia pseudofonticola Hustdtt          |                |
| 61  | Nitzschia sp.1                             |                |
| 62  | Nitzschia subacicularis Hustdtt            | 2 1 16 2 1     |
| 63  | Pinnularia braunii (Grunow) Cleve           | 2 2            |
| 64  | Pinnularia diversens var. linearis Østrup   |                |
| 65  | Pinnularia microstauron Ehrenberg          | 59             |
| 66  | Pleurosigma salinarum Grunow               | 1 1            |
| 67  | Pleurosigma laevis (Ehrenberg) Compère     |                |
| 68  | Rhopalodia gibbauda Ehrenberg O. Müller    | 1 88 2 107 222 |
| 69  | Sellaphora amoenae Lange-Bertakot          | 7 2 1          |
| 70  | Sellaphora gibbaula Lange-Bertakot         | 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 robu Leceneq                     | 3 1            |
| 74  | Surirella splendidae Krammer               | 1 2 3          |
| 75  | Synedra ulna (Nitzsch) Ehrenberg          | 7 1 1 6 5 115 7 2 3 |
| 76  | Synedra ulna var. aequalis (Kützing)       | 97             |
|     | Hustdtt                                    |                |
## 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 mazzanensis (Meister)Krammer | 51          | 18            |
| Centrales      | Melosiraceae         | Meloseira varians Agardh         | 45              | 68            |
| Centrales      | Thalassiosiraceae    | Thalassiosira sp.1               | 19              | 12            |
| Pennales       | Achnanthaceae        | Achnanthes biaesolettiana Grunow | 50              | 41            |
| Pennales       | Achnanthaceae        | Achnanthes cremulata Grunow      | 46              | 17            |
| Pennales       | Achnanthaceae        | Achnanthes esiqua var. constricta (Torka) Hustedt | 44            | 2             |
| Pennales       | Achnanthaceae        | Achnanthes frequenstissimun (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. rostrata (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 placenta 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       | Nitzschia 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| Fragilariae| Fragilaria bidens Heiberg                             | 40              | 9             |
| Pennales| Fragilariae| Fragilaria capucina Desmazières                       | 39              | 152           |
| Pennales| Fragilariae| Fragilaria leptostauron (Ehrenberg) Hustedt           | 56              | 1             |
| Pennales| Fragilariae| Fragilaria tenera (W. Smith) Lange-Bertalet          | 25              | 7             |
| Pennales| Fragilariae| Fragilaria ulna var. acus (Kützing) Lange-Bertalot   | 21              | 9             |
| Pennales| Fragilariae| Synedra lanceolata (Kützing) Reichardt                | 43              | 5             |
| Pennales| Fragilariae| Synedra ulna var. aequalis (Kützing) Hustedt          | 34              | 117           |
| Pennales| Fragilariae| 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 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 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| Enchyonema 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| Encyonopsis 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           |
## Appendix 1. Diatom data

| 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 scalpoides (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 gracile 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 gibhula 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    | *Pleurosigma 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 | KLK  | 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  | 1.58                    | 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 | CHS | CNL | CTU | CSN | CSK | CPT | CTM | CSJ | CKM | CSP | CSU | VSS | VSR | VTR | VCT | VLX | VCL | VTC | VCD |
| 1   | *Pseudodiaptomus beieri* Brehm             | 0   | 0   | 3   | 1   | 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   | 1   | 0   | 2   |
| 3   | *Vietodiaptomus hatinhensis* Dang          | 0   | 0   | 1   | 0   | 15  | 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   |
| 5   | *Neodiaptomus visnu* (Brehm)               | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 0   | 0   | 0   | 0   | 0   | 1   | 1   |
| 6   | *Neodiaptomus batalifer* (Kiefer)          | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   |
| 7   | *Ectocyclops phaleratus* (Koch)            | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 3   | 2   | 0   | 0   | 0   | 0   | 0   | 0   |
| 8   | *Microcyclops varicans* (Sars)             | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 9   | *Metocyclops leuckarti* (Claus)            | 0   | 24  | 1   | 1   | 2   | 10  | 8   | 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   |
| 11  | *Thermocyclops tahokaensis* (Harada)       | 0   | 0   | 0   | 1   | 1   | 3   | 1   | 0   | 0   | 0   | 0   | 8   | 0   | 0   | 0   | 0   | 0   | 0   |
| 12  | *Parastenocaris* sp.                       | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 0   | 0   |
| 13  | *Heterocyclops anomalus* Klie               | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 1   | 1   | 1   |
| 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   |

**Phylum Arthropoda**

**Class Crustacea**

**Subclass Copepoda**

**Order Clanoidea**

**Family Pseudodiaptomidae**

**Family Diaptomidae**

**Order Cyclopoida**

**Family Cyclopidae**

**Order Harpacticoida**

**Family Parastenocaridae**

**Subclass Ostracoda**

**Order Podocopida**

**Subclass Branchiopoda**

**Order Cladocera**

**Family Bosminidae**

**Family Cypridae**

**Family Copepida**
| No. | Taxon                                      | Sampling Sites |
|-----|--------------------------------------------|----------------|
| 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 0 0 0 |
| 16  | *Bosminopsis deitersi* Richard            | 0 5 45 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 7 2 |
| 17  | Diaphanosoma sarsi Richard                | 0 5 0 0 11 4 1 1 0 1 0 0 0 0 0 0 0 0 2 0 1 0 |
| 18  | Diaphanosoma paucispinum Brehm            | 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 19  | *Monodaphnia macleayi* (King)             | 0 1 0 0 0 0 2 0 0 0 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 1 0 2 0 0 0 0 0 0 0 0 0 0 0 0 |
| 21  | Disparalona rostrata (Koch)               | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 0 0 0 0 0 0 0 0 |
| 22  | Leydigia acanthocercoides (Fischer)       | 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 |
| 23  | Biapertura intermedia (San)               | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 |
| 24  | Phylum Aschelminthes                       |                |
| 25  | Class Eurotatoria                          |                |
| 26  | Family Philodinidae                       |                |
| 27  | Trichoria tetractis (Ehrenberg)           | 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 22 18 0 0 0 0 0 0 |
| 28  | Rotaria neptunia (Ehrenberg)              | 0 0 0 0 0 0 1 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 29  | Philodina megalotrocha (Ehrenberg)        | 0 0 0 0 0 0 9 15 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 |
| 30  | Philodina citrina Ehrenberg               | 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 31  | Philodina sp.                              | 0 0 0 0 0 0 0 0 10 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 32  | Family Notommatidae                       |                |
| 33  | Notomnata aurita (O.F.Muller)             | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 7 0 0 0 0 0 0 0 |
| 34  | Cephalodella exigua (Gorse)               | 0 0 0 0 0 0 27 0 0 0 12 0 9 1 0 0 0 0 0 0 0 0 0 0 |
| 35  | Cephalodella carolinus (O.F. Muller)      | 0 0 0 0 0 0 0 0 0 0 0 31 8 0 0 0 0 0 0 0 0 0 0 0 |
| 36  | Cephalodella gibba Ehrenberg              | 0 0 0 0 0 0 0 0 1 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 37  | Scardium longicaudum (Muller)             | 0 0 0 0 0 0 4 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 |
| 38  | Family Trichocercidae                     |                |
| 39  | Diurella similis (Wierzejski)              | 1 6 3 5 8 46 66 0 0 0 0 0 0 0 0 0 0 0 1 0 0 |
| 40  | Diurella tigris (Muller)                  | 0 0 0 0 17 17 0 0 1 0 0 1 2 0 0 0 0 0 0 0 0 0 0 |
| No. | Taxon                                | Sampling Sites |
|-----|--------------------------------------|----------------|
| 34  | *Diurella weberi* Jennings           |                |
| 35  | *Trichocerca cylindrica* (Imhof)     |                |
| 36  | *Trichocerca capucina* (Wiersejski et Zacharias) |                |
| 37  | *Trichocerca rattus rattus* Muller   |                |
| 38  | *Trichocerca pusilla* Jennings      |                |
| 39  | **Family Synchaetidae**              |                |
| 40  | *Polyarthra vulgaris* Carlin         |                |
| 41  | *Polyarthra mira* Voigt              |                |
| 42  | *Plexaoma hudsoni* (Imhof)           |                |
| 43  | **Family Testudinellidae**           |                |
| 44  | *Pompholyx complanata* Gose          |                |
| 45  | *Pompholyx sulcata* Hudson           |                |
| 46  | **Family Asplanchnidae**             |                |
| 47  | *Asplanchna sieboldi* (Leydig)       |                |
| 48  | **Family Gastropodidae**             |                |
| 49  | *Ascomorpha ecandis* Perty           |                |
| 50  | *Ascomorpha ovalis* (Carlin)         |                |
| 51  | **Family Lecaniidae**                |                |
| 52  | *Lecane iconita* (Turner)            |                |
| 53  | *Lecane luna* (Muller)               |                |
| 54  | *Lecane curvicornis* (Murray)        |                |
| 55  | *Lecane hastata* (Murray)            |                |
| 56  | *Lecane pusilla* Harring             |                |
| 57  | **Family Monostylidae**              |                |
| 58  | *Monostyla bala* (Goose)             |                |
| 59  | *Monostyla quadridentata* Ehrenberg  |                |

Appendix 2. Zooplankton data
| No. | Taxon                          | Family          | Sampling Sites |
|-----|-------------------------------|-----------------|----------------|
|     |                               |                 | CPP CBS CNL CTU CSN CKP Okt CMR CSJ CKM CSP CSU VSS VSR VTR VCT VLX VCL VTC VCD |
| 60  | Mytilina ventralis (Ehrenberg) | Mytilinidae     | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 |
| 61  | Euchlanis dilatata Ehrenberg  | Euchlanidae     | 0 0 0 0 0 8 1 1 1 0 0 6 12 0 0 0 0 0 0 0 0 |
| 62  | Diplotus davidiacei Gosse      |                 | 0 0 0 0 0 0 0 0 0 0 0 6 0 0 0 0 0 0 0 1 |
| 63  | Diplotus propatula (Gosse)    |                 | 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 64  | Endactylota endactylota Gosse  |                 | 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 65  | Brachionus angulata Gosse      | Brachionidae    | 0 25 185 0 105 1056 5 0 0 13 0 0 0 0 0 1 0 1 41 6 0 |
| 66  | Brachionus arenic (Linnæus)    |                 | 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. calyciflorus Pallas | Brachionidae | 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 |
| 68  | Brachionus calyciflorus cf. anuaeiformis (Brehm) | Brachionidae | 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 | Brachionidae | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 |
| 71  | Brachionus falcatus Zacharias   |                 | 0 38 31 0 4 471 13 0 0 0 0 0 0 0 0 0 0 9 1 0 |
| 72  | Brachionus quadridentatus var. quadridentatus Hemann | Brachionidae | 0 0 0 0 1 1 0 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 0 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  | Platias quadricornis Ehrenberg |                 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 76  | Platias patulus patulus (Muller) |                 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 77  | Keratella ulga 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) | Filiniidae | 0 3 92 1 6 6 6 0 3 0 0 0 0 0 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 | Filiniidae | 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 0 201 143 0 0 3 0 0 0 0 0 0 0 0 0 0 |
| 82  | Filinia longiseta (Ehrenberg)  |                 | 0 12 1 0 42 272 23 0 0 4 0 0 0 0 0 0 0 2 0 0 0 |
| 83  | Filinia brachyta (Rouselet)    |                 | 2 0 0 0 6 0 244 0 0 1 0 0 0 0 0 0 0 0 1 0 0 |
| No. | Taxon                                      | Family          | Sampling Sites |
|-----|-------------------------------------------|-----------------|----------------|
| 84  | *Tetramastix opolensis* Zacharias          | Hexathridae     | CPP CBS CNL CTU CSN CSK CPT CKT CMR CSJ CKM CSP CSU VSS VSR VTR VCT VLX VCL VTC VCD |
| 85  | *Hexathra mira* (Hudson)                  | Phylum Sarcomastigophora | 0 198 14 0 1 0 8 0 0 0 2 1 0 0 0 3 4 3 4 5 4 2 10 5 |
| 86  | *Arcella vulgaris* Ehrenberg              | Lobosea         | 6 0 2 2 1 38 59 13 6 8 5 5 23 41 8 0 1 6 2 1 3 |
| 87  | *Arcella conica* Deflante                 | Arcellidae      | 0 0 0 0 0 5 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 88  | *Arcella hemisphaerica* Perty             | Arcellidae      | 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 89  | *Arcella aculeata* Stein                  | Centropyxidae   | 1 0 0 0 0 5 1 13 2 2 5 1 23 23 17 2 5 5 5 0 2 |
| 90  | *Diffugia elegans* Penard                 | Diffugiidae     | 1 0 157 4 0 15 0 9 11 0 0 0 2 1 0 4 19 12 44 91 15 |
| 91  | *Diffugia urceolata* Carter               | Diffugiidae     | 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 2 6 0 |
| 92  | *Diffugia corona* Wallisch                | Diffugiidae     | 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 8 1 1 0 0 1 0 1 1 |
| 93  | *Diffugia tuberculata* Leidy              | Diffugiidae     | 0 0 0 0 0 2 13 0 8 3 0 2 4 5 0 3 0 0 0 0 0 0 0 0 |
| 94  | *Diffugia globulosa* Dujardin             | Diffugiidae     | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 12 12 5 2 0 2 14 3 0 0 |
| 95  | *Diffugia tuberculata* (Wallich)          | Diffugiidae     | 0 0 0 0 0 13 20 71 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 96  | *Diffugia lanceolata* Penard              | Diffugiidae     | 0 0 0 0 0 0 0 1 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 97  | *Diffugia sp.*                            | Diffugiidae     | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 98  | *Lesquereusia spiralis* (Ehrenberg)       | Filosea         | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 4 0 0 0 0 0 0 |
| 99  | *Euglypha alveorata* Dujardin             | Euglyphaeidae   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 100 | *Ceratium* spp.                           | Volvocidae      | 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 |
| 101 | *Pleodorina californica* Shaw             | Volvocidae      | 7 74 7 3 0 0 0 0 0 0 0 0 1 0 0 1 3 20 13 0 1 |
| No. | Taxon                  | CPP | CBS | CNL | CTU | CSN | CSK | CPT | CKT | CMR | CSJ | CKM | CSP | CSU | VSS | VSR | VTR | VCT | VLX | VCL | VTC | VCD |
|-----|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 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   | 8   | 5   | 7   | 5   | 49  | 0   | 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   | 0   | 0   | 0   | 0   | 0   | 0   |
| 105 | Chironomidae - Diptera| 0   | 0   | 0   | 0   | 1   | 0   | 3   | 1   | 3   | 2   | 2   | 4   | 0   | 1   | 0   | 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        | Sidiidae                 | *Diaphanosoma sarsi* Richard              | 54              | 20            |
| Crustacea        | Sidiidae                 | *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 lumholzti* 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 barrosi 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 acanthoceroides* (Fischer) | 39             | 8             |
| Crustacea      | Chydoridae  | *Alona rectangula* Sars             | 43              | 9             |
| Crustacea      | Chydoridae  | *Alona davidii* Richard             | 44              | 5             |
| Crustacea      | Chydoridae  | *Biapertura karua* (King)           | 47              | 4             |
| Crustacea      | Chydoridae  | *Biapertura intermedia* (Sars)      | 50              | 5             |
| Eurotatoria    | Philodinidae| *Trichotria tetractis* (Ehrenberg)  | 41              | 28            |
| Eurotatoria    | Philodinidae| *Rotaria rotaria* (Pallas)          | 39              | 2             |
| Eurotatoria    | Philodinidae| *Rotaria neptunia* (Ehrenberg)      | 71              | 4             |
| Eurotatoria    | Philodinidae| *Philodina roseola* (Ehrenberg)     | 48              | 48            |
| Eurotatoria    | Philodinidae| *Philodina megalatrocha* (Ehrenberg)| 59             | 7             |
| Eurotatoria    | Philodinidae| *Philodina citrina* Ehrenberg       | 13              | 2             |
| Eurotatoria    | Philodinidae| *Philodina sp.*                      | 33              | 15            |
| Eurotatoria    | Notommatidae| *Monomata sp.*                      | 43              | 1             |
| Eurotatoria    | Notommatidae| *Notomnata aurita* (O.F.Muller)     | 43              | 15            |
| Eurotatoria    | Notommatidae| *Notomnata sp.*                     | 44              | 1             |
| Eurotatoria    | Notommatidae| *Cephalodella compacta* Wiszniewski | 0              | 4             |
| Eurotatoria    | Notommatidae| *Cephalodella catellina* (O.F.Muller)| 34            | 13            |
| Eurotatoria    | Notommatidae| *Cephalodella exigua* (Gosse)       | 23              | 13            |
| Eurotatoria    | Notommatidae| *Cephalodella gibba* Ehrenberg      | 21              | 3             |
| Eurotatoria    | Notommatidae| *Cephalodella auriculata* (O.F.Muler)| 94            | 1             |
| Eurotatoria    | Notommatidae| *Cephalodella sp.*                  | 17              | 6             |
| Eurotatoria    | Notommatidae| *Scaridium longicaudum* (Muller)    | 44              | 11            |
| Eurotatoria    | Trichoceridae| *Diurella similis* (Wierzejski)     | 57              | 28            |
| Eurotatoria    | Trichoceridae| *Diurella tigris* (Muller)          | 52              | 18            |
| Eurotatoria    | Trichoceridae| *Diurella weberi* Jennings          | 63              | 4             |
| Eurotatoria    | Trichoceridae| *Diurella tensior* (Goose)          | 0               | 2             |
| Eurotatoria    | Trichoceridae| *Diurella brachyura* (Gosse)        | 43              | 4             |
| Eurotatoria    | Trichoceridae| *Trichocerca gracilis* (Tessin)     | 56              | 12            |
| Eurotatoria    | Trichoceridae| *Trichocerca cylindrica* (Imhof)    | 40              | 3             |
| Eurotatoria    | Trichoceridae| *Trichocerca capicina* (Wierzejski et Zacharias)| 66          | 7             |
| Eurotatoria    | Trichoceridae| *Trichocerca longiseta* (Schrank)   | 60              | 2             |
| Eurotatoria    | Trichoceridae| *Trichocerca rattus minor* Fad      | 36              | 1             |
| Eurotatoria    | Trichoceridae| *Trichocerca rattus* Muller         | 64              | 7             |
| Eurotatoria    | Trichoceridae| *Trichocerca pusilla* Jenniagns     | 46              | 30            |
| Eurotatoria    | Trichoceridae| *Trichocerca bicristata* (Gosse)    | 39              | 1             |
| Eurotatoria    | Synchaetidae| *Polyarthra vulgaris* Carlin         | 47              | 95            |
| Eurotatoria    | Synchaetidae| *Polyarthra mira* Voigt             | 54              | 6             |
| Eurotatoria    | Synchaetidae| *Ploesoma hudsoni* (Imhof)          | 49              | 19            |
| Eurotatoria    | Testudinellidae| *Testudinella patina* (Hermann)    | 47              | 5             |
| Eurotatoria    | Testudinellidae| *Testudinella mucronata* (Gosse)   | 43              | 3             |
| Eurotatoria    | Testudinellidae| *Testudinella sp.*                  | 0               | 2             |
| Eurotatoria    | Testudinellidae| *Pompholyx complanata* Gosse        | 32              | 15            |
## Appendix 2. Zooplankton data

| Class          | Family                  | Taxon                   | Tolerance score | Total samples |
|----------------|-------------------------|-------------------------|-----------------|---------------|
| Eurotatorea    | Testudinellidae         | *Pompholyx sulcata*     | 32              | 32            |
| Eurotatorea    | Asplanchnidae           | *Asplanchna sieboldi*   | 52              | 26            |
| Eurotatorea    | Asplanchnidae           | *Asplanchna girodi*     | 35              | 5             |
| Eurotatorea    | Asplanchnidae           | *Asplanchna priodonta*  | 45              | 5             |
| Eurotatorea    | Asplanchnidae           | *Asplanchnopus multiceps* | 69          | 13            |
| Eurotatorea    | Gastropodidae           | *Ascomorpha ecaudis*    | 34              | 53            |
| Eurotatorea    | Gastropodidae           | *Ascomorpha agilis*     | 12              | 3             |
| Eurotatorea    | Gastropodidae           | *Ascomorpha ovalis*     | 56              | 4             |
| Eurotatorea    | Gastropodidae           | *Ascomorpha sp.*        | 30              | 10            |
| Eurotatorea    | Lecanidae               | *Lecane leontina*       | 27              | 6             |
| Eurotatorea    | Lecanidae               | *Lecane luna*           | 42              | 40            |
| Eurotatorea    | Lecanidae               | *Lecane curvicornis*    | 40              | 8             |
| Eurotatorea    | Lecanidae               | *Lecane hastata*        | 48              | 11            |
| Eurotatorea    | Lecanidae               | *Lecane pusilla*        | 42              | 6             |
| Eurotatorea    | Lecanidae               | *Lecane unguulata*      | 38              | 2             |
| Eurotatorea    | Lecanidae               | *Lecane ludwigii*       | 36              | 1             |
| Eurotatorea    | Lecanidae               | *Lecane signifera*      | 39              | 4             |
| Eurotatorea    | Lecanidae               | *Lecane sp.*            | 43              | 1             |
| Eurotatorea    | Lecanidae               | *Monostyla bulla*       | 33              | 32            |
| Eurotatorea    | Lecanidae               | *Monostyla crenata*     | 50              | 9             |
| Eurotatorea    | Lecanidae               | *Monostyla lunaris*     | 41              | 27            |
| Eurotatorea    | Lecanidae               | *Monostyla quadridentata* | 67          | 1             |
| Eurotatorea    | Lecanidae               | *Monostyla closterocerca* | 25          | 2             |
| Eurotatorea    | Proalidae               | *Proales decipiens*     | 56              | 1             |
| Eurotatorea    | Mytilinidae             | *Mytilina ventralis*    | 36              | 9             |
| Eurotatorea    | Mytilinidae             | *Mytilina compressa*    | 14              | 1             |
| Eurotatorea    | Colurellidae            | *Lepadella patella*     | 34              | 9             |
| Eurotatorea    | Colurellidae            | *Lepadella sp.*         | 29              | 1             |
| Eurotatorea    | Colurellidae            | *Colurella uncinata*    | 38              | 1             |
| Eurotatorea    | Euchlanidae             | *Euchlanis dilatata*    | 44              | 25            |
| Eurotatorea    | Euchlanidae             | *Euchlanis sp.*         | 39              | 2             |
| Eurotatorea    | Euchlanidae             | *Diplois daviesiae*     | 42              | 14            |
| Eurotatorea    | Euchlanidae             | *Dipleuchlanis propatula* | 55          | 4             |
| Eurotatorea    | Euchlanidae             | *Eudactylota eudactylota* | 67          | 2             |
| Eurotatorea    | Brachionidae            | *Brachionus angularis*  | 54              | 49            |
| Eurotatorea    | Brachionidae            | *Brachionus urceus*     | 54              | 5             |
| Eurotatorea    | Brachionidae            | *Brachionus cf. urceus* | 43              | 3             |
| Eurotatorea    | Brachionidae            | *Brachionus calyciflorus* cf. calicyflorus* | 62          | 14            |
| Eurotatorea    | Brachionidae            | *Brachionus calyciflorus* cf. anuaeiiformis* (Brehm) | 59          | 3             |
| Eurotatorea    | Brachionidae            | *Brachionus caudatus*   | 52              | 14            |
| Eurotatorea    | Brachionidae            | *Brachionus forficula forficula* | 70          | 2             |
| Eurotatorea    | Brachionidae            | *Brachionus falcatus*   | 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   | *Platias quadricornis* Ehrenberg          | 50              | 3             |
| Eurotatorea   | Brachionidae   | *Platias 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* (Linnæus)          | 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       | Epistyliidae   | *Epistylis plicatilis* Ehrenberg          | 47              | 2             |
| Ciliata       | Epistyliidae   | *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  | *Centropyx aculeata* Stein                | 40              | 79            |
| Lobosea       | Centropyxidae  | *Centropyx constricta* Ehrenberg          | 29              | 12            |
| Lobosea       | Diffugiidae    | *Protocucurbitella coroniformis* Gauthier-Lie`vre & Thomas | 32             | 9             |
| Lobosea       | Diffugiidae    | *Protocucurbitella sp.*                   | 46              | 4             |
| Lobosea       | Diffugiidae    | *Pseudodiffugia gracilis* Schlumberger    | 8               | 10            |
| Lobosea       | Diffugiidae    | *Pseudodiffugia fascicularis* Penard      | 11              | 8             |
| Lobosea       | Diffugiidae    | *Diffugia elegans* Penard                 | 51              | 71            |
| Lobosea       | Diffugiidae    | *Diffugia urceolata* Carter               | 52              | 29            |
| Lobosea       | Diffugiidae    | *Diffugia corona* Wallich                 | 49              | 15            |
| Lobosea       | Diffugiidae    | *Diffugia lobostoma* Leidy                | 31              | 56            |
| Lobosea       | Diffugiidae    | *Diffugia acuminata* Ehrenberg            | 35              | 24            |
| Lobosea       | Diffugiidae    | *Diffugia piriformis* Ehrenberg           | 36              | 21            |
| Lobosea       | Diffugiidae    | *Diffugia globulosa* Dujardin             | 35              | 39            |
| Lobosea       | Diffugiidae    | *Diffugia scalpellum* Penard              | 0               | 1             |
| Lobosea       | Diffugiidae    | *Diffugia molest* Penard                  | 19              | 2             |
| Lobosea       | Diffugiidae    | *Diffugia lanceolata* Penard              | 22              | 11            |
| Lobosea       | Diffugiidae    | *Diffugia amphora* Leidy                  | 25              | 1             |
### Appendix 2. Zooplankton data

| Class    | Family       | Taxon                                      | Tolerance score | Total samples |
|----------|--------------|--------------------------------------------|-----------------|---------------|
| Lobosea  | Diffugiidae  | *Diffugia tuberculatus* (Wallich)          | 49              | 11            |
| Lobosea  | Diffugiidae  | *Difflugia 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 |
|-----|------------------------------|----------------|
| 1   | Haustorius sp                | CPP CKL CNL CTU CSN CKT CMR CSJ CKM CSP CSU VSS VSP VVL VTC VCL VCT VCD |
| 2   | Scaphusa sp                  | 0 0 0 0 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   | Carbidae 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   | Rhantis 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 6 0 0 0 0 0 0 0 0 0 0 |
| 9   | Macronyxus sp                | 0 0 0 0 0 0 0 0 0 0 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 0 0 0 0 0 0 0 0 0 0 |
| 15  | Psephenus sp                 | 0 0 0 0 0 0 0 0 0 0 0 2 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 0 1 0 43 15 25 17 0 0 |
| 19  | Macrobrachium dienbienphuensis | 0 0 0 0 0 0 0 0 0 0 0 0 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 lancasteri     | 5 2 1 0 0 11 0 8 20 2 0 0 0 1 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           | 0 0 0 0 0 0 0 0 0 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 0 0 0 0 2 0 1 0 0 0 0 0 0 |
| 25  | Parathelphusidae sp          | 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 1 0 0 0 0 0 |
| 26  | Decapoda unknown             | 0 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 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 |
| No. | Taxon                          | Sampling sites |
|-----|-------------------------------|----------------|
| 29  | Culicoides sp                 | 0 0 0 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 0 0 0 |
| 31  | Ablabesmyia sp                | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 |
| 32  | Chironomus sp                 | 0 0 10 0 0 0 5 0 5 1 3 2 7 51 0 1 0 8 0 0 0 0 0 |
| 33  | Rhaphitum canpestre           | 0 0 0 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 0 0 0 0 0 22 0 1 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 0 0 0 |
| 36  | Tabaninae sp                  | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 |
| 37  | Antocha sp                    | 0 0 0 0 0 0 0 0 0 0 0 0 3 0 2 0 0 0 0 0 0 0 0 0 |
| 38  | Limnophila sp                 | 0 0 0 0 0 0 0 0 0 0 0 0 2 0 1 0 0 0 0 0 0 0 0 0 |
| 39  | Pedica sp                     | 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 |
| 40  | Baetella sp                   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 |
| 41  | Baetis sp                     | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 |
| 42  | Centropilum sp                | 0 0 0 0 0 0 0 1 0 2 3 1 3 0 0 0 0 0 0 0 0 0 0 0 |
| 43  | Cloeon sp                     | 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 |
| 44  | Gratia narumaeae              | 0 0 0 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 46  | Platybaetis sp                | 0 0 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 10 28 0 0 0 0 0 |
| 47  | Caenodes sp                   | 0 3 5 0 0 0 0 3 0 0 7 3 0 9 0 0 0 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 0 0 0 |
| 49  | Ephemerella commondema        | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 0 1 0 0 0 0 0 0 |
| 50  | Eatonigenia sp                | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 51  | Ephemera sp                   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 52  | Cinygmina sp                  | 0 0 0 0 0 0 0 0 0 0 0 0 5 1 0 0 2 0 0 0 0 0 0 0 |
| 53  | Thalerosphyrus sp             | 0 0 0 0 0 0 0 0 0 0 0 0 1 0 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 0 0 0 |
| 55  | Chloroterpes sp               | 0 0 0 0 0 0 0 0 0 2 0 8 1 20 0 5 1 0 0 0 0 0 0 0 |
| 56  | Chloroterpales sp             | 0 0 0 0 0 0 0 0 0 0 0 8 0 53 1 5 0 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 0 0 0 |
| 58  | Potamanthelus caenodes        | 0 0 0 0 0 0 0 0 0 9 0 4 0 2 0 0 0 0 0 0 0 0 0 0 |
| No. | Taxon                           | Sampling sites |
|-----|---------------------------------|----------------|
| 59  | Potamanthellus edmundsi         | 0 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 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 0 |
| 62  | Rheoanthes sp                   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 |
| 63  | Prospistoma annamese            | 0 0 0 0 0 0 0 0 0 5 1 0 0 0 0 0 0 0 0 0 0 0 |
| 64  | Prospistoma sinensis            | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 65  | Prospistoma wouterae            | 0 0 0 0 0 0 0 0 0 0 0 0 0 4 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 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 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 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 0 |
| 70  | Pitimera tigrina                | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 71  | Rheumatobates sp                | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 |
| 72  | Tanagynus sp                    | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 |
| 73  | Trepobates sp                   | 0 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 0 0 0 0 12 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 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 0 |
| 77  | Limnocoris sp                   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 |
| 78  | Cenocometus sp                  | 0 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 0 |
| 80  | Nychis suppho                   | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 81  | Parapleia sp                    | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 |
| 82  | Baptissa sp                     | 0 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 0 |
| 84  | Macrovelia sp                   | 0 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 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 0 |
| 87  | Petrophila confusalis           | 0 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   |
| 89  | Assimineidae sp           | 0   | 1   | 12  | 0   | 0   | 0   | 0   | 18  | 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   |
| 91  | Waltebiedia sp            | 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   |
| 93  | Hydrobiidae sp            | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 7   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 94  | Juliena sp                | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 4   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 95  | Karelania sp              | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 96  | Lacunapsis sp             | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 97  | Neotricula sp             | 0   | 0   | 14  | 0   | 0   | 0   | 0   | 40  | 3   | 2   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 98  | Pachydyria brevis         | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 22  | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 99  | Paraprosthenia sp         | 0   | 0   | 8   | 0   | 0   | 0   | 0   | 2   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 100 | Rehderiella sp            | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 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   |
| 102 | Pila scutata              | 0   | 0   | 0   | 0   | 5   | 0   | 8   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 103 | Stenothyra sp1            | 0   | 2   | 5   | 0   | 0   | 0   | 25  | 33  | 7   | 0   | 3   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 104 | Stenothyra sp2            | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 5   | 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   |
| 106 | Brotia sp                 | 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   |
| 108 | Filopaludina martensi     | 0   | 0   | 0   | 0   | 5   | 0   | 5   | 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   |
| 110 | Indiopoma sp              | 0   | 0   | 0   | 0   | 2   | 2   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 111 | Melogonia sp              | 0   | 0   | 0   | 0   | 83  | 0   | 28  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 112 | Sinotasia sp              | 0   | 0   | 0   | 0   | 0   | 3   | 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   | 0   |
| 114 | Nematoda                  | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
## Appendix 3. Littoral macroinvertebrate data

| No. | Taxon                        | Sampling sites |
|-----|------------------------------|----------------|
| 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 3 0 0 0 0 0 0 0 0 0 0 |
| 117 | Calopterygidae sp            | 0 0 0 0 0 0 0 0 0 2 1 1 0 1 0 0 0 0 0 0 0 |
| 118 | Chironomidae sp              | 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 |
| 119 | Cordulinae sp                | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 120 | Amphylia williamsoni         | 0 0 0 0 0 0 0 2 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 0 0 0 0 0 0 0 |
| 122 | Octogomphus sp               | 0 0 0 0 0 0 0 0 0 4 0 3 0 0 0 0 0 0 0 0 0 |
| 123 | Ophiogomphus sp              | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 124 | Progomphus sp                | 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 |
| 125 | Plathemis sp                 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 126 | Protoneura sp                | 0 10 0 0 0 0 3 0 2 0 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 0 0 2 0 10 0 0 0 0 0 |
| 130 | Polychaeta sp1               | 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 131 | Polychaeta sp2               | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| 132 | Sphaeromatida sp             | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 4 0 0 |
| 133 | Gannonema 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 | Saldoneureclipsis 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 | Hydromaneous sp              | 0 0 0 0 0 0 0 0 0 0 0 0 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 |
| No. | Taxon                        | Sampling sites |
|-----|-----------------------------|----------------|
| 142 | Macrostemum sp              |                |
| 143 | Pseudoleptonema sp          |                |
| 144 | Trichomacronema sp          |                |
| 145 | Hydroptila sp               |                |
| 146 | Mayatrixia sp               |                |
| 147 | Orthotrichia sp             |                |
| 148 | Ceraclea sp                 |                |
| 149 | Leptocerus sp               |                |
| 150 | Octatis sp                  |                |
| 151 | Sitodes sp                  |                |
| 152 | Trianodes sp                |                |
| 153 | Cryptochia sp               |                |
| 154 | Pedemoecus sp               |                |
| 155 | Molannodes sp               |                |
| 156 | Chinarrus sp                |                |
| 157 | Dolophilodes sp             |                |
| 158 | Tinodes sp                  |                |
| 159 | Fattigia sp                 |                |
| 160 | Stenopsyche siamensis       |                |
| 161 | Ensides ingalsianus         |                |
| 162 | Physunio cambodiensis       |                |
| 163 | Physunio eximinus           |                |
| 164 | Scabies crispa              |                |
| 165 | Corbicula sp                |                |
### 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     | Psphenidae | Acenus sp.            | 15              | 3             |
| Coleoptera     | Salpingidae| Aegialites sp.        | 40              | 2             |
| Coleoptera     | Elmidae    | Ancrynys sp.          | 24              | 3             |
| Coleoptera     | Carbaidae  | Carbaidae sp.         | 13              | 1             |
| Coleoptera     | Elmidae    | Cleptelmis sp.        | 13              | 32            |
| Coleoptera     | Hydrophilida| Derallius sp.        | 52              | 2             |
| Coleoptera     | Gyrinidae  | Dinecutas sp.         | 7               | 2             |
| Coleoptera     | Chrysomelida| Donacia sp.          | 25              | 3             |
| Coleoptera     | Dytsicidae | Dytsicidae sp.       | 63              | 1             |
| Coleoptera     | Scirtidae  | Elodes sp.            | 13              | 2             |
| Coleoptera     | Hydrophilida| Euxochrus sp.       | 40              | 3             |
| Coleoptera     | Georyssida | Georyssus sp.        | 48              | 2             |
| Coleoptera     | Gyринidae  | Gyretes sp.           | 49              | 3             |
| Coleoptera     | Gyринidae  | Gyринidae sp.        | 47              | 4             |
| Coleoptera     | Haliplidae | Haliphas sp.          | 56              | 1             |
| Coleoptera     | Carbaidae  | Harpalus sp.          | 25              | 1             |
| Coleoptera     | Hydrophilida| Helecharas sp.      | 31              | 2             |
| Coleoptera     | Heterocerida| Heterocerida sp.    | 64              | 1             |
| Coleoptera     | Elmidae    | Heterolimnus sp.     | 16              | 15            |
| Coleoptera     | Hydrophilida| Hydrobius sp.       | 42              | 2             |
| Coleoptera     | Hydrophilida| Hydrochara sp.      | 13              | 5             |
| Coleoptera     | Hydrophilida| Hydrochus sp.       | 0               | 2             |
| Coleoptera     | Hydrocharida| Hydrocharida sp.    | 32              | 2             |
| Coleoptera     | Dytsicidae | Hydrovatus sp.        | 25              | 1             |
| Coleoptera     | Dytsicidae | Laccophiles sp.      | 26              | 21            |
| Coleoptera     | Lampyrinae | Lampyrinae sp.       | 11              | 10            |
| Coleoptera     | Elmidae    | Lara sp.              | 32              | 4             |
| Coleoptera     | Elmidae    | Macrynychus sp.      | 34              | 13            |
| Coleoptera     | Mysidae    | Neomysis sp.          | 84              | 1             |
| Coleoptera     | Elmidae    | Optiovum sp.         | 13              | 1             |
| Coleoptera     | Elmidae    | Ordocraniuus sp.     | 47              | 3             |
| Coleoptera     | Elmidae    | Oulimnus sp.         | 25              | 10            |
| Coleoptera     | Hydrophilida| Paracymus sp.       | 30              | 2             |
| Coleoptera     | Haliplidae | Pelodytes sp.        | 26              | 3             |
| Coleoptera     | Psphenidae | Psphenus sp.         | 12              | 12            |
| Coleoptera     | Dytsicidae | Rhanntus sp.         | 32              | 10            |
| Coleoptera     | Scritidae  | Scritidae sp.        | 13              | 1             |
| Coleoptera     | Staphilinida| Staphilinidae      | 47              | 1             |
| Coleoptera     | Elmidae    | Stegelmis sp.        | 31              | 3             |
| Order          | Family               | Species                        | Tolerance score | Total samples |
|----------------|----------------------|--------------------------------|-----------------|---------------|
| Coleoptera     | Staphilinidae        | Thinopinus sp.                 | 56              | 2             |
| Colembola      | Isotomidae           | Isotomus 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 mieli           | 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            | Anopheelinae 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            | Limnaphila sp.                | 28              | 32            |
| Diptera        | Sciomyzidae          | Nanocladius sp.               | 22              | 7             |
| Diptera        | Stratiomyzidae       | 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          | Afronema 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              | Baeis sp.           | 32              | 98            |
| Ephemeroptera       | Caenidae              | Caenis sp.          | 44              | 21            |
| Ephemeroptera       | Caenidae              | Caenoculis sp.      | 32              | 87            |
| Ephemeroptera       | Caenidae              | Caenodes sp.        | 25              | 41            |
| Ephemeroptera       | Baetidae              | Centropilum 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 commodena | 24        | 18            |
| Ephemeroptera       | Ephemeridae           | Ephemerata sp.      | 26              | 36            |
| Ephemeroptera       | Baetidae              | Gratia naramonae    | 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         | Potamanthelis caenodes | 19        | 30            |
| Ephemeroptera       | Neoephmeridae         | Potamanthelis 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         | Rhoenanthes obscurus | 14              | 8             |
| Ephemeroptera       | Potamanthidae         | Rhoenanthes sp.     | 50              | 2             |
| Ephemeroptera       | Teloganosidae         | Teloganodes sp.     | 15              | 7             |
| Ephemeroptera       | Heptageniidae         | Thalerosp.kyrus sp. | 20              | 18            |
| Ephemeroptera       | Ephemeraldidae        | Urasanthes sp.      | 17              | 13            |
| Hemiptera           | Notonectidae          | Anisops sp.         | 49              | 6             |
| Hemiptera           | Aphiellochiridae      | Aphiellochirs sp.   | 18              | 20            |
| Hemiptera           | Notonectidae          | Aphielonecta 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     | Platycnemididae| _Heleocoris_ sp. | 0               | 1             |
| Hemiptera     | Nepidae        | _Laccotrephes_ sp. | 43              | 1             |
| Hemiptera     | Naucoridae     | _Limnocoris_ sp. | 50              | 1             |
| Hemiptera     | Gerridae       | _Linnogonus_ 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       | _Nabandelas_ 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       | _Rhogovelia_ 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       | _Tanagogomus_ sp. | 8               | 2             |
| Hemiptera     | Gerridae       | _Tenagogomus_ sp. | 0               | 1             |
| Hemiptera     | Gerridae       | _Tinagogomus_ sp. | 25             | 3             |
| Hemiptera     | Gerridae       | _Trepobates_ sp. | 33              | 3             |
| Hemiptera     | Veliidae       | _Trochopus_ sp. | 56              | 1             |
| Hemiptera     | Gerridae       | _Ventidius_ sp. | 28              | 25            |
| Hymenoptera   | Trichogrammatidae | _Hydrophilia aquivolans_ | 47          | 1             |
| Isopoda       | Sp.haerotmatidae | _Sp.haerotmatid_ 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| Thiariidae     | _Ademietta housei_ | 52            | 3             |
| Mesogastropoda| Assimineidae   | _Assimineidae_ | 37              | 9             |
| Mesogastropoda| Bithyniidae    | _Bithynia_ sp. | 27              | 64            |
### Appendix 3. Littoral macroinvertebrate data

| Order                      | Family                  | Species                        | Tolerance score | Total samples |
|----------------------------|-------------------------|--------------------------------|-----------------|---------------|
| Mesogastropoda             | Bithyniidae             | *Bithynia walttebledia*        | 11              | 4             |
| Mesogastropoda             | Thiaridae               | *Brodia* 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             | *Hydorissiosia sp.*            | 21              | 3             |
| Mesogastropoda             | Viviparidae             | *Indiopoma sp.*                | 69              | 6             |
| Mesogastropoda             | Hydrobiidae             | *Jullienia* sp.                | 31              | 7             |
| Mesogastropoda             | Hydrobiidae             | *Karelisia* sp.                | 21              | 1             |
| Mesogastropoda             | Hydrobiidae             | *Lacunosia* sp.                | 22              | 14            |
| Mesogastropoda             | Lymnaeidae              | *Lymnaea* sp.                  | 40              | 14            |
| Mesogastropoda             | Viviparidae             | *Mekongia* sp.                 | 41              | 31            |
| Mesogastropoda             | Thiaridae               | *Melanoctes tuberculata*       | 50              | 6             |
| Mesogastropoda             | Hydrobiidae             | *Necrtiula* 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             | *Paraprostosthenia* 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 Viviparida?         | 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                | *Cleia 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             |
|             | Calopterygidae    | Calopteryx maculata      | 17              | 4             |
| Odonata     | Chlorocyphidae    | Chlorocyphidae sp.       | 31              | 8             |
| Odonata     | Corduliiidae      | Cordulinae sp.           | 30              | 9             |
| Odonata     | Gomphiidae        | Dromogomphus sp.         | 19              | 20            |
| Odonata     | Coenagrionidae    | Enallagma civile         | 28              | 5             |
| Odonata     | Libellulidae      | Epicordulia princeps     | 25              | 1             |
| Odonata     | Gomphiidae        | Erpetogomphus sp.        | 3               | 6             |
| Odonata     | Euphaeidae        | Euphaeidae sp.           | 36              | 9             |
| Odonata     | Gomphiidae        | Gomphus sp.              | 41              | 4             |
| Odonata     | Aeshnidae         | Gynacantha sp.           | 14              | 3             |
| Odonata     | Gomphiidae        | Hagenius brevistylus     | 14              | 1             |
| Odonata     | Calopterygidae    | Hetaerina titia          | 0               | 2             |
| Odonata     | Libellulidae      | Macrothemis              | 27              | 9             |
| Odonata     | Gomphiidae        | Meglogomphus sp.         | 84              | 1             |
| Odonata     | Gomphiidae        | Octogomphus sp.          | 19              | 28            |
| Odonata     | Gomphiidae        | Ophiogomphus sp.         | 35              | 40            |
| Odonata     | Libellulidae      | Plathemis sp.            | 24              | 62            |
| Odonata     | Platycnemididae   | Platycnemidae sp.        | 56              | 1             |
| Odonata     | Gomphiidae        | Progomphus sp.           | 20              | 16            |
| Odonata     | Protoonuridae     | Protoonura sp.           | 39              | 44            |
| Odonata     | Gomphiidae        | Stylogomphus albisylus   | 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 | Hydropsyidae      | Agraylea sp.             | 18              | 3             |
| Trichoptera | Hydropsyidae      | Amphipsyche sp.          | 5               | 1             |
| Trichoptera | Calamoceridae     | Anisocentropus brevi     | 38              | 4             |
| Trichoptera | Hydropsyidae      | Arctopsycha sp.          | 9               | 6             |
| Trichoptera | Leptoceridae      | Ceraclea sp.             | 8               | 3             |
| Trichoptera | Philopotamidae    | Chimarrat sp.            | 28              | 25            |
| Trichoptera | Limnephilidae     | Cryptocha sp.            | 24              | 5             |
| Trichoptera | Diseudopsididae   | Diseudopsis sp.          | 8               | 2             |
| Trichoptera | Philopotamidae    | Dolophilodes sp.         | 52              | 7             |
| Trichoptera | Ecnomidae         | Ecnomus sp.              | 5               | 1             |
| Trichoptera | Branchycercentra  | Eobrachycentrus sp.      | 36              | 2             |
| Trichoptera | Sericostomatidae  | Fattigia                 | 21              | 6             |
| Trichoptera | Calamoceridae     | Ganonema extensum        | 41              | 5             |
### Appendix 3. Littoral macroinvertebrate data

| Order          | Family               | Species             | Tolerance score | Total samples |
|----------------|----------------------|---------------------|-----------------|---------------|
| Trichoptera    | Glososomatidae       | Glososoma 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       | Hydaticinus sp.     | 6               | 4             |
| Trichoptera    | Hydropsychidae       | Hydromanicus sp.    | 24              | 5             |
| Trichoptera    | Hydropsychidae       | Hydropsyche bettni | 21              | 4             |
| Trichoptera    | Hydropsychidae       | Hydropsyche sp.     | 21              | 38            |
| Trichoptera    | Hydropsychidae       | Hydroptila sp.      | 19              | 8             |
| Trichoptera    | Hydropsychidae       | Ihytrichia sp.      | 25              | 1             |
| Trichoptera    | Leptoceridae         | Leptocerus sp.      | 21              | 16            |
| Trichoptera    | Limnephilidae        | Limnephilus         | 27              | 2             |
| Trichoptera    | Limnephilidae        | Macrostemum sp.     | 13              | 26            |
| Trichoptera    | Limnephilidae        | Madeophylax sp.     | 35              | 3             |
| Trichoptera    | Limnephilidae        | 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    | Nyciophylax sp.     | 53              | 5             |
| Trichoptera    | Leptoceridae         | Oecetis 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        | Pseudoepora sp.     | 25              | 1             |
| Trichoptera    | Hydropsychidae       | Pseudoleptonema sp. | 6               | 3             |
| Trichoptera    | Duseudopsidae        | Pseudoneureclipsis sp. | 20            | 5             |
| Trichoptera    | Limnephilidae        | Pseudostenophylax sp. | 13           | 7             |
| Trichoptera    | Pteryganeidae        | Pilostomis sp.      | 56              | 2             |
| Trichoptera    | Rhyacophilidae       | Rhyacophila sp.     | 6               | 1             |
| Trichoptera    | Sericostomatidae     | Sericostoma sp.     | 25              | 2             |
| Trichoptera    | Leptoceridae         | Setodes sp.         | 21              | 11            |
| Trichoptera    | Duseudopsidae        | Seuloneureclipsis sp. | 7              | 6             |
| Trichoptera    | Leptoceridae         | Stiodes 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 cambadiensis | 59           | 1             |
| Order     | Family       | Species                  | Tolerance score | Total samples |
|-----------|--------------|--------------------------|-----------------|---------------|
| Uniioroida| Amblemidae   | Physunio eximinus        | 59              | 1             |
| Uniioroida| Amblemidae   | Physunio sp.             | 13              | 1             |
| Uniioroida| Amblemidae   | Pilsbryoconcha exilis    | 6               | 1             |
| Uniioroida| Amblemidae   | Scabies crispata         | 61              | 8             |
| Uniioroida| 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                    | 36               | 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                       |
| No. | Taxon                                      | Sampling sites |
|-----|--------------------------------------------|----------------|
|     | Phylum Annelida                            |                |
|     | Class Polychaeta                           |                |
|     | Order Neveimorpha                          |                |
|     | Family Nephthydida                         |                |
| 1   | *Nephthys polybranchia* (Southern)         | 19             |
|     | Family Nereida                             |                |
| 2   | *Nama* castis abiuma* Muller              | 18 30          |
| 3   | *Neanthes caudata* (Delle Chiaje)          | 4              |
|     | Order Spiomorpha                           |                |
|     | Family Ariciida                            |                |
| 4   | *Scoloplos* sp.                            | 2              |
|     | Family Spionida                            |                |
| 5   | *Prionospio* sp.                           | 19             |
| 6   | *Polydora* sp.                             | 3              |
|     | Class Oligochaeta                          |                |
|     | Family Naidida                             |                |
| 7   | Genus sp.                                  | 7 16 7 10 4 1  |                |
|     | Family Tubificida                          |                |
| 8   | *Lumodrilus 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 Neritida                            |                |
| 10  | *Neritina rubida* (Pease)                  | 5              |
|     | Order Mesogastropoda                       |                |
|     | Family Stenothyridae                       |                |
| 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.                            |                |
|     | Family Hydrobiidae                        |                |
| 15  | Pachydrobia sp.                           | 1 2 4 18       |
| 16  | Hubendickia cnooki Brandt                 | 175            |
| 17  | Hubendickia sp.                           | 1              |
| 18  | Hydrorissoia sp.                          | 12             |
| 19  | Paraprososia sp.                          | 75             |
| 20  | Jullenia acuta Poirier                    | 6              |
|     | Family Viviparidae                        |                |
| 21  | Filopaludia (Filopaludina) filosa (Reeve) | 1 3 4          |
| 22  | Filopaludia (Filopaludina) dolaris (Gould)| 1 1            |
| 23  | Mekongia swainsoni breueri (Kobelt)       | 3              |
| 24  | Mekongia swainsoni flavida n. subsp.      | 7 43           |
|     | Family Bythiniiidae                       |                |
| 25  | Bithynia sp.                              | 3 6 60 1 3 6   |
| 26  | Watebledia siasmensis (Moellendorf)       | 1              |
|     | Family Fluminicoliidae                    |                |
| 27  | Genas sp.                                 | 2 3            |
|     | Family Thiariidae                         |                |
| 28  | Sermyla tornataela (Lea)                  | 1 5 5 2 4 1 10 4 |
| 29  | Meleancides tuberculatus (Muller)         | 1 2 1          |
## Appendix 4. Benthic macroinvertebrate data

| No. | Taxon                                      | Sampling sites |
|-----|--------------------------------------------|----------------|
|     |                                            | CPP CBS CNL CTU CSN CSK CPT CKT CMR CSI CKM CSP CSU VSS VSR VTR VCT VLX VCL VTC VCD |
| 30  | Cyclotropis sp.                            |                |
|     | Class Bivalvia                             |                |
|     | Order Arcoidea                             |                |
|     | Family Arcoidea                            |                |
| 31  | Scaphula pinna Benson                      | 1 2            |
|     | Order Mytiloida                            |                |
|     | Family Mytilida                            |                |
| 32  | *Limnoperna siamensis* (Morelet)           | 3 9 8          |
|     | Order Veneroida                            |                |
|     | Family Dreissenidae                        |                |
| 33  | *Sinomytilus harmandi* (Rochebrune)        | 2 42 11 9      |
|     | Family Corbiculida                         |                |
| 34  | *Corbicula lamarckiana* Prime              | 2              |
| 35  | *Corbicula leviuscula* Prime               | 41             |
| 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           |
| 38  | *Corbicula moreeliiana* Prime              | 11 38 1        |
| 39  | *Corbicula cyreniformis* Prime             | 17 2           |
| 40  | *Corbicula blandiana* Prime                | 1 21 2 6 1     |
|     | 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  | *Pilsbryocconcha lemeslei* (Morelet)                                  |                |
| 47  | *Pilsbryocconcha exilis exilis* (Lea)                                 | 1 1            |
| 48  | Scabies sp.                                                           |                |
| 49  | *Trapezioides exolescens comptus* (Deshayes)                           | 3 1            |
|     | Phylum Arthropoda                                                     |                |
|     | Class Crustacea                                                       |                |
|     | Order Amphipoda                                                       |                |
|     | Family Gammaridae                                                     |                |
| 50  | *Melita sp.*                                                          | 3 7 31 18 10 2 21 |
|     | Family Oedicerotida                                                   |                |
| 51  | *Perioculodes sp.*                                                    | 4 104          |
|     | Family Corophiidae                                                    |                |
| 52  | *Corophium sp.*                                                       | 8 66           |
| 53  | Kamaka sp.                                                            | 18             |
| 54  | *Grandidierella lignorum* Barnard                                    | 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  | *Apsudes vietnamensis* Dang                                           | 3 1            |
| 58  | Genus sp.                                                             |                |
### Appendix 4. Benthic macroinvertebrate data

| No. | Taxon                                      | Sampling sites |
|-----|--------------------------------------------|----------------|
|     |                                            | CPP CBS CNL CTU CSN CSK CPT CKT CMR CSI CKM CSP CSU VSS VSR VTR VCT VLX VCL VTC VCD |
| 59  | *Macrobrachium pilimanus* (De Man) Family Palaemonidae | 1 1 |
| 60  | *Alpheus bistiscus* (De Man) Class Insecta Family Alpheidae | |
| 61  | *Baetis sp.* Family Caenidae | 1 |
| 62  | *Caenis sp.* Family Leptoplebiidae | 13 15 1 6 2 |
| 63  | *Leptophlebia sp.* Family Baetidae | 1 |
| 64  | *Traverella sp.* | 2 |
| 65  | *Choropterpes sp.* Family Ephemeridae | 2 |
| 66  | *Ephemera sp.* Family Palingentidae | 1 |
| 67  | *Eatonigenia sp.* | 74 |
| 68  | *Pentagenia sp.* Order Plecoptera Family Perlidae | 182 103 2 |
| 69  | *Perla sp.* Order Odonata Family Gomphidae | 1 |
| 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 |
| 73  | *Libellula* sp.       | 1              |
|     | Order Hemiptera       |                |
|     | Family Naucoridae     |                |
| 74  | *Naucoris* sp.        | 2              |
|     | Order Coleoptera      |                |
|     | Family Elmidae        |                |
| 75  | Genus sp.             | 3              |
|     | Family Dytiscidae     | 5 4 3          |
| 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 |
|     | Order Lepidoptera     | 5 1 2          |
|     | Family Crambidae      | 79 2 8         |
| 80  | Genus sp.             | 1              |
|     | Order Diptera         |                |
|     | Family Heleidae       |                |
| 81  | *Calcicodes* sp.      | 5 3 22         |
|     | Family Calcidae       | 2              |
| 82  | *Chaoborus* sp.       | 2 2            |
|     | Family Limonidae      |                |
| 83  | *Eriocera* sp.        | 21             |
| 84  | *Pelicia* sp.         | 2              |
### Appendix 4. Benthic macroinvertebrate data

| No. | Taxon | Sampling sites |
|-----|-------|----------------|
|     |       | CPP | CBS | CNL | CTU | CSN | CSK | CPT | CKT | CMR | CSI | CKM | CSP | CSU | VSS | VSR | VTR | VCT | VLX | VCL | VTC | VCD |
| 85  | Ablabesmyia sp. | 6   | 3   | 2   | 39  | 26  | 3   | 2   | 15  | 8   | 77  | 2   | 2   | 5   | 1   | 50  |
| 86  | Chironomus sp. | 2   | 7   | 2   | 4   | 1   | 4   | 4   | 9   | 25  | 10  | 7   | 2   | 5   | 1   | 7   |
| 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  |
| 93  | Smittia sp. | 33  |
| 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   | 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 abituma Muller | 74 | 28 |
| Neveimorpha | Nereidae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Spiomorpha | Ariciidae | Scoloplos sp. | 85 | 6 |
| Spiomorpha | Spionidae | Prionospio sp. | 77 | 15 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Oligochaeta | Naididae | Namalycastis longicirris (Takahasi) | 94 | 2 |
| Oligochaeta | Naididae | Namalycastis abituma Muller | 74 | 28 |
| Oligochaeta | Naididae | Neanthes caudata (Delle Chiaje) | 82 | 1 |
| Order          | Family                | Taxon                              | Tolerance score | Total samples |
|---------------|-----------------------|------------------------------------|-----------------|---------------|
| Veneroida     | Corbiculidae          | Corbicula lamarckiana Prime        | 34              | 51            |
| Veneroida     | Corbiculidae          | Corbicula leviscula Prime          | 55              | 23            |
| Veneroida     | Corbiculidae          | Corbicula tenuis Clessin           | 46              | 247           |
| Veneroida     | Corbiculidae          | Corbicula moreletiana 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            | Apopisidium clarkeanum (Nevill)    | 24              | 3             |
| Unionoida     | Amblemiidae           | Hyriopsis (Hyriopsis) bialatus Simpson | 43             | 1             |
| Unionoida     | Amblemiidae           | Ensiidens ingallsianus ingallsianus (Lea) | 56             | 10            |
| Unionoida     | Amblemiidae           | Pseudodon vondembuschanus ellipticus (Conrad) | 50             | 1             |
| Unionoida     | Amblemiidae           | Pseudodon inoscularis cumingi (Lea) | 50              | 1             |
| Unionoida     | Amblemiidae           | Pseudodon cambojensius cambojensius (Petit) | 56             | 3             |
| Unionoida     | Amblemiidae           | Uniandra contradens ascia (Hanley) | 43              | 8             |
| Unionoida     | Amblemiidae           | Uniandra sp.                       | 25              | 3             |
| Unionoida     | Amblemiidae           | Pilbryoconcha exilis compressa (Martens) | 43             | 2             |
| Unionoida     | Amblemiidae           | Pilbryoconcha lemeslei (Morelet)   | 76              | 2             |
| Unionoida     | Amblemiidae           | Pilsbryoconcha exilis exilis (Lea) | 59              | 1             |
| Unionoida     | Amblemiidae           | Physunio cambodiensis (Lea)        | 29              | 4             |
| Unionoida     | Amblemiidae           | Physunio micropterus (Morelet)     | 84              | 1             |
| Unionoida     | Amblemiidae           | Scabies sp.                        | 50              | 1             |
| Unionoida     | Amblemiidae           | Trapezoidens exolescens comptus (Deshayes) | 59             | 3             |
| Amphipoda     | Gammaridae            | Melita sp.                         | 75              | 49            |
| Amphipoda     | Oecicerotidae         | Periculodes 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    | Apsueididae           | Apsueudes vietnamensis Dang        | 82              | 2             |
| Cumaceae      | Family                | Genus sp.                          | 82              | 1             |
| Decapoda      | Palaeomonidae         | Macrobrachium pilimanus (De Man)   | 35              | 3             |
| Decapoda      | Atyidae               | Caridina nilotica Roux             | 33              | 3             |
| Decapoda      | Atyidae               | Caridina sp.                       | 6               | 1             |
| Decapoda      | Alpheidae             | Alpheus bisinciscus (De Man)       | 82              | 1             |
| Ephemeroptera | Baetidae              | Cloeon sp.                         | 20              | 13            |
| Ephemeroptera | Baetidae              | Baetis sp.                         | 30              | 19            |
| Ephemeroptera | Baetidae              | Centrotitulum 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           | Ephemerida sp.                     | 30              | 48            |
| Ephemeroptera | Ephemeridae           | Afromera sp.                       | 32              | 12            |
| Ephemeroptera | Ephemeridae           | Hexagenia sp.                      | 61              | 1             |
## Appendix 4. Benthic macroinvertebrate data

| 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  | Potamantidae | 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        | Calopterygida| 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      | Naucorididae | Naucoris sp.    | 28              | 12            |
| Coleoptera     | Gerridae     | Genus sp.       | 0               | 1             |
| Coleoptera     | Elmidae      | Heterlimnius sp.| 19              | 23            |
| Coleoptera     | Hygrobiidae  | Hyphrydia sp.   | 13              | 2             |
| Coleoptera     | Dolichopodida| Hydrophorus sp.  | 47              | 1             |
| Coleoptera     | Haplidae     | Genus sp.       | 63              | 1             |
| Coleoptera     | Elmidae      | Genus sp.       | 35              | 15            |
| Coleoptera     | Dytiscidae   | Genus sp.       | 5               | 1             |
| Coleoptera     | Staphiliidae | Bledias sp.     | 44              | 1             |
| Trichoptera    | Rhyacophilida| Rhyacaphila sp. | 17              | 3             |
| Trichoptera    | Hydroptilida | Oxyethira sp.   | 25              | 1             |
| Trichoptera    | Hydroptilida | Agraylea sp.    | 75              | 1             |
| Trichoptera    | Hydroptilida | Genus sp.       | 43              | 1             |
| Trichoptera    | Economidae   | Economus sp.    | 29              | 16            |
| Trichoptera    | Psychomyiida | Genus sp.       | 50              | 32            |
| Trichoptera    | Philopotamida| Genus sp.       | 42              | 53            |
| Trichoptera    | Hydropsychida| Hydropsyche sp. | 25              | 5             |
| Trichoptera    | Hydropsychida| 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   | Ericera 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./m²) | 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./m²) | 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          |
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