MEKONG RIVER COMMISSION SECRETARIAT	
Office of the Secretariat in Vientiane 184 Fa Ngoum Road, Ban Sithane Neua, P.O. Box 6101, Vientiane, Lao PDR Tel: (856-21) 263 263 Fax: (856-21) 263 264	**Office of the Secretariat in Phnom Penh** 576 National Road, no. 2, Chak Angre Krom, P.O. Box 623, Phnom Penh, Cambodia Tel: (855-23) 425 353 Fax: (855-23) 425 363
mrcs@mrcmekong.org	*www.mrcmekong.org*

MRC Initiative on Sustainable Hydropower (ISH)

IMPROVED ENVIRONMENTAL AND SOCIO-ECONOMIC BASELINE INFORMATION FOR HYDROPOWER PLANNING

ISH11 PHASE 2 REPORT: Aquatic Ecology Annex

20 December 2013

MRC Initiative on Sustainable Hydropower (ISH)

Produced by	MRC Initiative for Sustainable Hydropower
Produced for	MRC Member Countries
ISH11 Project Team	Dr Helen Locher, Team Leader, Sustainable Hydropower Specialist Dr Jens Sjorslev, Social Specialist Dr Bruce Aylward, Economics Specialist Mr Kent Hortle, Fisheries Specialist Dr Ilse Stubauer, Aquatic Ecologist Dr Lois Koehnken, Sediment, Water Quality & Hydrology Specialist Mr Frank Lieber, Database Specialist Dr Mak Solieng, Cambodia National Consultant Dr Latdaphone Banchongphanith, Lao PDR National Consultant Dr Apichart Termvidchakorn, Thailand National Consultant Dr Nguyen van Tuan, Viet Nam National Consultant
MRCS ISH Staff	Voradeth Phonekeo, ISH Programme Coordinator Simon Krohn, ISH Chief Technical Officer Piseth Chea Inthaneth Norasingh Athanaphone Chanchouly Vansath Sisadeth, Junior Riparian Professional Socheat Penh, Junior Riparian Professional Hung Dang Van Viet, Junior Riparian Professional Janka Rokob

ISH11 Document History

Date	Authors	Status	Comment
31 Mar 2013	Ilse Stubauer	ISH11 Phase 1 Report Aquatic Ecology Annex	An Annex to the ISH11 Phase 1 Report 31 Mar 2013
20 Dec 2013	Ilse Stubauer	ISH11 Phase 2 Report Aquatic Ecology Annex	Information updated based on inputs and further research. Includes a status and gap analysis against the Guiding Framework. Includes more specific recommendations for improvement proposals based on further research and consultations. Includes an Annotated Bibliography and Response to Comments Received.

Abbreviations and Acronyms

AIP	Agriculture and Irrigation Programme (of the MRCS)
ATSPT	Average Tolerance Score per Taxon
BDP	Basin Development Planning Programme (of the MRCS)
BOKU	University of Natural Resources and Life Sciences, Vienna, Austria
CCAI	Climate Change Adaptation Initiative (of the MRCS)
CNMC	Cambodia National Mekong Committee
DCA	Detrended Component Analysis (statistical method)
EHM	Ecological Health Monitoring (within EP)
EP	Environment Programme (of the MRCS)
FMMP	Flood Management and Mitigation Programme (of the MRCS)
FP	Fisheries Programme (of the MRCS)
IBFM	Integrated Basin Flow Management
IC	International Consultant
IKMP	Information and Knowledge Management Programme (of the MRCS)
ISH	Initiative on Sustainable Hydropower (of the MRCS)
IUCN	International Union for Conservation of Nature
LMB	Lower Mekong Basin
LNMC	Lao PDR National Mekong Committee
MHS	Multi Habitat Sampling
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NC	National Consultant
NMC	National Mekong Committee
OAA	Other Aquatic Animals
PCA	Principal Component Analysis (statistical method)
QA/QC	Quality Assurance / Quality Control
RSAT	Rapid basin-wide Sustainability Assessment Tool
TNMC	Thailand National Mekong Committee
ToR	Terms of Reference
VNMC	Viet Nam National Mekong Committee
WI	Work Instruction
WUP	Water Utilization Program
WWF	World Wide Fund for Nature

Table of Contents

List of Figures

List of Tables

1 Context within the ISH11 Baseline Monitoring Project

Biomonitoring to assess the ecological health or ecological status of freshwaters (mainly rivers) has evolved primarily in Europe and the USA since 1900, whereas in Asian regions assessment approaches are mainly based on analysis of chemical data. As proven in Europe, Australia and North America, biological data are worthwhile for detecting environmental degradation and determining the ecological status of rivers. While water quality data are often indicating the situation at present and react in short term to changes, most aquatic biota indicate conditions over time as they have long life spans and have to cope with different environmental situations. Nevertheless, some biota also react to sudden changes of important factors.

The value of the manifold services that healthy aquatic ecological systems provide to the society must not be underestimated and in this context, the importance of biomonitoring has to be highlighted. Ecosystem services such as self-purification capacity and its relation to groundwater and clean drinking water are often taken for granted. Maintaining robust aquatic ecosystems provides several other services like habitat for fisheries and food production, spawning grounds for fish (see also Annex on fisheries) or habitats for indigenous species to support biodiversity. Societal benefits for humans like traditional way of life, recreational areas etc. are also part of ecosystem services (Barbour & Paul 2010).

With respect to hydropower planning and management, aquatic life plays a key role in defining the state of the river and riverine environment before potential environmental impacts (e.g. by alterations of flow, habitat, temperature and other physical parameters) happen (some details are given in chapter 4). After establishment of hydropower plants, monitoring aquatic ecology parameters helps to understand ecosystem health and related services as mentioned.

For all disciplines, the ISH11 ToR outlined that:

"The study should build upon existing knowledge, information and monitoring experience within the MRC framework and other relevant initiatives in the LMB".

For aquatic ecology, data from MRC Ecological Health Monitoring under EP is the first priority to be used. The data have been collected for several years with the same effort and consistent methods. They have been developed by international expert together with local specialists and thus incorporate both some international best practices and local knowledge on applicability and constraints.

Within ISH11, several disciplines target various environmental issues. Some of the many linkages between aquatic ecology and other environmental disciplines are outlined below.

Water quality:

- Oxygen content and organic matter often relate to pollution indicators that can be derived from macroinvertebrates.
- Statistical analyses and plots (e.g. PCA, DCA) combining macroinvertebrate and diatom taxa with chemical parameters can help identify indicators that have the greatest explanatory power for environmental changes observed.
- The amount of nutrients in reservoirs analysed in relation to faunal composition can provide insights into the degree of siltation and accumulation in the reservoir.
- Water quality classes suitable for aquatic life can be linked to Ecological Health Classes.

Sediments and Hydrology:

- Sediment size classes from sediment monitoring and substrate characteristics estimated during field work can relate to aquatic fauna and flora composition, if both data collections are done at the same sites and time (e.g. MHS protocols, see Attachment 7 to this Annex)
- Major changes in sediment along the longitudinal gradient of the river can relate to aquatic fauna and flora composition patterns
- Changes in species composition can be strongly related to changes in flow velocity, water depth and other hydraulic parameters
- Notable changes in species composition can in cases be related to habitat fragmentation

Fish ecology:

- Other aquatic animals (OAA) found at a site in fisheries monitoring may have relationships to the taxa sampled directly in the river. This may not provide direct linkages, as OAA are specifically hunted at certain parts of the river whereas standardised sampling may use different substrates, but it may have added value on the faunistic overview and the taxa catalogue used in aquatic ecology.
- Findings from river monitoring at the same site, e.g. in relation to ecological status or stomach contents in fish, can relate to biota present at a site and combined information can greatly enhance understanding of linked processes.

2 Best Practice in Aquatic Ecology Monitoring

2.1 Monitoring Objectives

Many best practice approaches in aquatic ecology monitoring use biological groups indicating mid- to long-term interactions with environmental conditions and reacting predictably to pressures along a gradient. Sound approaches monitor two or more biological groups to address different levels in the food web. The issues when using biological groups in aquatic ecology monitoring are outlined below.

- *Planktonic organisms* are not well-integrated in routine monitoring. On the one hand this is because they are considered to indicate more the water quality in the water column; on the other hand monitoring approaches have mainly been developed in temperate rivers where occurrence of plankton is limited. In terms of tropical streams and related to hydropower, monitoring plankton needs to be further discussed for the Mekong (e.g. algal (phytoplankton) blooms, zooplankton as the critical food resource for fish larvae).
- *Microalgae* (diatoms) are known to reflect short-term changes (e.g. nutrient level, physical changes), to have high reproduction rates and short life cycles. Being dependent on light, their use in large rivers with high suspended solids is a challenge.
- *Macrophytes* play an important role e.g. in the wetlands, in the delta and the inundation area. They are not integrated in routine bio-monitoring in the LMB, as far as known to date.
- *Macroinvertebrates* are the main group used in bio-monitoring worldwide due to long-term use in many countries. They are key components in food webs, linking nutrient resources with higher trophic levels. They have long-life spans and life-stages of different sensitivities.
- *Fish* are long-lived, mobile, indicate various habitat conditions, and are on top of the aquatic food web. They are mainly used to monitor mid-term to long-term effects. Being of major importance for the LMB, fish are considered separately (Section 6 and the Fisheries Annex).

Microalgae, macroinvertebrates, and fish are the groups mostly used worldwide in general, as well as specifically for hydropower-related monitoring. During field work, site and habitat characteristics as well as physical parameters like conductivity are recorded per site in best practice approaches to be able to link biological indicators to certain changes e.g. in hydromorphology.

Routine monitoring of aquatic ecology is not too costly, e.g. compared to assessing toxic pollutants chemically or with toxicity tests. Aquatic ecology monitoring is used worldwide complementary to (chemical) water quality monitoring, providing information over longer time spans based on the life cycles of biota.

A monitoring programme for aquatic ecology should ideally give a picture of the whole basin. The ISH11 project focuses on the Mekong mainstream and includes transboundary issues, but certainly information regarding catchment and tributaries is important e.g. regarding hydropower cascades and upstream/downstream effects. Biota do not “adhere to sharp borders” and both longitudinal and lateral information is essential.

Regarding information for hydropower planning and management, reactions of aquatic ecology to changes in and along the river need to be understood. These topics may be challenging, both due to lack of scientific background knowledge for certain regions in general and due to multiple pressures especially on large rivers.

2.2 Field and Laboratory Work

This chapter does not focus on describing methods for all aquatic ecology groups in detail, but aims on highlighting general aspects and providing examples for good-practice field and lab work. Examples for field work procedures in aquatic ecology, which are based on international approaches, are described in the MRC "biomonitoring handbook" (MRC 2010a).

Field and laboratory methods as well as data analysis for aquatic ecology are mostly tailored to river systems where they are applied. Thus there is no singular worldwide best practice approach available. Methods in use must be appropriate for the river system under study. Some general issues to be considered are mentioned below:

- Existence of standardised methods in field work and correct application
- Existence of standardised methods in lab work and correct application
- A specific issue is taxonomic identification, which needs ongoing capacity-building and training to maintain competencies

For large, turbid rivers especially field methods are a challenge. Sampling needs to give a realistic picture of the biology of such rivers, but it is evident that it has to be targeted to certain parts of the rivers. A standardised sampling approach allows collecting representative data for reliable assessment. EHM includes standardised approaches for all biological groups.

It also takes into account the difficulties that occur in large rivers, e.g. by sampling invertebrates in littoral areas and mid-channel with different methods. Littoral sampling is done in wade-able areas with a hand-net. Deeper sections are sampled by boat and with a grab, which is good practice in aquatic ecology monitoring for large rivers.

Figure 1 – Littoral sampling in EHM. Photo from MRC

Figure 2 – Grab for sampling invertebrates in deeper-water areas. Photo from BOKU

Besides the already mentioned methods in the MRC "biomonitoring handbook", a further example is provided in the attachments on the so-called Multi Habitat Sampling (MHS), which is widely used in Europe and the US to collect invertebrates. The MHS has been adapted and applied in several Asian countries and is also used in the LMB (Getwongsa & Sangpradub 2008, Uttaruk et al. 2011). The MHS method is applicable for wade-able sections of a river. For a large river like the Mekong mainstream, such a method provides data for only a part of the river- similar to littoral sampling in EHM. The littoral zone represents the wade-able near-shore areas. Biota collected there are indicative for human influences to those parts of the river. The method is very similar to the littoral sampling approach in EHM. It includes a higher degree of standardisation via habitat specific sampling and provides possibilities to link invertebrate data to substrate.

Figure 3 – MHS-net and MHS-sampling. Photo from BOKU

For invertebrates, sampling both littoral and benthic (deeper-water) areas is a very good approach. Using a grab is a simple, effective approach, when applied correctly. It is good for sampling fine substrates, but needs to assure that stones do not get stuck between the two halves of the grab. This would cause a leakage of the substrate without knowing how much is left in the grab.

Lab work for invertebrates needs highly trained personnel, both for sorting and identification.

For benthic diatoms, again mostly the wade-able section of the river is sampled (as in EHM). As diatoms are plants, they need light and are thus not abundant or even not occurring in deep parts of turbid rivers. Field methods do not need much equipment (bottles, brushes). Lab work is time consuming and identification needs highly skilled personnel.

Zooplankton sampling is also not costly and is easy, but lab work needs highly skilled personnel. Phytoplankton sampling is time consuming in the field, but if only productivity is measured, not much lab work is needed. For plankton sampling, turbidity of rivers is a challenging factor regarding presence of plankton and application of nets (clogging by suspended solids).

For lab work in general, best practice is aiming on receiving high quality taxa lists for all biological groups investigated. This starts with quality assurance in e.g. sample preservation, allocation of unique sampling codes, correct sample storage etc. Sorting processes need to follow standardised approaches. Species identification needs to be done to the best level possible and taxonomic identification keys need to be up-to date and applicable for the area under study.

Figure 4 – Plankton net. Photo from MRC

2.3 Data Analysis

For analysing data with respect to hydropower there is no defined common approach available in aquatic ecology that could be followed.

The approaches used in aquatic ecology are e.g. use of Diversity or Biotic Indices, Multimetric or Multivariate Approaches or Functional Approaches. Examples are e.g. the European Water Framework Directive (2000), the ANZECC guidelines (2000) and the Australian River Assessment System (AUSRIVAS) or several US EPA guidelines (e.g. Barbour *et al*, 1999).

Multimetric systems (e.g. Multimetric index, Index of Biotic Integrity; Karr 1993, Karr & Chu 1999) are very much used for evaluating reaction to stressors, including a reference site based approach (benchmark against which investigated sites can be compared).

Such best practice approaches need to be developed tailor-made for freshwater ecosystems. Most methods include the following:

- Typology, based on e.g. freshwater ecoregions; catchment size classes, altitude classes and main geology (classes),
- A set of reference sites per type
- A set of impaired sites (pre-classified via environmental variables along a gradient)

- Sampling with standardised methods for all sites, including measuring physico-chemical and environmental variable at the respective sampling site
- Developing stressor-specific assessment methods including benchmarks against which investigated sites can be compared.

Multimetric approaches represent a means to integrate a set of metrics, which represent structural and functional attributes of an ecosystem (such as taxa richness, abundance, dominance, functional feeding groups …) (Li Li et. al 2010). An issue in data analysis is the interpretation of cause and effects. Indicators that are able to discriminate effects of hydropower need to be developed specific to the river system under study.

2.4 Data Management

The data collected for aquatic ecology parameter groups should not be stored only for project-specific or for short-term use. Data should not be stored in a software programme or format that makes data storage and use error prone. A user-friendly database including good metadata information is state-of-the-art and enables data availability for long-term use.

Biological data storage also requires up-to-date taxonomic information, i.e. valid taxa names, correct spelling, correct taxonomic hierarchy etc. Taxa catalogues that lie in the background of a database can be kept up-to-date without losing data.

A biomonitoring database may serve as central aquatic ecology database to support all kinds of information needs, including for hydropower planning and management.

3 Aquatic Ecology Monitoring in the LMB and State of Knowledge

3.1 Overview on Data Availability

Scientific studies on taxonomic issues for specific aquatic groups in the Greater Mekong Basin started in the time of faunistic expeditions in the 19th and early 20th century (e.g. freshwater mussels and snails in Viet Nam by Crosse & Fischer, 1876; caddisflies in Thailand by Martynov, 1931). Such studies provide detailed information on single groups / families / species but do not give broad overviews of aquatic ecology. These studies provide some inputs necessary to catalogue the aquatic fauna and to derive ecological information. Such catalogues provide basic information in developing and applying ecological health assessment systems.

In the past few decades, several studies covering topics within the fields of "aquatic ecology", "biological assessment of freshwater ecosystems" and "ecological health of rivers" in the Greater Mekong Subregion have been carried out. The information is scattered and patchy both in terms of biological groups and geographical coverage under study. Studies sometimes focus on single rivers, catchments, sub-basins and / or specific taxonomic groups, and are short-term or single data collection events (e.g. Grimas, 1988).

As a result of a water quality workshop in Bangkok in 1986, attempts for a biological investigation programme complementary to the chemical water quality monitoring started (Smith, 1988, Hart *et al.,* 2001). Eleven sites in the Mekong mainstream were investigated for benthic invertebrates and 27 in the tributaries / plain of reeds. These older data would be interesting to review to see which taxa were found before the operation of dams, and they also may provide valuable input into the taxa catalogues to be used in the "biomonitoring database", but unfortunately the report does not provide species lists.

Authors of reports to the MRC suggested previously that "efforts should be made to collect all published and unpublished information on the biology and ecology of the Mekong River and its tributaries, and to prepare a synthesis of this information that summarises current knowledge in this area" (Hart *et al*. 2001). Although a variety of information has been collected covering the biology of the Mekong and its tributaries, the information is not easily available, because not all is stored in a central location or it is not available electronically.

The MRC has made attempts to gain an overview on bioassessment in freshwater ecosystems in the Member Countries in 2001 and 2002, when local experts were contracted for this purpose. The reviews were not specific for the Mekong River, but country-related (Parnrong Supatra, 2002 for Thailand; Pan Van Niem, 2002 for Viet Nam; Srum Lim Song et al., 2002 for Cambodia). The reports provide information in different ways, partly on different topics, and with different degrees of analysis and rigour. They include information about, for example, methods that were tested for aquatic bioassessment, regions where studies have been undertaken, skilled personnel in the countries, and literature lists. The three reports do not contain any raw data on aquatic ecology, and as they discuss information at a country level, existing data from the Mekong mainstream are not highlighted. The Cambodian report also mentions that there are some institutions that collect data on aquatic ecology, but methods and interpretation are not unified and at that time there was "limited capacity in terms of expertise, staff, and networks for biological assessment".

In the following years the MRC has undertaken several efforts to improve such limitations. The efforts and resulting biomonitoring programme - the Ecological Health Monitoring - are described in Section 3.2.

For aquatic ecology data that supports hydropower-related information needs, the focus has to be on data from standardised sampling, which is the case with the MRC's Ecological Health Monitoring. A high degree of standardisation in terms of sampling, sorting and to some extent identification is

needed in aquatic ecology, to ensure comparability of data. Indicators like biomass or richness depend on field and lab methods applied. Calculations of indicators have a high degree of uncertainty if different methods are applied, and as a consequence interpretations made cannot be considered then.

The availability and accessibility of the MRC biomonitoring data was clarified during Phase 1 of the ISH11 study. The data have been reviewed regarding locations, timing of sampling, parameter groups sampled, methods applied in field and lab, and data evaluation. Details are given in Sections 3.2 to 3.6.

Additional to the MRC Ecological Health Monitoring, ISH11 national consultants were asked to discuss availability of other aquatic ecology routine monitoring data with NMCs and Line Agencies The ISH11 international consultant further discussed this topic during technical workshops with Line Agencies. Other sources of potential information, such as Mekong Wetlands Biodiversity Programme, IUCN, WWF etc. have been screened for data availability.

It became clear that research studies for e.g. hydropower companies are done by universities but the data go back to the data owner and are often not publicly available. Other sources of information mentioned above do not provide data in the format needed.

As a result the ISH11 –study has focussed on EHM data for its review and improvement suggestions.

3.2 Development of the MRC Ecological Health Monitoring

Article 3 of the 1995 Mekong Agreement aims “to protect the environment, natural resources, aquatic life and conditions, and ecological balance of the Mekong River Basin…..”. Water quality monitoring assesses potential water pollution that may affect the river’s aquatic ecology, and thus covers one part of this aim (details provided in the ISH11 Phase 2 Water Quality Annex).

Monitoring biota directly was initiated in 2002 through the *Ecological Health Monitoring Programme* (in previous years called “biomonitoring”) with the intention to assess and monitor the long-term ecological health of the lower Mekong River. During a pilot study in 2003 carried out under MRC financial support by international consultants and local experts, the following biological groups were selected for application *1) Zooplankton, 2) Benthic diatoms, 3) Littoral macroinvertebrates* and *4) benthic macroinvertebrates.*

Phytoplankton (primary production), macro-algae and fish were tested for inclusion in the EHM, but it was found at the time that these groups were not suitable mainly due to practical reasons.

The overall objective of the programme was to survey biological groups that were defined to have priority for the LMB in 2002 and 2003 under the guidance of an international team. A set of sites was selected for investigation with the purpose to cover sub-areas in the LMB. They should include different management interests. Some reference sites were selected, defined by six criteria related to physico-chemical parameters and human influences upstream of and adjacent to a site. Data from reference sites were used to calculate biological benchmarks against which data from any site in the LMB can be compared as per definition of the method.

A regular, ongoing monitoring based on the four biological groups named above began in 2004 in the Mekong and selected tributaries in Cambodia, Lao PDR, Thailand, and Viet Nam. From 2004 to 2007, methods for sampling and analysing were tested and refined in line with international best practice approaches. Field and lab work was done by one team comprising experts from line agencies of all four LMB countries and international experts.

During the research period, five zones of the Lower Mekong were verbally described via flow effects and substrate characteristics, as physical habitats vary along the course of the Mekong River. A short,

more general overview on macroinvertebrate and algal composition and possible alterations induced by flow-changes was worked out (IBFM reports).

The five zones were not used to set up a river typology, which is in many best-practice approaches used to define biological bench-marks per type. One reason was that based on the number of sites, differences in types could not clearly be found (Campbell et al 2009).

In more detail, the sites investigated in 2004-2007 for biomonitoring jointly by a team of international and national experts were selected and distributed along the LMB sub-areas as follows:

- The sites surveyed in 2004 were chosen to provide a broad geographic coverage across the Lower Mekong Basin.
- In 2005 site selection focused on geographical distribution in northern Lao PDR and the northern parts of Thailand, both in the BDP sub-area 1 (Northern Lao) and 2 (Chiang Rai), and southern Lao PDR and eastern Cambodia, in sub-area 7 (Se San/SrePok/Se Kong).
- Data collection in 2006 focused on the Mekong mainstream and major tributaries downstream of Stung Treng (Cambodia), including sites in sub-areas 6 (Southern Lao), 7 (Se San / Sre Pok / Se Kong), 8 (Kratie), 9 (Tonle Sap), and 10 (Delta).
- A survey in 2007 was done in central Lao PDR, and along the border of Lao PDR and Thailand. Sites from previous years were re-sampled in the Se Kong River (Lao PDR and Cambodia), the Se San and Sre Pok in Cambodia. The sites were in sub-areas 3 (Nong Khai / Songkram), 4 (central Lao PDR), 5 (Mun-Chi), 6 (southern Lao PDR), and 7 (Se San / Se Kong / SrePok).

The whole monitoring programme was financed by the MRC Environment Programme. In 2008, monitoring was handed over to the National Mekong Committees and Line Agencies in the four LMB countries, accompanied by training activities.

Figure 5 shows the EHM programme timeline.

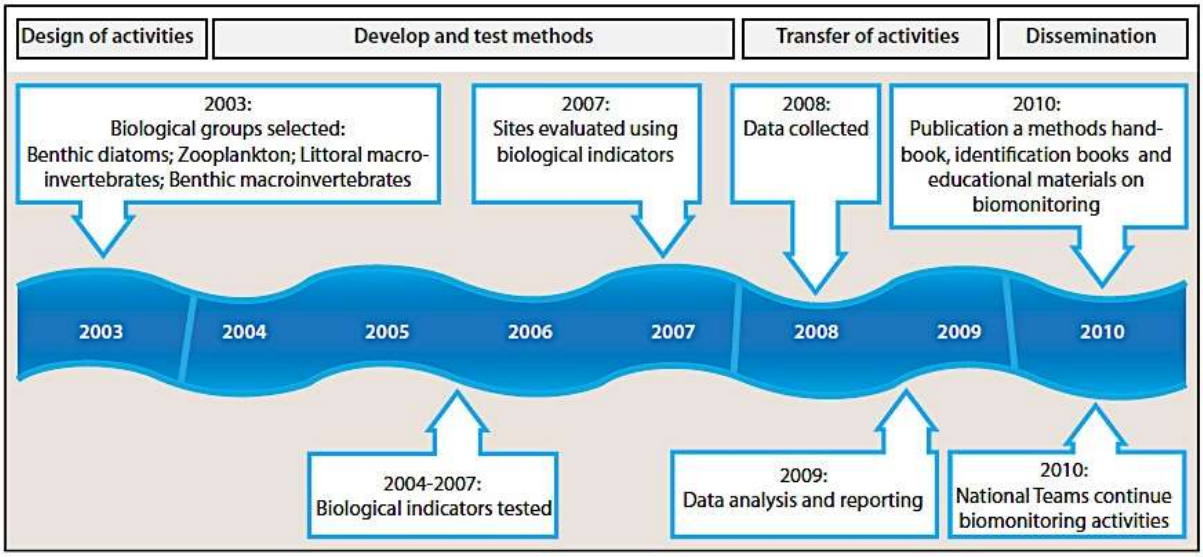


Figure 5 – Timeline for "biomonitoring" (EHM) in the LMB (Mekong and tributaries)

3.3 Sampling Sites and Timing in EHM

A total of 68 sites were sampled from 2004 to 2008 in the LMB, some of them multiply visited. Of these, 12 sites are directly located along the Mekong mainstream and 56 in the tributaries; some were sampled in the junctions of the Mekong and tributaries.

In 2011 and 2013 a total of 41 of sites were investigated for ecological health monitoring by NMCS and line agencies, including the 12 Mekong mainstream sites and 29 tributary sites (Larsen, *pers. Comm.*). In Laos, Thailand and Viet Nam 8 sites were sampled each. In Cambodia 17 sites including 9 new sites never sampled before were monitored.

Table 1 shows the number of sites per year. Information is taken from the biomonitoring database and may be not fully consistent with EHM maps and graphs shown in EHM report cards, as some sites are not displayed for various reasons.

Table 1 – Number of sampling sites per year

Year	No of sites
2004	20
2005	16
2006	21
2007	20
2008	32
2011	41
2013	41

Table 2 informs about site name and code and parameter groups sampled per year for the 12 Mekong mainstream sites.

Table 2 – EHM Mekong Mainstream sampling sites, 2004 – 2008 as available in Access biomonitoring database; information about 2011 and 2013 received from EP

Country	SiteCode	River	Site name	2004	2005	2006	2007	2008	2011*
Lao PDR	LDN	Mekong	Dome Noi				B, L, D, Z	B, L, D, Z	B, L, D, Z
Lao PDR	LMX	Mekong	Xiang Kok		B, L, D, Z			B, L, D, Z	B, L, D, Z
Lao PDR	LPB	Mekong	Luang Prabang	B, L, D, Z	B, L, D, Z			B, L, D, Z	B, L, D, Z
Lao PDR	LVT	Mekong	Ban Huayhome	B, L, D, Z			B, L, D, Z	B, L, D, Z	B, L, D, Z
Thailand	TCS	Mekong	Chiang Saen					B, L, Z	B, L, D, Z
Thailand	TNP	Mekong	Nakhon Phanom					B, L, Z	B, L, D, Z
Cambodia	CKT	Mekong	Kampi pool	B, L, D, Z		B, L, D, Z		B, L, D	B, L, D, Z
Cambodia	CMR	Mekong	Ramsar Site		B, L, D, Z	B, L, D, Z	B, L, D, Z	B, L, D	B, L, D, Z
Cambodia	CNL	Mekong	Nak Loeung			B, L, D, Z			B, L, D, Z
Viet Nam	VCL	Mekong	Cho Moi			B, L, D, Z		B, L, Z	B, L, D, Z
Viet Nam	VTT	Mekong	Tan Chau					B, L, Z	B, L, D, Z
Viet Nam	VVL	Mekong	My Thuan					B, L, Z	B, L, D, Z

Key:

- B = Benthic invertebrates; L = Littoral invertebrates; D = Diatoms; Z = Zooplankton
- 2004 to 2008: data in biomonitoring database
- 2011*: some data in excel and partly only in word; 2013: same sites as in 2011, data under preparation

Attachment 1 gives more information about rivers, locations and years for the whole EHM (tributary and Mekong mainstream sites). Exact sampling locations seem to have been shifted along the years. Sites with same three-letter-codes do not have the exact same names in the single years, and geographical coordinates available in the database are almost never identical for the single sites.

In principle, zooplankton, diatoms, littoral and benthic macroinvertebrates were investigated per site. In practice, for some sites one or other parameter group is missing in the database due to several reasons.

Figure 6 shows the locations of Mekong mainstream EHM sites and their position regarding existing and planned mainstream hydropower dams. The green dots indicate sites samples from 2004 to 2008; the red dots and red three-letter codes show sites from 2011 (re-sampled in 2013). Different positions of green and red dots for the same site name/site code are also shown, because sites have been slightly shifted between the years (coordinates' information 2004-2008 taken from Access "biomonitoring database"; 2011 coordinates received from EP)

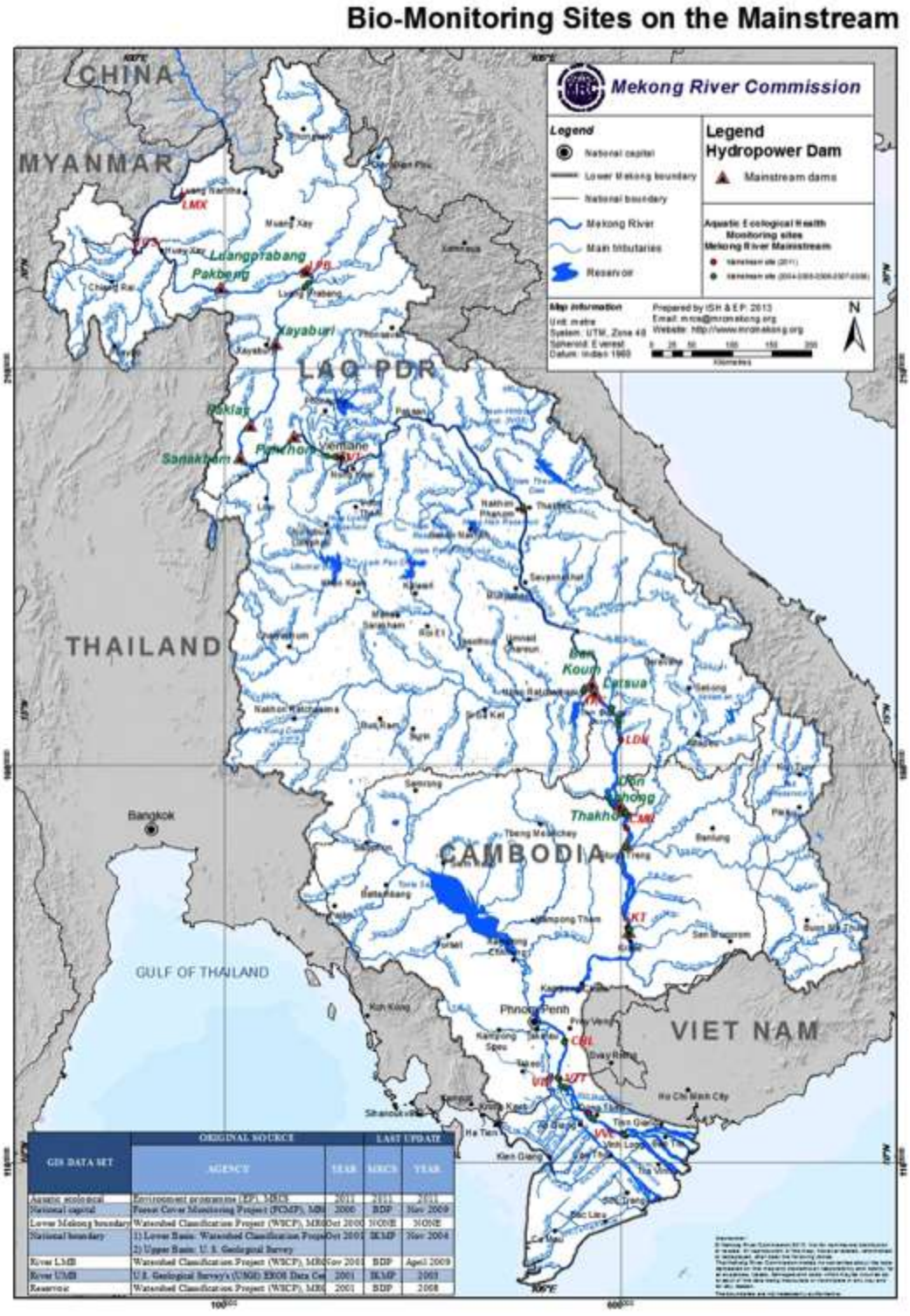


Figure 6 – Mekong Mainstream sites sampled in MRC Ecological Health Monitoring

EHM is currently planned in a two-year cycle. Field work has to be done in the low flow period, as specified in the EHM methods ("biomonitoring handbook"), which is preferably during dry season in March or April. Assessment method development regarding Ecological Health Class has been made with data from the dry season. The system is thus based on and calibrated to biota present at this low flow period. To receive reliable, good quality data and results, exact adherence to dry season sampling is important. Whenever the sampling is shifted to rising or high flow season, data must be looked at critically as evaluation results may be questionable.

3.4 Field and Laboratory Work in EHM

The following information is recorded per sampling site:

- Environmental variables, noted in a field data sheet like river width, depth, Secci-depth, pH, temperature…
- Substrate characteristics score (ranking substrate suitability as habitat for invertebrates)
- Site disturbance score via a set of 12 questions on human influences (info on water diversions, channel alteration, bank stability, extent of riparian vegetation, human activities at and above the site)
- Biological samples on
  - Benthic diatoms
  - Littoral invertebrates
  - Benthic invertebrates
  - Zooplankton

For all 4 biological groups *standardised field protocols* for sampling were developed and are in use as well as field data sheets for substrate characteristics, environmental variables and recording a so called site disturbance score (which is later used for site evaluation).

Field data sheets are available for:

- Environmental variables
- Substrate characteristics scoring
- Site disturbance scoring
- Benthic diatoms collection
- Zooplankton collection
- Littoral macroinvertebrate collection and benthic macroinvertebrate collection, both recording also substrate types

Field gears, application of sampling and sample storing are described in detail in the "Biomonitoring Methods for the Lower Mekong Basin" (MRC 2010a). This biomonitoring handbook has also been translated into the four riparian languages.

The figure below gives an example for sampling macroinvertebrates.

A D-frame net with 30cm x 20cm opening and mesh size of 475µm is used for sampling.

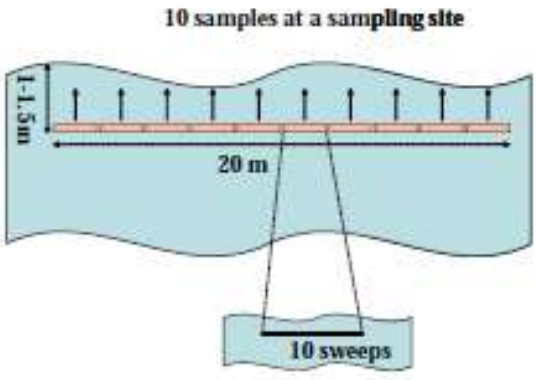


Figure 7 – Net for sampling littoral invertebrates and sketch for sitting of samples at site

Procedures to be applied in aquatic ecology after field work differ for each of the biological groups. Important common procedures address proper preservation, labelling and storage of samples as well as sample treatment according to given protocols and work instructions. For EHM, those are described in the "biomonitoring handbook" (MRC 2010). To produce good quality data one critical step in aquatic ecology worldwide is identification of taxa. This requires experts with up-to-date identification knowledge, adequate equipment (microscopes), and up-to-date identification literature valid for the region where it is applied.

For identification of taxa in the EHM process, a benthic invertebrate key for the LMB is available (Sangpradub & Boonsoon 2006) and an update is planned. A key for zooplankton is on the way (Phan Doan Dang, Nguyen Van Khoi, Dang Ngoc Thanh, Ho Thanh Hai and Le Thi Nguyet Nga, in print) as well as for diatoms (Tatporn Kunpradid, Pongpan Leelaharangkri, Suttawan Supan, Yuwadee Peerapornpisal, in print). For each of the four biological groups, the outcomes of the lab work are taxa lists per sample (taxon name and number of specimen), noted in excel sheets. Quality assurance and quality control issues and approaches have been raised and discussed during the EHM development process, but have not been implemented to date.

3.5 Data Analysis in EHM

Biological metrics calculation methods for classification of ecological health were also developed and standardised for further application during the 2004 to 2007 activities in biomonitoring. Candidate metrics were tested against environmental variables. Selection of metrics and calculation is described in detail in the MRC Technical Paper No. 20 (MRC 2008). The 3 biological metrics – also called indicators – used for site classification are abundance, average richness and tolerance, expressed as mean Average Tolerance Score per Taxon (ATSPT) per site for each of the 4 biological groups.

The calculation is done by team members, and since 2008 has been the responsibility of the NMC / Line Agency teams performing the EHM. An excel sheet with calculation modes has been prepared and distributed amongst the NMCs. In case of new findings or new species, the taxa lists used by the Line Agencies are updated by the respective expert in charge in each country, and consequently the lists differ for the four countries. The 12 indicators resulting from the calculation are compared against benchmarks that were derived from assessment of reference sites sampled in EHM. River typology resulting in different indicators or benchmarks for Mekong mainstream and small tributaries is not included. The guidelines for site classification are as follows:

		Reference site values		
Indicator	Biological group	10th percentile	90th percentile	Guideline of healthy ecosystem
Abundance (mean number of individual organisms per sample).	Diatoms	136.22	376.34	Greater than 136.22
	Zooplankton	22.33	174.07	Greater than 22.33
	Littoral macroinvertebrates	46.68	328.56	Greater than 46.68
	Benthic macroinvertebrates	5.37	56.34	Greater than 5.37
Average richness (mean number of taxa per sample).	Diatoms	6.54	11.78	Greater than 6.54
	Zooplankton	9.80	20.20	Greater than 9.80
	Littoral macroinvertebrates	5.37	18.48	Greater than 5.37
	Benthic macroinvertebrates	1.87	7.88	Greater than 1.87
Average tolerance Score per taxon (ATSPT).	Diatoms	30.85	38.38	Less than 38.38
	Zooplankton	34.83	41.80	Less than 41.80
	Littoral macroinvertebrates	27.80	33.58	Less than 33.58
	Benthic macroinvertebrates	31.57	37.74	Less than 37.74

Figure 8 – Guidelines for site classification *(taken from MRC 2010)*

The number of indicators meeting the guidelines is transferred to one of 4 Ecological Health Classes, based on a classification system (e.g. if 10-12 indicators shown in Figure 8 meet guidelines given in rights column the site is rated as class A).

The resulting EHM classes per site are presented in tabular form (Table 3) and in maps both in EHM Report Cards and as MRC Technical Reports.

Table 3 – Sampling sites, years and Ecological Health Classes (Information received from EP, in Report Card 2011 print)

Site Code	Location	Year				
		2005	*2006*	*2007*	*2008*	*2011*
Lao PDR						
LMX	Mekong River, Ban Xiengkok Luangnamtha	*B*			*D*	*D*
LPB	Mekong River, at Done Chor, Luangprabang	*A*			*B*	*A*
LVT	Mekong River (B. Huayhome) Vientiane			*B*	*C*	*C*
LBF	Sebang Fai River, Khammouan			*B*	*B*	*C*
LBH	Sebang Hieng River, Savannakhet			*A*	*C*	*B*
LSD	Sedone River, Ban Hae, Pakse			*B*	*B*	*B*
LKL	Lower Se Kong River, Ban Somsanouk, Attapeu	*A*		*B*	*C*	*C*
LDN	Mekong River, Ban Muang Pathumphone (Done Ngiew)			*A*	*B*	*A*
Thailand						
TCS	Mekong River , Chiang San				*B*	*B*
TKO	Nam Kok at Chiang Rai	*A*			*A*	*B*
TSM	Mekong Junction of Mekong-Songkram Rivers			*C*	*A*	*C*
TNP	Mekong River, Nakorn Panom				*C*	*B*
TNK	Nam Kham River at the Mukdaharn Province			*C*	*B*	*B*
TUN	Mun River, Ubon Rachathani				*A*	*A*
TMU	Mun River, Kong Chiam,	*B*			*B*	*C*
TKC	Mun-Mekong junction, Kong Chiam				*A*	*C*
Cambodia						
CMR	Mekong River, Ramsar Site, Stung Treng	*B*	*A*	*B*	*B*	*A*
CKM	Se Kong River, Kbal Koh, Stung Treng	*A*	*B*	*B*	*A*	*B*
CUS	Se San River, Dey It, Rattanakiri	*A*	*B*	*B*	*A*	*C*
CSS	Se San River, Veunsai, Ratanakiri					*B*
CSP	Srepok River, Phik, Rattanakiri	*A*	*A*	*A*	*B*	*A*
CSJ	Se San River, Downstream of Srepok River junction	*A*	*B*	*A*	*A*	*A*
CKT	Mekong River, Kampi Pool, Kratie		*A*		*A*	*A*
CPT	Prek Te River, Preh Kanlong, Kratie					*C*
CCK	Tonle Sap Lake, Chong Khnease, Siem Reap					*B*
CSK	Stoeng Sangke River, Battambang		*C*		*B*	*C*
CSN	Stung Sen River, Kampong Thom					*B*
CTU	Tonle Sap River, Peek Kdam Ferry, Kandal					*B*
CPP	Tonle Sap River, Phnom Penh Port					*B*
CPS	Pursat River, Damnak Ampil, Pursat					*B*
CKK	Bassac River, Koh Khel, Kandal					*B*
CNL	Mekong River, Neak Loeung, Prey Veng					*B*
CKL	Tonle Sap Lake, Kampong Luong		*B*		*C*	*B*
Viet Nam						
VTP	Mekong River Thuong Phuoc, Dong Thap				*C*	*B*
VTT	Mekong River Thuong Thoi, Dong Thap,				*C*	*B*
VKB	Bassac River, Khanh Binh, An Giang				*B*	*B*
VDP	Bassac River, Da Phuoc, An Giang,				*C*	*B*
VCL	Mekong River, Cao Lanh, Dong Thap		*C*		*C*	*B*
VLX	Bassac River, Long Xuyen, An Giang		*C*		*B*	*C*
VVL	Mekong River, My Thuan, Vinh Long				*C*	*C*
VCT	Bassac River, Phu An, Can Tho		*C*		*B*	*B*

3.6 Data Management in EHM

3.6.1 Data Storage and Availability

A "biomonitoring database" was established by EP and IKMP, compiling existing data provided by the Environment Programme. The MS Access database contains data collected between 2004 and 2008 during development and testing of biomonitoring methods (MRC 2010) in the Lower Mekong Basin under EP, as mentioned above. A short metadata file is available, providing limited information.

Data on four biological groups, 1) benthic and 2) littoral macroinvertebrates, 3) diatoms, and 4) zooplankton are stored by site, sampling event and sample. Short site descriptions and environmental variables are also part of the database. For most sites the ecological health class (A-D) is also recorded. Indicators used for deriving the EHM class are not recorded.

The database is used for data storage, providing a graphical user interface to access monitoring sites and related data. The database is not programmed as a tool for any calculation of biological metrics or similar indicators. It does not provide options for directly applying assessment methods.

Access to this database may be requested via the MRC data portal (portal.mrcmekong.org). A MRC Data License agreement is needed, but availability of the database is free of charge. Data are copyright protected and MRC has the exclusive right to publish the data.

Environmental variables are also part of the database, but some gaps are visible in the database. It is not clear if some data were not recorded in field work or if transfer to the database was missing.

Data from 2011 and 2013 are stored in Excel data sheets by the Line Agencies. Taxa related data are transferred to MRC-EP mostly in Excel format – but sometimes also only as word tables - after Ecological Health Monitoring is finished. Environmental data are not part of the excel lists. The information in the Excel sheets does not contain metadata and can only be meaningfully handled by personnel involved in the establishment of the data. Data from 2011 and 2013 are not yet included in the MRC database but it is planned to integrate them (Larsen *pers. comm.*).

3.6.2 Use in Reporting

Results from 2004-2007 were summarised in several MRC technical reports (Davidson et al. 2006; MRC 2008; Vongsombath et al. 2009a, 2009b). Data from the 2008 monitoring - not included in the testing phase – are published in a further technical paper (Dao 2010). The guidelines for biomonitoring methods are another important product based on this set of data, published only in 2010 (MRC 2010a).

A product to provide the general public with a short overview on the purpose, methods and outcome of ecological health monitoring is the Mekong River Report Card on Aquatic Ecosystem Health. It provides short text and a map showing monitoring sites and ecological health classes. Two cards were published to date: results from 2004- 2007 and from 2008. The Mekong River Report Card on Aquatic Ecosystem Health 2008 also shows temporal changes in EHM classes from 2004-2008. The 3rd Mekong River Report Card includes results from 2011 and in the process of being published.

4 Gap Analysis with Respect to ISH11 Guiding Framework

The guiding framework principles for information needs regarding hydropower planning and management are described in detail in the ISH11 Phase 2 Main Report.

4.1 Aquatic Ecology Information Needs and Parameters Relevant to Hydropower Planning and Management

Aquatic ecology parameters used to inform hydropower planning and management underlie some requirements such as: i) biota must be relevant for the area under investigation and ii) biota should be able to reflect environmental changes that may be induced by hydropower. Field and lab work done in a consistent way (use of same methods) and high personnel capacity especially for taxonomic identification for reliable quality data are two vital aspects, which are not limited to hydropower information needs. To answer management and cause-effect questions is often a critical issue in biology, as relationships are multi-dimensional and research on ecological basics of fauna and flora is not fully known but an ongoing process. There is no "one-and-only" aquatic ecology parameter to answer all hydropower related questions. Sound approaches monitor more than one biological group to address different levels in the food web and to reflect different spatial and temporal aspects.

Biota reflect the overall ecological integrity and ecological health of freshwater. They are often long-living and are incorporating many effects they are exposed to over time. The status of biological communities provides direct information to water managers, decision makers and the interested public about their environment, e.g. via coloured maps showing ecological status per site. Maintaining or restoring aquatic ecosystem integrity ensures that ecosystem services are intact, and requires that the biological, physical, and chemical components of overall ecological integrity are maintained (Barbour & Paul 2010). Some information required in context with hydropower is summarised below.

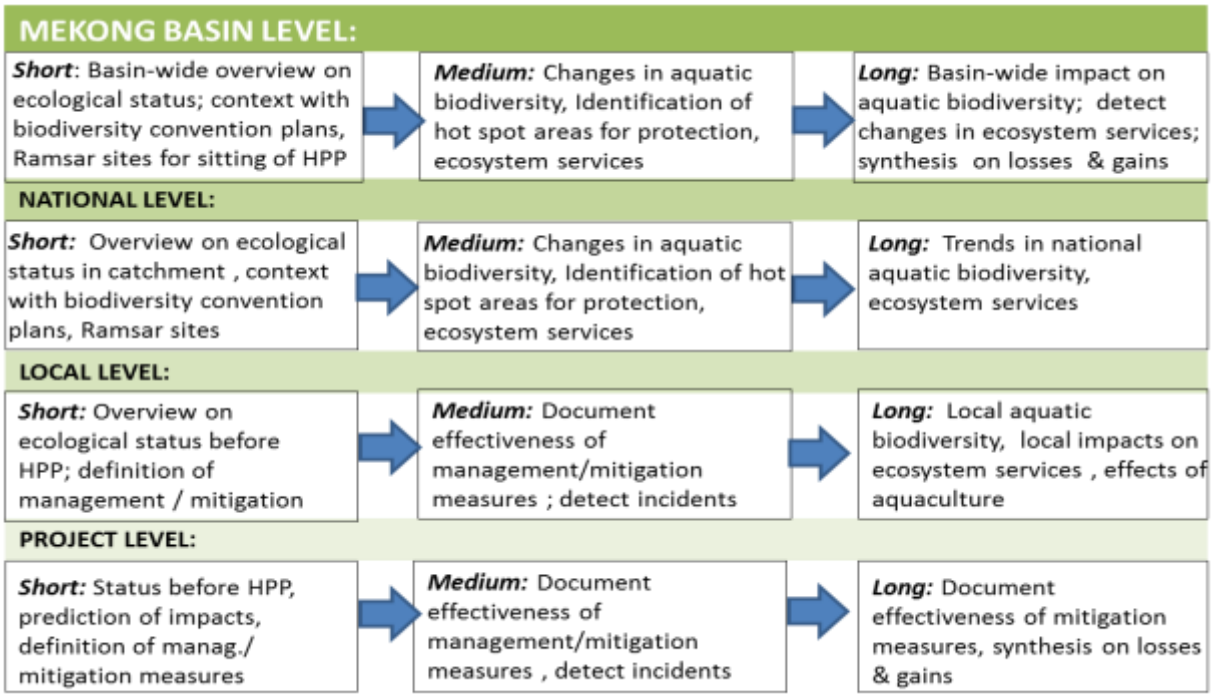


Figure 9 – Information needs to support hydropower planning

In aquatic ecology the focus lays on data sampled for different biological groups. These data are evaluated in context with possible hydropower related pressures. The main needs are to choose relevant sampling sites, collect standardised samples, to have standard approaches for laboratory sorting and to identify biota to the best level possible.

For defining appropriate aquatic ecology data to support hydropower planning and management, effects on the aquatic ecology have to be considered. Worldwide, rivers suffer from multiple pressures (e.g. Wong et al. 2007); this is also valid for the Mekong River (e.g. ICEM 2010). Cause-effect chains concerning biology and ecosystem functions and processes in (large) rivers are not easy to understand, and will be subject to research in the next years/decades worldwide (Vienna Declaration 2011). The goal should always be to maintain or achieve overall good ecological status of waterbodies as a basis for ensuring provision of aquatic ecosystem services.

Figure 10 gives an overview on issues to be considered in context with impoundments. The figure focuses on temperate rivers and may not directly be transferable to tropical rivers, but the principle interactions are shown.

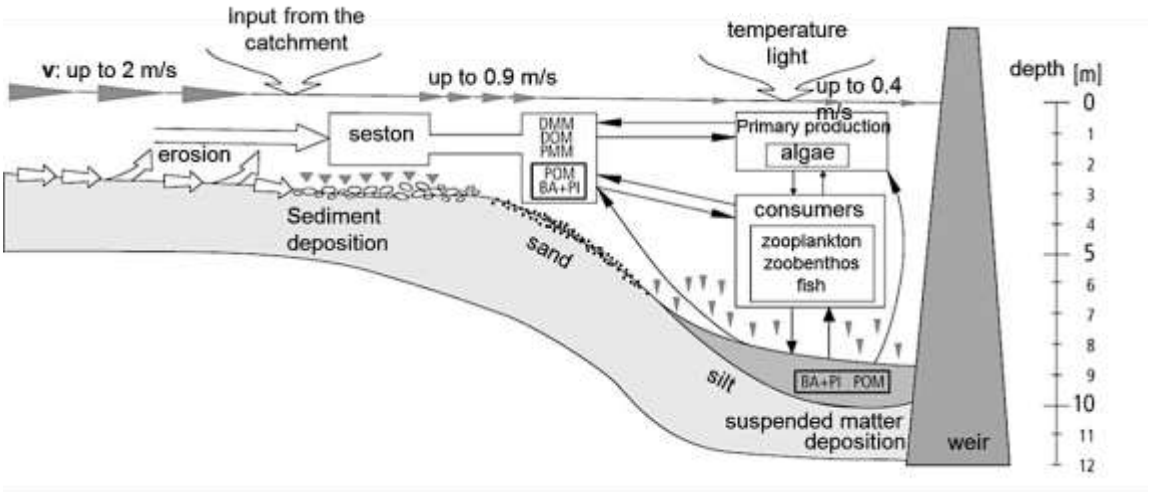


Figure 10 - interactions of aquatic ecology and physico-chemical parameters (Schmutz 2012 pers.comm)

Based on Figure 10, biological groups relevant to hydropower that should be monitored include:

- primary producers (phytoplankton, diatoms),
- primary consumers (zooplankton, zoobenthos i.e. macroinvertebrates), and
- secondary consumers (fish, zoobenthos i.e. macroinvertebrates).

Each biological group may provide information on the status of the environment via indicators. These can be calculated from biological data sampled. Examples for indicators are composition of taxa, richness, diversity, tolerance metrics, or presence or absence of certain biota compared to reference sites. Indicator development depends on the monitoring and assessment approach followed (standardised sampling) and state of ecological knowledge for the biological groups

The relevance for and questions occurring in context with hydropower planning and management are exemplified in detail for the parameter group aquatic invertebrates. Several aspects are also true for the other parameter groups diatoms, zoo- and phytoplankton, whereby these are more bound to water velocity and depth, water chemistry e.g. oxygen content, and nutrient content / mobilisation.

Table 4 - Parameters Relevant for Hydropower Planning – Examples of Aquatic Invertebrates

Parameter group	Relevance for hydropower planning and operation on basin level	Parameter / indicator examples
aquatic invertebrates (benthic and littoral)	Need to understand effects of hydrological and hydro-morphological changes on biota: (e.g. due to spatial and temporal changes in substrate type composition or water velocity) • impounded sections: effects both in reservoirs and on downstream sections; e.g. due to sediment trapping and retention, sediment flushing, fragmentation of functional habitats (stagnant vs free-flowing sections along the mainstream) • hydropeaking: effects on downstream sections; e.g. due to unnatural high/low runoff rates and amplitude, • minimum flow: effects on downstream sections; e.g. too little residual flow Need to understand associated effects e.g. changes in water quality on biota • oxygen content • Nutrient retention, accumulation of organic matter • Nutrient (re-)mobilisation	*changes in aquatic invertebrate biodiversity related with mentioned effects, may be expressed as "observed over expected values":* invertebrate species composition (site specific, in hydro-ecological zones, longitudinal) ratios in invertebrate taxa groups (indicating e.g. changes in sediment composition, biological responses to habitat quantity and distribution) flow indicators (e.g. as in IBFM report) No. of sensitive organisms within the whole catchment, percentage of loss of sensitive organisms ratios rheophilic to stagnophilic organisms grazers/filter feeders to collector dominated assemblages organisms indicating little organic amount (oligosaprobic) to organisms indicating higher organic amount (e.g. alpha-mesosaprobic) (link to water quality) changes in biomass of macroinvertebrates (link to fisheries indicators)

4.2 Gap Analysis – Locations

The present EHM monitoring network is designed to give a basin-wide overview on rivers in the LMB. Aquatic ecology information is present in all sub-basins of the LMB and in each hydro-ecological zone, but the total number of 12 sites in the Mekong mainstream is a very small number compared to the 2,300 km river length. The longitudinal distribution of biota along Mekong mainstream is not adequately reflected. Sampling sites in areas where a number of hydropower plants are planned, e.g. from Luang Prabang to Vientiane and Chiang Kong are missing. Currently there is one EHM site at Luang Prabang and one at Vientiane, but no site in between.

For transboundary information, some priority sites (as specified in the ISH11 Phase 2 Main Report) are missing (e.g. Lao-Thailand). Some tributaries are sampled directly at the confluence with the Mekong mainstream (e.g. TKC: Kong Chiam at Mun-Mekong junction, TSM: Mekong Junction of Mekong-Songkram Rivers), which does not clearly reflect the one or other.

Options to address these gaps could include increasing the number of mainstream locations in the routine EHM, and /or setting up diagnostic studies at hydropower target areas. Such investigations should be designed to include upstream and downstream sites of hydropower plants to understand conditions in and effects of impounded sections as well as downstream effects of e.g. hydropeaking or residual flow. In the long term, the MRC could initiate commitments of hydropower projects to investigate the areas affected by the hydropower plant with the same methods as used in EHM. This would enhance the network density along the Mekong mainstream and in the LMB.

4.3 Gap Analysis – Parameters

The EHM biological groups benthic and littoral invertebrates, diatoms and zooplankton reflect a broad range of biota and several levels in the food web, which is both targeted to Mekong and in line with international best practices. Other important groups in aquatic ecology are e.g. phytoplankton, higher algae, macrophytes, amphibians, and fish. Specific groups like dragonflies, damselflies or molluscs which are important for wetlands also play an important role in the Mekong basin.

All mentioned groups are important for the Mekong and investigation would make sense to have a good ecosystem overview. This would need more research studies in the Mekong and the region on taxonomy, occurrence and distribution of biota and ecological background knowledge (new species, new findings, ecological information that is provided by biota). Involvement of a wide range of experts on taxonomy and ecology on diverse biota would be needed, and research needs to be (financially) supported. Fauna and flora catalogues of the LMB need to be generated, to gain an overview on biodiversity in the Mekong Basin and the Mekong mainstream. Sensitive species need to be catalogued and categorised before they will be extinct. For hydropower information, ecological background information could be used to find new indicators that react to hydropower-induced river alterations and help explain causes and effects of changes.

4.4 Gap Analysis – Timing

Aquatic biological groups (invertebrates, diatoms, plankton…) show seasonal variations, as their life cycles are often connected with the hydrological regime of a river. For scientific study purposes and aquatic biodiversity overviews, mostly several seasons are sampled to show within-year variations. For *monitoring programmes with assessment methods targeted to detect environmental changes* samples should be taken in a defined season. This enables the setting of criteria against which samples can be calibrated (e.g. “observed over expected” ratios).

Mekong Ecological Health Monitoring is such a program and the dry season is sampled in line with international best practice methods for aquatic invertebrates, diatoms and zooplankton. The dry season is technically easier to sample than the flood season and rather stable conditions are given. Secondly, biota experience the greatest stress during the dry season due to high temperatures and low dilution, and in monitoring programmes it is most interesting to find out what are the worst conditions in the river. For hydropower planning and management, the low flow season sampling is recommended to be kept for the above-mentioned reasons. The EHM method can thus be applied at locations of interest for hydropower information, and the dry season is also suitable for developing indicators targeted to inform hydropower at least for invertebrates and diatoms. At hydropower-related locations it is recommended to take samples once a year to reflect annual conditions. This represents the current state at a location incorporating changes over time in the past year, as biota

(mainly invertebrates) are long-term integrators due to long generation times. Such investigations will provide a valuable long-term data set to evaluate basin-wide trends and changes over time.

For phytoplankton, which has not been sampled so far, sampling in at least two seasons should be tested, ideally more. Plankton is more of a short-term indicator that may show different densities in different seasons. Recommendation for sampling time and the number of occasions would result from initial trials, possibly during ISH11 Phase 3.

In terms of hydropower operations, event-based sampling may be undertaken under certain circumstances. Reservoir flushing may be such an event, in which losses in invertebrate biomass and diversity may be experienced.

Regular surveys at hydropower influenced locations are recommended additional to the routine monitoring. Such surveys should e.g. be targeted to hydropeaking. Effects from hydropeaking are not limited to the downstream locations of power plants but can influence long stretches in the river, depending on the ratios of peaks and down surge and locations and magnitude of tributary flows. This will provide additional longitudinal information and will support basin-wide information.

4.5 Gap Analysis – Information Management

EP receives data from NMCs mostly in excel format, sometimes only as pdf or Word format. This does not provide a consistent system of data storage. Additionally, the taxa lists used in the excel files are not consistent across the countries, as experts add new findings on their own without centralised information exchange. Quality control of data is not applied, and needs to be initiated.

For EHM 2004 to 2008 data, EP and IKMP have generated an Access biomonitoring database derived from the excel lists. The database provides a good starting point, but has a weak design of tables and relations. Several types of information are replicated including different spelling.

Data from 2011 and 2013 could be integrated in the database, but is recommended only after redesign of the database. After this, regular, timely data storage in an easily accessible database can assist in minimising delay in data availability for end-users.

The raw data (all information recorded in the field data sheets) on substrate scoring and site disturbance are not part of the database. All the information provided in these field protocols can be helpful to understand existing pressures. Especially regarding hydropower information needs, attempts to evaluate possible differences in taxa composition for different substrate types could be made based on such information.

The taxa lists need to be enhanced as they currently provide a weak (zoological, phytological) systematic framework. The database should be re-designed, tables reduced as far as meaningful, including removal of weaknesses and errors. Further options are update of the contents by integrating information that was and is collected in the field but stored in excel without having been transferred to Access. The taxa lists in the database can be used to establish updated taxa catalogues for the Mekong and LMB. Knowledge from research studies and researchers from the region should be integrated in this process. Functions of the database could be upgraded by integrating input options for taxa or import functions for taxa lists (e.g. from excel).

4.6 Gap Analysis – Information Uses

Currently, the aquatic ecology information is used to calculate the EHM class per sites, which gives an overall picture of the river health. Three indicators for each of the biological parameter groups are calculated. The biological parameter groups are not evaluated individually, but “merged” in a resulting class. This provides potential to identify additional indicators, which are relevant to hydropower planning and development information needs.

The purpose of the assessment is – as already discussed - not targeted to detect specific stressors. Causes and effects of changes in fauna and flora are not much discussed in the EHM technical reports so far, which is not specific for LMB, but an issue worldwide mainly due to lack of research on multi-stressor effects to rivers.

Upgrading ecological information as well as linking with other disciplines would provide information indicating e.g. changes in sediment composition, biological responses to habitat quantity and distribution or flow indicators (e.g. as suggested in the IBFM reports, Campbell 2006).

The database could in the long-term not only store data but could be programmed to directly calculate indicators and ecological state, which would enhance information use. These types of analyses are also relevant to other basin development projects and MRC studies, such as the Council Study.

5 Improvement Proposals

5.1 Approach and Rationale

Aquatic ecology has long been considered an important topic for the LMB, in terms of indicating aquatic ecological health, providing ecosystem services and playing an important role in the fisheries food chain. The MRC Environment Programme has invested much effort in getting developed a biomonitoring method for the LMB from 2003 onwards. The resulting design and implementation of Ecological Health Monitoring as a long-term biological monitoring programme shows the awareness about the importance of aquatic ecology for the Lower Mekong Basin. The EHM programme provides a very good anchoring point for upgrades, additional investigations both in term of locations and parameters, and method refinement and integration of additional/new indicators that help to identify and interpret different pressures.

EHM can make use of low-tech methods, thus increasing cost-effectiveness. Overall, information collected can be used to work on assessment systems tailored to assess impacts of different stressors. It can also support definition of ecological quality objectives. Information from aquatic biological groups can best be used whenever field and laboratory work is done in a consistent, accurate way over the long-term, which provides comparable data sets.

The improvement proposals relating to aquatic ecology information for hydropower planning and management build on and enhance activities in EP's EHM. The gap analysis shows that many Guiding Framework criteria are either not met or only partially met for aquatic ecology information from the perspective of how well it can inform hydropower planning and management needs. Three different proposals for aquatic ecology aspects have emerged during discussions with Programmes and Member Countries, identifying options to support, improve and complement existing EP activities with respect to hydropower planning and management information needs.

Proposal AE1 'Aquatic Ecology Indicators for Hydropower Information' addresses a number of aspects of the Guiding Framework that are presently not fully met. The proposal would help to identify indicators from links with data from other disciplines, increase the field data set, identify options to increase consistency, and consider the potential for analytical tools.

Proposal AE2 on phytoplankton monitoring addresses a parameter gap against the Guiding Framework.

Proposal AE3 is to strengthen the biomonitoring database. This would address several identified gaps in the Guiding Framework relating to parameters and information management by building capacity, increasing consistency, and improving QA/QC.

Identified gaps in monitoring locations can be seen in Tables 17 and 18 in the Main Phase 2 Report. The improvement proposals presented below are not aimed to close these locations gaps, and this would need to be considered within the EHM considerations.

5.2 Proposal AE1: Aquatic Ecology Indicators for Hydropower Information

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2a) Provide inputs to indicators related to hydropower planning and management.* EHM indicators need supporting environmental and pressure data.
- *2. Parameters Monitored; 2d) Able to help predict as well as explain cause and effect of changes.* Requires better understanding of stressors, further data analysis, and linkages with other disciplines for "diagnostic capability"

- *3. Timing of Data Collection; 3b) Frequency captures natural or operational system changes and migratory cycle.* Annual monitoring at priority locations would better meet hydropower information needs.
- *4. Information Management;* 4a) Quality management systems are in place to ensure consistency across countries. Systems are not in place or do not appear consistent across countries.
- *5. Information Use;* 5b) Links to tools are available for decision-support and analysis. Analytical approaches and tools for biomonitoring data relevant to hydropower have not yet been developed.

Objective and Description: Proposal AE1 contains several aspects, which are data evaluation to suggest aquatic ecology indicators for hydropower relevance, enlarge data sets to address hydropower management needs and enhancement, and support capacity-building for EHM.

Specific objectives are:

- to review existing EHM data in detail to better ascertain the present state of knowledge and to identify additional data analysis approaches which may enhance information for hydropower management;
- to trial integrated sampling (aquatic ecology, hydrology, water quality…) at selected sites in the Mekong River over a certain period, e.g. IHS11 Phase 3 in 2014 including several capacity building options; and
- to support a steady increase in Mekong mainstream aquatic ecology data and improve data quality to help answer questions occurring in context with specific influences, e.g. hydropower management.

Currently in the EHM the evaluation of sites is done by calculating an "Ecological Health Class". Three indicators (i.e. abundance, richness, tolerance) for each of the four aquatic ecology groups (benthic and littoral invertebrates, diatoms, zooplankton) are classified and grouped, leading to one of four classes. This gives an overall picture of the biological conditions at a site, in line with many international approaches. Data interpretation evaluating effects of specific influences is currently not foreseen. The potential for improvement and an aim of this proposal is to show ways of evaluation targeted to specific influences, e.g. reaction of biota on hydromorphological changes along the river.

For integrated sampling and enlargement of datasets, priority sites are recommended for trialling conducted by the Line Agencies, e.g. in a sampling campaign in low flow season 2014 (March) at two priority sites in each Member Country. The 4 biological groups - benthic invertebrates, littoral invertebrates, benthic diatoms and zooplankton - would be sampled for consistency in the EHM methodology. The methods used are described in the Biomonitoring Handbook (MRC 2010).

As a second option to get more data from priority sites, regular 2015 EHM could be extended by sampling as many of the ISH11 recommended priority locations as possible. This could be a specifically targeted part of EHM and would make use of synergies in sampling time and lab work. In that case, 2014 could be used for various capacity-building workshops that have high priority for Line Agencies and would ideally include younger professional who could continue EHM activities into the future.

Linkages:

- This proposal contributes to EP work programme activities, specifically Outputs 1.1 on monitoring environmental quality and ecological balance, 1.5 on monitoring systems updated to reflect information needs, 3.3 on understanding Mekong River ecosystem and support to impact

assessment of basin developments, and 4.1 on strengthening institutional and national capacities.

- This proposal directly supports BDP's development of the MRC Indicator Framework, and can further support capacity-building linked to decentralization, the Council and Delta studies and RSAT information needs.
- This activity promotes integration of disciplines, as indicators may combine flow, water quality, sediments and fisheries data collected by EP, FP and IKMP.
- Development of aquatic ecology indicators for hydropower information is strongly linked to the information end-use proposal IU2 to facilitate application of hydropower-relevant indicators.

Relevant MRC Procedures or Guidelines: None identified.

Proposed Activities and Outputs:

- Review data from 12 mainstream sites of the Ecological Health Monitoring 2004 - 2011, either all biological groups sampled or by way of example for one group e.g. invertebrates. Detailed approaches and timeline need to be discussed in more detail with EP. Output will be suggestions of ways to link biota and identify reactions of biota to sediment and morphological aspects, which can further help identify effects related to hydropower.
- Review the strengths and weaknesses of EHM Work Instructions and method application in a technical workshop with NMCs and Line Agencies.
- Discuss ideas to include quality assurance and quality control mechanisms and suggest options for inclusion in EHM.
- Several capacity-building components are proposed for inclusion.
  - A technical workshop is proposed prior to the next sampling to review and refresh proper application of Work Instructions in the field and include new, younger professionals to the "biomonitoring working group"
  - Identification workshops are proposed for taxonomic identification, which could be performed for each of the biological groups in a workshop attended jointly by persons from each Member Country doing the identification for the respective biological group. Suggestions would arise from these workshops for update of taxonomic identification keys for invertebrates and benthic diatoms, if needed.
- Integration of 2011 and 2013 data into the refined biomonitoring database (proposal AE3), to be available for several purposes including hydropower information needs.

Resource Requirements and Implementation Commitments: The requirements for this activity are estimated as follows, but based on suggestions from and discussions with Member Countries and Programmes on the content of the proposal the effort may be considerably different.

- Review data, EHM – IC 20 days.
- Discussions and Workshops for capacity building – IC 6 days for advice on concept, outline of programmes, suggestions to find "trainers".
- Technical workshop: review and discussion of methods – could be integrated in regular EHM meeting; additional 4 days for IC
- Field-based workshop for method application, to refresh know-how, and include young professionals. Transportation costs, DSA for participants, materials. Estimate 35 participants, 5

days, USD 35,000. IC days to be determined if participation needed. One team leader for each parameter groups from countries would need to commit to providing guidance for field work.

- Taxonomic training workshops. Costs for trainers, rental of lab facilities, transportation and DSA for participants. Estimated cost per workshop 15 000 to 20 000 USD, exclusive of costs for trainers. Commitment needed that trainings can happen at Universities with appropriate lab facilities (enough microscopes) e.g. in Thailand. Commitment also needed from experienced taxonomists to be trainers, and discussion needed on inclusion of international trainers.
- Costs for sampling in 2014 or EHM 2105, dependent on number of sites.
- Integration of 2011 data into Access database, to be discussed when database is refined; needs days from aquatic ecology specialists (ISH11 IC or from EP) and ISH11 IC for data management.

Sustainability Considerations: Regarding decentralisation, an agreement of future application of integrated sampling needs to be reached, otherwise the approach may not be sustainable. Capacity-building should be considered as ongoing activity with a programme outline for several years, specifically targeted to younger professionals who will continue EHM. A mentoring approach especially for identification is recommended, as well as voucher collections of species in each country.

Outcomes and Benefits: The overall benefits of this proposal are: i) the integration of a mid-term to long-term strategy for an enlarged dataset both for EHM and hydropower evaluation purposes; ii) the revival and continuation of initiatives started earlier in EHM e.g. QA/QC; and iii) the sustainability aspects mainly in terms of capacity-building. Outcomes may include:

- suggestions and examples how to link biota and identify reactions of biota to sediment and morphological aspects, which can further help identify effects related to hydropower;
- if trials for integrated sampling in 2014 are implemented, ways can be demonstrated how aquatic ecology can be linked to sediment, water quality, hydromorphology monitored in near time at the same locations;
- suggestions for improvement regarding data evaluation, method refinement (e.g. for Mekong delta), update of taxa catalogues and identification keys etc.;
- implementations of initial, simple quality assurance and quality control mechanisms; and
- capacity-building workshops for field work and taxonomic identification.

5.3 Proposal AE2: Phytoplankton Monitoring for Hydropower Information

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2a) Provide inputs to indicators related to hydropower planning and management*. Missing phytoplankton.
- *2. Parameters Monitored; 2b) Able to be replicated across the basin.* Methods for EHM parameter groups are defined in the Biomonitoring Handbook. Comparable Work Instructions for phytoplankton suggested.
- *4. Information Management; 4a) Quality management systems are in place to ensure consistency across countries.* Systems for consistency and quality assurance for phytoplankton would be needed.

Objective and Description: Phytoplankton as primary producers plays an important role in the food chain in large rivers. In the Mekong it serves as a key source for fish food. Primary production is

connected with water depth, water velocity, temperature and light conditions. It will thus be influenced by changing river characteristics that will occur along with river damming. This proposal supplements EP and FP programme activities to address hydropower information needs regarding changes in primary production in Mekong mainstream. Phytoplankton may not be relevant at the moment for all Mekong mainstream sites, i.e. currently more relevant for downstream, wetland and delta locations, but may become very relevant in impounded sections also in upstream areas of the Mekong mainstream. To gain "baseline" data and define expected values for phytoplankton indicators, phytoplankton monitoring is recommended. Sampling and analysing phytoplankton will complement proposal AE1.

Main objectives are to:

- test phytoplankton sampling for further application in the Mekong mainstream, in the context of hydropower information needs and possible inclusion in EHM; this will enhance EHM, fill gaps regarding evaluation of primary production, and trial techniques new for some Member Countries;
- initiate capacity-building in phytoplankton sampling in Member Countries by trainers from the region, and thus strengthen cooperation in the region and discuss options for further phytoplankton training needs in the Member Countries; and
- test initial evaluation of sites with phytoplankton data via links to water quality and fisheries parameters, if those are monitored in near time at the same locations.

Linkages:

- This proposal fits with EP work programme activities, specifically Outputs 1.1 on monitoring environmental quality and ecological balance, 1.5 on monitoring systems updated to reflect information needs, 3.3 on understanding Mekong River ecosystem and support to impact assessment of basin developments, and 4.1 on strengthening institutional and national capacities. Phytoplankton sampling may complement EHM for EP in terms of changing primary production in and through impounded sections.
- For FP work plan Output 2 related to fisheries status and trends, this proposal will provide valuable information on fish food sources and related changes.
- This proposal supports capacity-building linked to decentralization, and can potentially support the Council and Delta studies and RSAT information needs.

Relevant MRC Procedures or Guidelines: None identified.

Proposed Activities and Outputs: Proposal AE3 is a test approach and not all Member Countries presently have the equipment and capacity for phytoplankton sampling, processing and data interpretation. Viet Nam has good capacity and experts in phytoplankton, thus two mainstream sites in Viet Nam could serve as test sites in March/April and September during ISH11 Phase 3. Thailand could also provide very valuable phytoplankton expertise, and input from experts from Thailand is sought.

Phytoplankton composition and density vary across the year, and two seasons are suggested for trials. The first sampling is proposed for end March/April, done by the Vietnamese team possibly in context with integrated sampling (see also proposal AE1). It could be a test sampling for the following September in terms of practicability. In September, aquatic ecology experts from the three other Member Countries could take part in the sampling, sample processing and data generation in the form a capacity-building workshop. A first version of a WI would be produced by the Viet Nam team (in close cooperation with colleagues from Thailand, if possible). After this, data from two sites and two dates will be available for integration options with other ISH11 discipline towards development

of hydropower-relevant indicators, mainly water quality sampling and fisheries if done at the same locations and time.

Resource Requirements and Implementation Commitments: The requirements for this activity are estimated as follows, but based on suggestions from and discussions with Member Countries and Programmes on the content of the proposal the effort may be considerably different.

- ISH11 aquatic ecology IC for proposal initiation and support (5 days)
- Team from Viet Nam would need to commit to guide this proposal
- Financial support for field trials and capacity-building workshop preparation and performance by the Viet Nam team, gear as needed, Work Instructions written by the Viet Nam team
- Total commitment = approx. 40 000 USD

Sustainability Considerations: If the outcomes of the trial are judged useful by EP, FP, ISH11 and experts from Member Countries, and phytoplankton were to be integrated in routine sampling, capacity-building needs must be outlined as well as financial needs for the next few years. Regarding decentralisation, an agreement of future application would need to be reached, otherwise the approach may not be sustainable. Phytoplankton is of interest for both EP and FP purposes, but would ideally be anchored in EP where it could be linked to EHM.

Outcomes and Benefits:

- Phytoplankton data for the Mekong mainstream at two sites in Viet Nam, specifically selected in terms of hydropower information needs, on two different dates.
- Capacity-building in phytoplankton field work, and suggestions for further capacity-building in phytoplankton lab work.
- WIs for phytoplankton sampling and analysing.
- Testing of options to link phytoplankton data to water quality and fisheries parameters for the two sites, with options for new indicators related to hydropower information needs.
- A phytoplankton sampling and analysis approach which can be used by the EP to guide future monitoring activities.
- Support of RSAT topic 6: Data gained through long-term monitoring of phytoplankton help enhancing knowledge on Mekong aquatic biodiversity and help developing aquatic ecology indicators for hydropower information (RSAT topics 6.1 and 6.2), provided the approach is sustained after the trial.

5.4 Proposal AE3: Strengthening the Biomonitoring Database for Hydropower Information

Gaps Addressed in Guiding Framework: The following Guiding Framework criteria would be addressed or enhanced by this proposal.

- *2. Parameters Monitored; 2d) Able to help predict as well as explain cause and effect of changes.* Enables further data analysis and linkages with other disciplines for “diagnostic capability”.
- *4. Information Management; 4a) Quality management systems are in place to ensure consistency across countries.* Systems do not appear consistent across countries. Taxa catalogues are not up-to-date. Quality assurance system needed.
- *4. Information Management; 4b) Systems allow information to be centrally archived and shared*. The biomonitoring database would benefit from a number of improvements.

- *5. Information Use; 5a) Information is readily accessible for users*. Multi-year delays occur for aquatic ecology data accessibility.

Objectives and Description: The main objectives are to propose improvement options regarding technical design of Access database for future use, and to improve biological background information in the database. Regarding ISH11 main aims, the activities in this proposal will enhance the existing biomonitoring database user-friendliness, identify and initiate filling gaps regarding database content, and initiate integration of better taxonomic information.

Biomonitoring data from Ecological Health Monitoring 2004 to 2008 are available in an Access database generated by IKMP. The database has been built by transferring EHM data from excel tables into Access and thus several fields of information are duplicates, partly with unclear entries. This database is currently not in use by EP. EP stores some data (EHM 2011, 2013) in excel sheets and/or word documents received from countries. There is capacity for re-design, update and upgrade to make the database less error prone, avoid duplication of information, and integrate user-friendly data usage options. The biomonitoring database will serve as central aquatic ecology database to support information needs, e.g. for hydropower planning and management.

Besides technical re-design, subject-specific items should be updated and upgraded, i.e. “taxa catalogues” used in the EP biomonitoring database. The state of knowledge is as of 2008. New species and taxa groups found in the LMB for each of the 3 biological groups (invertebrates, diatom, zooplankton) need to be integrated. The same update is recommended for the excel sheet used by Line Agencies for EHM assessment which is an important topic for quality assurance.

For this update of the taxa catalogues it is recommended to hire one expert from the Member Countries for invertebrates, diatoms and zooplankton each, who is responsible for the work. Additionally the expert needs to contact and involve possible experts from the other countries to have agreed taxa catalogues across all Member Countries. Involvement of international experts needs to be discussed in a further step, as well as integration of ecological background information about the fauna and flora in LMB freshwaters.

Suggestions for data management and data delivery from Line Agencies to EP and further to IKMP for integration in the database could be outlined.

Linkages:

- This proposal particularly supports the EP work plan Output 4.1 on strengthening institutional and national capacities.
- It is integrally linked with the Information End-Use proposal IU1 on improving accessibility of datasets.
- This proposal strongly supports capacity-building linked to decentralization. It can potentially support BDP processes, the Council and Delta studies and RSAT information needs.

Relevant MRC Procedures or Guidelines: None identified.

Proposed Activities and Outputs: In Phase 3 of ISH11, the following activities could be undertaken:

- ISH11 and EP discuss and agree on functional specifications and requirements of database contents and use (data vs information), database management, technical options, etc;
- suggest options for re-design of existing biomonitoring database in a stepwise approach, based on EP requirements;
- initial re-design of database (e.g. remove double information, typing errors, initial and easy to do adjustments in database fields…); and

- propose updates for taxa catalogues for invertebrates, diatoms, zooplankton or at least roadmap for the update .

Resource Requirements and Implementation Commitments: The requirements for this activity are estimated as follows, but based on suggestions from and discussions with Member Countries and Programmes on the content of the proposal the effort may be considerably different.

- Proposal initiation and set up by aquatic ecology and database specialist ICs (20 days)
- EP to define the requirements of the database structure, contents and output options in cooperation with ISH11 database and ISH11 aquatic ecology IC.
- Member Countries: additional (taxonomic) experts from LMB countries would need to be involved and financed, e.g. for update of taxa catalogues and quality control.
- International taxonomic experts for quality checking should be involved to get up-to-date taxa catalogues.
- Estimated costs depend on effort needed for update of taxonomic catalogues. Approximate total = 60,000 USD, dependent on approach taken and extent of defined requirements.

Sustainability Considerations: Immediate and mid-term sustainability can only be achieved if personnel for database management are available. This needs either to be personnel with aquatic ecological background, or they must work very closely with such EP experts. In the long-term, database management and new data integration need to be done centrally for quality assurance purposes. A second option would be establishment of a web-based version with data import-options for Member Countries. In this case a hotline or user-support desk would need to be established. A handbook on content and use of the database should be written and kept up-to-date. Both in a centralised or decentralised version, NMCs or Line Agencies must either use uniform data sheets (e.g. excel) for easy data import or a web-based, direct input function must be computed. Regular capacity-building on biomonitoring database issues should be anchored in the EP work programme. Formal agreements for EP to manage the database into the future after decentralisation, and Member Countries to send EHM data to EP, may be required.

Outcomes and Benefits: The main output, supporting site-specific and basin-wide hydropower information, will be a well organised database where data and information about aquatic ecology routine monitoring are stored, regularly updated and easily accessible. Regarding hydropower-relevant information, data can be used to show basin-wide trends as well as point information, e.g. above and below hydropower plants. Options for integration of ecological background information of biota as well as integration of abiotic environmental information related to sites are given and will inform hydropower-related indicator development over time. Data can be used by EP as well as all other MRC programmes, NMCs, line agencies and stakeholders for multiple purposes. These may include:

- EHM method refinement e.g. regarding hydro-ecological zones or mainstream versus tributary catchments;
- easier evaluation of long term trends in EHM indicators;
- overview on biodiversity of freshwater biota on basin, sub-basin, river type or ecological zone, catchment, mainstream level;
- basin-wide evaluations of changes in aquatic flora and fauna over time; and
- different kinds of pressure-related data evaluations can be trialled when larger scale and site information about pressures is included.

6 Conclusions

During Phase 1 and Phase 2 of the ISH11 study, several consultations with MRC Programmes, NMCs and Line Agencies have been undertaken. The information on existing aquatic ecology, and the identification of opportunities for upgrading existing activities from Programmes and Member Countries to enhance hydropower-relevant information, have been discussed back and forth and several refinements have been made in the last 12 months. Proposals described in the ISH11 Phase 2 Main Report and this Annex are all based on these discussions, including as much as possible the views of Programmes (especially EP as the Programme responsible for EHM) and Member Countries.

The main aim of the aquatic ecology improvement proposals is to build on and enhance the existing EHM both in general and to meet hydropower information needs.

Improvement efforts would best be directed to strengthening data through **capacity-building in taxonomic identification and improvement to the biomonitoring database** for information management. Quality assurance mechanisms and quality control in the lab should be initiated. Further improvements from a hydropower perspective relate to locations and timing of sample collection, trialling phytoplankton monitoring because of its fisheries information links, and development of indicators

Following national and regional consultation on the ISH11 Phase 2 Report, the ISH11 team aims to work with and through the MRC Programmes to identify funding opportunities for implementation of the ISH11 proposals agreed upon by the MRC Member Countries.

7 References

Barbour MT, Paul MJ (2010) Adding value to water resource management through biological assessment of rivers. In: Moog O, Sharma S, Hering D (eds), Rivers on the Hindu Kush-Himalaya – Ecology and Enviromental Assessment. Hydrobiologia 651: 17-24.

Campbell I (2006) IBFM Phase 2/3 Pilot-Specialist Report on Aquatic Invertebrates. Unpublished manuscript.

Campbell IC, Chessman BC, Resh VH (2009) The development and application of biomonitoring in the Lower Mekong River System. In: Campbell I.C. (ed), The Mekong: Biophysical Environment of an International River Basin. Chapter 13: 321-334, Aquatic Ecology Series, Elsevier, ISBN 978-0-12-374026-7.

Crosse H, Fischer P (1876) Mollusques fluviatiles, recueillis au Cambodge, par la mission scientifique française de 1873. Journal de Conchyliologie 24: 313-334.

Dao Huy Giap, Tatporn Kunpradid, Chanda Vongsombath, Do Thi Bich Loc, and Prum Somany (2010) Report on the 2008 biomonitoring survey of the lower Mekong River and selected tributaries, MRC Technical Paper No. 27. Mekong River Commission, Vientiane.69 pp. ISSN 1683-1489

Davidson Supatra Parnrong, Tatporn Kunpradid, Yuwadee Peerpornisal, Nguyen Thi, Mai Linh, Bounnam Pathoumthong, Chanda Vongsombath and Anh Duc Pham (2006) Biomonitoring of the Lower Mekong and selected tributaries. *MRC Technical Paper No.13*, Mekong River Commission, Vientiane. 100 pp. ISSN: 1683–1489.

Getwongsa P, Sangpradub N, (2008) Preliminary Study on Development of Biotic Index for Rapid Bioassessment in Mekong II Basin (Thailand). KKU Sci. J.36 (Supplement) 122-136 (2008).

Grimas U (1988) Water quality investigations in the Lower Mekong Basin. Biological Monitoring – an Evaluation. Report to the Interim Mekong Committee, 25 pp plus Annexes

Hart BT, Jones MJ, Pistone G (2001) Transboundary Water Quality Issues in the Mekong River Basin. Report to the Mekong River Commission, 65 pp plus Annex.

ICEM (2010): MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream, Hanoi, Viet Nam, 198 pp.

Karr JR (1993) Defining and assessing ecological integrity beyond water quality. Environmental Toxicology and Chemistry 12:1521-1531

Karr JR, Chu EW (1999) Restoring life in running waters: Better biological monitoring. Island Press, Washington, D.C

Kunpradid Tatporn, Pongpan Leelaharangkri, Suttawan Supan, Yuwadee Peerapornpisal (in print) Identification of Freshwater Benthic Diatom of the Lower Mekong Basin. Mekong River Commission, Vientiane,123 pp.

Li Li, Binghui Zheng, Lusan Liu (2010) Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. Procedia Environmental Sciences 2: 1510–1524

Martynov AB (1931) Report on a collection of insects of the order Trichoptera from Siam and China. Proceedings of the United States National Museum 79: 1-20

MRC (2008) Biomonitoring of the lower Mekong River and selected tributaries. MRC Technical paper No. 20, ISSN 1683-1489. Mekong River Commission, Vientiane.

MRC (2010a) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.

MRC (2010b) Report on the biomonitoring survey of the lower Mekong River and selected tributaries. MRC Technical paper No. 27, ISSN 1683-1489. Mekong River Commission, Vientiane.

Pan Van Niem (2002) Draft Report on Review of Biological Assessment of Freshwater Ecosystems in Viet Nam. Report submitted to Viet Nam National Mekong Committee Environment Program, 30 pp.

Phan Doan Dang, Nguyen Van Khoi, Dang Ngoc Thanh, Ho Thanh Hai and Le Thi Nguyet Nga (in print). Identification of Freshwater Zooplankton of the Mekong River and its Tributaries. Mekong River Commission, Vientiane. 182 pp.

Parnrong Supatra (2002) A Review of Biological Assessment of Freshwater Ecosystems in Thailand. Report submitted to Mekong River Commission – Environment Program, 36 pp.

Sangpradub N, Boonsoong B, 2006. Identification of freshwater invertebrates of the Mekong River and its tributaries. Mekong River Commission, Environment Programme, Vientiane, Lao PDR. ISBN 978-92-95061-01-9.

Smith SH (1988) Bottom Fauna Monitoring in the Lower Mekong Basin, Part III, Mekong River Commission, Phnom Penh, Cambodia, 25 pp plus Annexes.

Srum Lim Song, Neou Bonheurm, Uy Ching (2002) A Review of Biological Assessment of Freshwater Ecosystems. Report submitted to Mekong River Commission, Final Draft, 38 pp. (CAMBODIA)

Uttaruk P, Pravat Voharndee, Phuttipong Jusanit, Panya Bunyaadunyakit,Sutep Suriya, Thongman Jaengjaithum, Kanchana Nittayaand Narumon Sangpradub (2011) Development of biotic index based on rapid bioassessment approaches using benthic macroinvertebrates for Chi and Mun headwater streams, northeast Thailand AES Bioflux, 2011, Volume 3, Issue 1: 29-43.

Vienna Declaration (2011) Vienna Declaration on the Status and Future of the World's Large Rivers. Vienna, 13th of April, 2011, http://worldslargerivers.boku.ac.at

Vongsombath Chanda, Pham Anh Duc, Nguyen Thi Mai Linh, Tatporn Kunpradid, Supatra Parnrong Davison, Yuwadee Peerapornpisal, Sok Khom, Meng Monyrak (2009a): Report on the 2006 biomonitoring survey of the lower Mekong River and selected tributaries, *MRC Technical Paper No. 22*. Mekong River Commission, Vientiane. 124 pp.

Vongsombath Chanda, Pham Anh Duc, Nguyen Thi Mai Linh, Tatporn Kunpradid, Supatra Parnrong Davison, Yuwadee Peerapornpisal, Sok Khom, Meng Monyrak (2009b): Report on the 2007 biomonitoring survey of the lower Mekong River and selected tributaries, *MRC Technical Paper No 23*. Mekong River Commission, Vientiane. 75 pp.

Wong CM, Williams CE, Pittock J, Collier U, Schelle P (2007) World's top 10 rivers at risk. World Wide Fund for Nature (WWF) International. Gland, Switzerland.

Attachment 1 – List of Sampling Sites in Ecological Health Monitoring

Table 5 gives an overview on all EHM sites sampled between 2004 and 2008. The information is derived from the biomonitoring database (in the MRC Master Catalogue). The table informs about site name and site code as well as coordinates. The names and writing of sites is exactly displayed as it is in the database. Some sites have been slightly shifted between the years. It is obvious from the coordinates that some sites - having the unique three-letter site code – have been shifted between the years. The naming of the sites is thus also not consistent.

In 2011 and 2013 the same sites as in 2008 were sampled (information received from EP). Also in these years, the coordinates are for some sites slightly differing from 2008, but not included in the table below, as the information is not yet published.

Table 5 – EHM Sampling Sites in the LMB, 2004 – 2008 as available in Biomonitoring Database

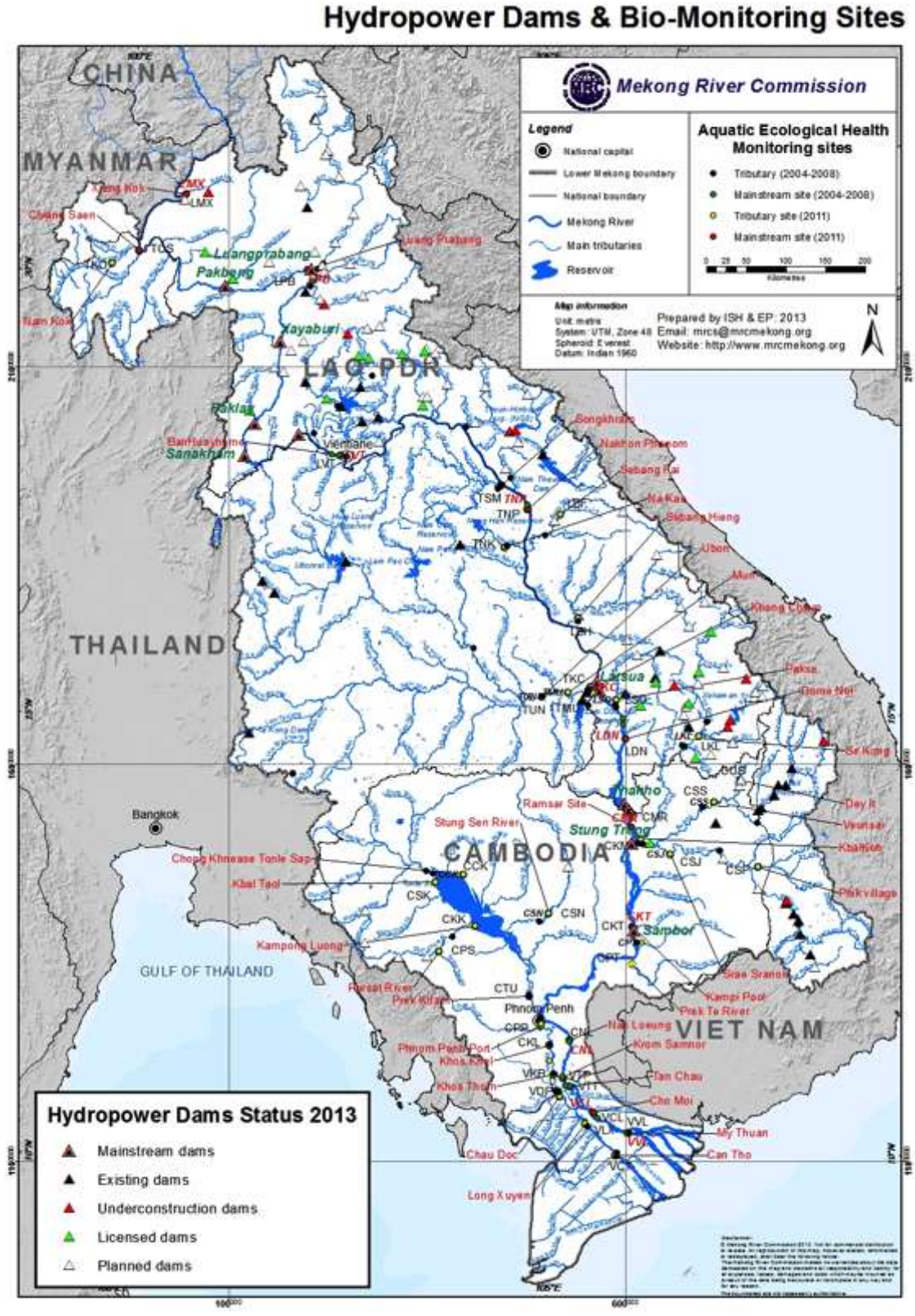
Country	River name	Monitoring Site Name	Monitoring Site Code	X UMT	Y UMT	Year
Laos	Mekong	Above Luang Prabang, upstream of Pak Nam Karn	LPB	201739	2203028	2004
Laos	Mekong	Above Luang Prabang, upstream of Pak Nam Karn	LPB	206113	2206957	2005
Laos	Mekong	Done Chor	LPB	206113	2206957	2008
Laos	Mekong	Upstream of Vientiane	LVT	229378	1990015	2007
Laos	Mekong	Upstream of Vientiane	LVT	239871	1988731	2004
Laos	Mekong	Ban Huayhome	LVT	239871	1988731	2008
Laos	Mekong	Pakse, upstream of Se Done mouth	LPS	587623	1671756	2004
Laos	Mekong	Done Nguei	LDN	596193	1657517	2008
Laos	Mekong	Done Ngieu island	LDN	596621	1650516	2007
Laos	Mekong	Near Ban Xieng Kok, Muang Luang	LMX	670860	2311778	2005
Laos	Mekong	Ban Xiengkok	LMX	670860	2311778	2008
Laos	Mekong	Near Houa Khong water quality station	LMH	723733	2383320	2005
Laos	Mekong ?	Sebang Fai	LBF	498437	1888075	2007
Laos	Nam Ka Ding	Haad Sai Kam	LKD	398583	2023903	2007
Laos	Nam Ka Ding	Haad Sai Kam	LKD	398871	2023713	2004
Laos	Nam Khan	Between Hat Hian and Ban Houay Ung	LNK	203428	2200953	2005
Laos	Nam Mo	Upstream of bridge near mine	LNM	280667	2088210	2007
Laos	Nam Ngum	Upstream of confluence with Nam Lik	LNG	237411	2049992	2007
Laos	Nam Ngum	Upstream of confluence with Nam Lik	LNG	240744	2050118	2004
Laos	Nam Ou	About 5 km from river mouth	LNO	212495	2222855	2004
Laos	Nam Ou	Between Ban Pak Ou and Ban Hat Mat	LOU	219345	2229380	2005
Laos	Nam Ton	50 km from Vientiane	LNT	208083	2016581	2007
Laos	Se Bang Hieng	under the bridge	LBH	498434	1887920	2008
Laos	Se Bang Hieng	Se Bang Hieng	LBH	540315	1779816	2007
Laos	Se Done	Ban He, upstream of Pakse	LSD	586345	1673985	2007

Country	River name	Monitoring Site Name	Monitoring Site Code	X UMT	Y UMT	Year
Laos	Se Done	Ban Hae	LSD	587623	1671756	2008
Laos	Sebang Fai	Sebang Fai, under the bridge	LBF	454745	1959958	2008
Laos	Sekong	Ban Xou	LKL	670696	1623478	2008
Laos	Sekong	Ban Xou Touat, Attapeu Province	LKL	670721	1623450	2007
Laos	Sekong	Ban Xou Touat, Attapeu Province	LKL	673642	1622904	2005
Laos	Sekong	Ban Xakhe, Attapeu Province	LKU	701679	1653515	2005
Laos	Sekong	Ban Xakhe, Attapeu Province	LKU	702400	1653117	2007
Thailand	Mekong	Nakhon Phanom	TNP	476094	1926454	2008
Thailand	Mekong	Khong Chiam	TKC	552099	1694552	2008
Thailand	Mekong	Chiang Saen	TCS	614718	2240109	2008
Thailand	Mekong	Wiangkhain, between Sop Ing Tai and Ban Huai Ian, near Cham Pong	TMC	655974	2231281	2005
Thailand	Nam Chi	Wat Srithararm, Yasothon	TCH	407724	1745362	2004
Thailand	Nam Kham	Na Kae	TNK	450473	1874626	2007
Thailand	Nam Kham	Nam Kham	TNK	450496	1874332	2008
Thailand	Nam Mae Ing	Near Ban Ten	TMI	640355	2213637	2005
Thailand	Nam Mae Kok	About 15 km upstream of Chieng Rai Weir	TKO	576165	2205993	2004
Thailand	Nam Mae Kok	About 15 km upstream of Chieng Rai Weir	TKO	576410	2205793	2005
Thailand	Nam Mae Kok		TKO	582195	2201793	2008
Thailand	Nam Mun	Ubon new	TUN	494860	1685056	2008
Thailand	Nam Mun		TMU	552465	1673182	2008
Thailand	Nam Mun	Ban Tha Phae, Ubon Ratchathani	TMU	553283	1692193	2004
Thailand	Nam Mun–Chi	Mekong (Mun - Kong Chiam)	TMM	552854	1692378	2007
Thailand	Nam Songkhram	About 8 km from river mouth	TSK	438501	1946480	2004
Thailand	Nam Songkhram	About 8 km from river mouth	TSK	440989	1948666	2007
Thailand	Nam Songkhram	Mekong junction	TSM	443775	1951509	2008
Thailand	Nam Songkhram	Mekong	TSM	444135	1951422	2007
Cambodia	Bassac	Koh Khel	CKL	503327	1246641	2006
Cambodia	Bassac	Koh Khel	CKL	503786	1245255	2008
Cambodia	Mekong	Nak Loeung	CNL	528321	1250852	2006
Cambodia	Mekong	Stung Treng Ramsar site	CMR	604976	1539456	2006
Cambodia	Mekong	Stung Treng Ramsar site	CMR	605696	1539736	2007
Cambodia	Mekong	Stung Treng Ramsar site	CMR	607964	1537129	2005
Cambodia	Mekong	Kampi Pool	CKT	609207	1393544	2006
Cambodia	Mekong	Kampi Pool	CKT	610914	1393502	2008
Cambodia	Mekong	Kampi Pool	CKT	610951	1393569	2004
Cambodia	Mekong	Stung Treng Ramsar site	CMR	618663	1504098	2008
Cambodia	Prek Te River	Prek Te River	CPT	613899	1374811	2006
Cambodia	Se Kong	Kbal Koh	CKM	606331	1539069	2008

Country	River name	Monitoring Site Name	Monitoring Site Code	X UMT	Y UMT	Year
Cambodia	Se Kong	River Mouth	CKM	615508	1500632	2006
Cambodia	Se Kong	River Mouth	CKM	615573	1500696	2007
Cambodia	Se Kong	River Mouth	CKM	615596	1500691	2005
Cambodia	Se San	Downstream of confluence with Sre Pok	CSJ	615573	1500688	2007
Cambodia	Se San	Downstream of confluence with Sre Pok	CSJ	620973	1499412	2006
Cambodia	Se San	Downstream of confluence with Sre Pok	CSJ	621005	1499145	2005
Cambodia	Se San	Downstream of Srepok River junction	CSJ	621744	1498832	2008
Cambodia	Se San	Veunsai District, Rattanakiri Province	CSS	695488	1546145	2005
Cambodia	Se San	Veunsai District, Rattanakiri Province	CSS	696445	1545480	2004
Cambodia	Se San	Dey It Village	CUS	717794	1490553	2008
Cambodia	Se San	Pum Pi village, Rattakiri Province	CSU	764506	1526065	2006
Cambodia	Se San	Pum Pi village, Rattakiri Province	CSU	764687	1526041	2005
Cambodia	Se San	Pum Pi village, Rattakiri Province	CSU	764707	1526063	2007
Cambodia	Sre Pok	Kampong Saila, Lumpat	CSP	716971	1490691	2004, 2005
Cambodia	Sre Pok	Kampong Saila, Lumpat	CSP	717104	1490800	2007
Cambodia	Sre Pok	Kampong Saila, Lumpat	CSP	717424	1490804	2006
Cambodia	Sre Pok	Phik village, Lumpat	CSP	765124	1525674	2008
Cambodia	Stoeng Sangke	Battambang	CSK	348375	1465699	2006
Cambodia	Stoeng Sangke	Battambang	CSK	357473	1461902	2008
Cambodia	Stoeng Sen	Kapongthom	CSN	490998	1401845	2006
Cambodia	Stung Pursat	4 km upstream of Prek Thot	CPS	381258	1382944	2004
Cambodia	Tonle Sap	Prek Kdam ferry	CTU	477884	1309367	2004
Cambodia	Tonle Sap	Prek Kdam ferry	CTU	478364	1307071	2006
Cambodia	Tonle Sap	Phnom Penh Port	CPP	491666	1280205	2006
Cambodia	Tonle Sap	Phnom Penh Port	CPP	492492	1279903	2004
Vietnam	Bassac	Khanh Binh, An Phu, An Giang	VKB	509482	1210872	2008
Vietnam	Bassac	Chau Doc	VCD	510969	1188413	2006
Vietnam	Bassac	Da Phuoc, An Phu, An Giang	VDP	514690	1188035	2008
Vietnam	Bassac	Chau Doc	VCD	515263	1187502	2004
Vietnam	Bassac	Long Xuyen, An Giang	VLX	551897	1143437	2008
Vietnam	Bassac	Can Tho	VCT	588365	1110673	2006
Vietnam	Bassac	Phu An, Cai Rang, Can Tho	VCT	589048	1106685	2008
Vietnam	Bassac ?	Long Xuyen	VLX	551878	1143546	2006
Vietnam	Cao Lanh ? or Mekong ?		VCL	563807	1153868	2006
Vietnam	Mekong	Thuong Phuoc 1, Hong Ngu,	VTP	519830	1205766	2008

Country	River name	Monitoring Site Name	Monitoring Site Code	X UMT	Y UMT	Year
		Dong Thap				
Vietnam	Mekong	Tan Chau	VTC	524259	1195808	2006
Vietnam	Mekong	Tan Chau	VTC	528931	1194535	2004
Vietnam	Mekong	Thuong Thoi, Hong Ngu, Dong Thap	VTT	528951	1194447	2008
Vietnam	Mekong	My Thuan, Vinh Long	VVL	603698	1134514	2008
Vietnam	Mekong ?	Tan Hau, Tan Thuan Tay, Cao Lanh, Dong Thap	VCL	563798	1153777	2008
Vietnam	Se San	Kon Tum hydrographic station	VSS	180527	1588158	2006
Vietnam	Se San	Kon Tum hydrographic station	VSS	180575	1587838	2004
Vietnam	Sre Pok	Ban Don hydrographic station	VSP	802270	1426825	2004
Vietnam	Sre Pok	Upper Sre Pok	VSR	817329	1396950	2006
Vietnam	Vinh Long	Vinh Long	VTR	603976	1135759	2006

Attachment 2 –Map Showing Hydropower Dams in the LMB and all EHM Sites (2004-2011)



Attachment 3 - Gap Analysis with Respect to Guiding Framework Including Information on Long-Term Improvement Options for Aquatic Ecology

The table below gives the same information as in the ISH11 Phase 2 Main Report for short term improvement options in Aquatic Ecology, and is extended by the far right-hand column which gives ideas for long-term improvement options.

Guiding Principles for MRC Basin-Scale HP Planning & Mgmt Info	Aquatic Ecology - short term improvement options	Aquatic Ecology - long term improvement options
1. LOCATIONS OF DATA COLLECTION		
1a) Cover all Mekong River hydro ecological zones	✓ Zones are covered, number of sites per zone to increase for sound longitudinal overview and basis for evaluation of longitudinal changes	Include special focus on: Tonle Sap area, wetlands, tributaries with HP via research or diagnostic studies for understanding basin wide processes; include sites above / below each planned HP to understand longitudinal changes; discuss with HP operators to monitor aquatic ecology with EHM methods and share data and results
1b) Near proposed or operational hydropower project or group of projects	◐ Missing some Upper Lao locations near HPPs	
1c) Enable understanding of mainstream processes	◐ Present number of sites do not adequately reflect biota distributions; some sites monitored at junctions - reconsider locations for clearer indication if state of mainstream or tributary is monitored	
1d) Facilitate understanding of changes occurring across national boundaries	◐ Missing some priority transboundary locations	
2. PARAMETERS MONITORED		
2a) Provide inputs to indicators related to hydropower planning and management	◐ Missing phytoplankton **(AE2);** EHM indicators provide overall classification, data interpretation re. effects of pressures needs supporting environmental & pressure data; exemplified testing of possible indicators suggested **(AE1);**	Need for ecological background info on individual species - input from research institutions & scientists needed, targeted research studies needed; consider specific indicators to detect HP effects on wetlands
2b) Able to be replicated across the basin	✓ Methods for EHM parameter groups are defined in Biomonitoring handbook, work instructions for phytoplankton suggested **(AE2)**	ongoing capacity building for all AE groups (regular identification trainings); involve young-generation experts to enable smooth take over of EHM; revive "mentoring" approach (as in EHM development); "train-the trainers"; voucher collections for species
2c) Able to be measured and analysed at a low cost	↗ Monitoring and equipment not costs intensive; investment in capacity buidling needed	
2d) Able to help predict as well as explain cause and effect of changes	✗ Requires better understanding of stressors, further data analysis, and linkages with other disciplines for "diagnostic capability" **(AE1, AE3)**	see left cell; see also long-term options for 2a
3. TIMING OF DATA COLLECTION		
3a) Length of record covers the cycles of natural variability (seasonal, annnual, decadal)	↗ Will be improved with increasing length of data record	

3b) Frequency captures natural or operational system changes and migratory cycle	✗	Annual monitoring at priority locations would better meet HP-info needs **(AE1)**	
4. INFORMATION MANAGEMENT		
4a) Quality management systems are in place to ensure consistency across countries	✗	Systems do not appear consistent across countries. Taxa catalogues are not up-to-date **(AE1, AE2, AE3);** initiate quality assurance system ((e.g. sample record book)	QA/QC development; Introduce QC system for accuracy of identifications; ring-tests
4b) Systems allow information to be centrally archived and shared	◐	The biomonitoring database would benefit from a number of improvements **(AE3)**	Regular, timely update of database, update of taxa catalogues
5. INFORMATION USE		
5a) Information is readily available for users (e.g. Member Countries, developers, NMCs, Line Agencies)	◐	Multi-year delays occur for aquatic ecology data accessiblity **(AE3, IU1)**	Ensure that database is a living document after decentralisation
5b) Links to tools are available for decision-support and analysis	✗	Analytical approaches and tools for "biomonitoring" data relevant to HP have not yet been developed **(AE1, IU1, IU2)**	see long-term options for 2a

Attachment 4 - Responses to Comments Received

In this chapter comments on Aquatic Ecology received by Member Countries and MRC Programmes from a number of consultations are cited and responses are given.

The Aquatic Ecology (AE) proposals for improvement have slightly changed during ISH11 Phase 1 and Phase 2. To avoid confusion, the currently valid proposal number is used in the text below. It may by not exactly the same wording as in the minutes referred to, but gives the up-to-date proposal numbers. Expressions in brackets [ ] are included by the ISH11 International Consultant (IC) if completion of the text is needed for improved understanding of the comment received.

---

1 Minutes of 1st Regional Consultation 06/03/2013

Lao PDR mentioned: "Considering the current capacity of line agencies, the collection of parameters/indicators listed in Table 10 alone is challenging, particularly those relating to aquatic ecology for there is a lack of expertise in this area. (Additional comment: Suggest to continue what have been done for the Ecological Health activities under the Environmental Program of MRC to fully utilize the existing capacity.) Suggest experts of ISH11 to coordinate with related Progammes of MRC to recheck the data availability and ensure the project activities are not overlapped with the existing programmes' work scope."

Response: The table 10 mentioned gave examples for aquatic ecology indicators, which were discussed during Phase 1 and Phase 2. By integrating the comment above and similar ones, the AE proposals AE1 and AE3 focus on enhancing existing information to gain good quality data. These proposals include continuation of EHM, as suggested above. ISH11 ICs are working in close cooperation with the MRC programmes; implementation of proposals will be done via the regular Programme mechanism (in AE via EP).

Lao PDR mentioned: "The university [NUOL] does not have its own budget to implement regular study on the bio species. Most of the practices were implemented based on the requests from various project particularly hydro projects on a contract basis. Collected data were handed to the project and disclosure of those data needs authority from concerned projects."

Response: Lately, NUOL had one project financed by the IUCN to investigate a number of locations between Luang Prabang and Vientiane with the same methods as used in EHM (as also mentioned in the 1st National Consultation in Lao and the Technical Workshop in October, see below). NUOL provided the IUCN contact address to the ISH11 IC and ISH11 will ask for those data. If we will receive them they can be evaluate and possibly used to enhance aquatic ecology information in the mentioned Mekong mainstream stretch.

Thailand mentioned: Information priorities: "Biological: Species composition of phytoplankton, Zooplankton, Benthos , Mollusca and Fishes (include catch data, spawning and rearing ground, flood plain)."

Response: Zooplankton and benthos including Mollusca are investigated in Ecological Health Monitoring. ISH11 suggests in the AE proposals to continue and extend it to additional Mekong mainstream locations. With respect to species composition, proposal AE1 recommends to test additional data evaluation possibilities to underpin hydropower information needs. Proposal AE2 deal with phytoplankton trials for Mekong mainstream. Fish are considered separately in the Fisheries Annex.

Vietnam mentioned the need for information in "Changes in amount of species and groups, Aquatic animals, Aquatic plants, Sea water impacts".

Response: Aquatic animals and plants and possible changes in their species compositions are considered in the AE proposals as far as possible (aquatic invertebrates, diatoms, zoo-and phytoplankton). Further aquatic biota are referenced in the Phase 2 report in some passages, but are largely beyond the scope of the ISH11 study, as is sea water impact. These topics would most likely be a focus of the Delta Study.

Cambodia mentioned the following priorities in Environmental data (those related to ISH11 discipline Aquatic ecology are marked in Italics by the IC):

Water quality, Sediment, *Aquatic ecology, Ecological health,* Fisheries resources, Fauna and flora, Biodiversity, Wetlands and protected areas, Others.

Response: ISH11 has considered the suggestions in several proposals; aspects of aquatic ecology, ecological health, fauna and flora and biodiversity are integrated in all AE proposals as far as practical. The ISH11 IC for Aquatic Ecology agrees that wetlands and protected areas play an important role in the LMB and hydropower context. The ISH11 team has cross-referenced this context in several passages in the ISH11 Phase 2 Main Report, but has also highlighted that these topics are largely beyond scope of the ISH11 study.

---

2 Minutes of Cambodia 1st National Consultation 05/04/2013

Cambodia mentioned: "Biomonitoring will require capacity development, particularly in terms of species identification and technique in samples sorting there is need to set up laboratories and research. Capacity on data collection technique, sampling, data keeping, and analysis and interpretation for additional parameters are required."

Response: These topics were discussed in more detail during the technical workshop in August 2013 in Siem Reap. Regarding capacity-building, this is foreseen in all Aquatic Ecology improvement proposals. A number of identification training workshops are proposed (refer to proposals AE1 and AE2), as well as a "train-the trainer" approach or a mentoring approach. Details have to be further discussed and outlined with the Environment Programme.

---

3 Minutes of Cambodia 2nd National Consultation 12-14/09/2013

Cambodia mentioned: "Some terms and acronyms used are not consistent with the MRC programmes. For example, Aquatic Ecology is termed by ISH11 while the EP terms it as Environmental Health Monitoring (EHM)."

Response: ISH11 uses two different "key words" by choice, because they do not have exactly the same meaning. The term Environmental Health Monitoring explicitly names the biomonitoring activities in the LMB, which have defined parameters groups, monitoring and evaluation approaches. ISH11 proposed in the ToR and Inception Report to review Aquatic Ecology in Mekong mainstream in wider terms, e.g. to discuss which parameter groups could also be useful. Thus the term "Aquatic Ecology" was further used when talking about riverine biota in a wider senses (e.g. also

phytoplankton). “Ecological Health Monitoring” is only used when the definite EHM monitoring in the LMB is meant.

Cambodia mentioned: “It was clarified that the EHM data have not been stored into the IKMP Database yet.”

Response: All EHM data from 2004 to 2008 from all four Member countries are centrally stored in a so called “Biomonitoring database” (Access database), which can be requested via the MRC data portal. 2011 and 2013 data are not yet in the database. More information about the database is given in this Annex in Section 3.

Cambodia mentioned: “The Aquatic Ecology Monitoring Group also had exhausted comments during the Technical Meeting.”

Response: Yes, AE was discussed in detail during this workshop. Comments raised there are answered below at the section on Cambodian Technical Workshop in August 2013.

Cambodia mentioned: For improvement in Aquatic Ecology Monitoring, the Monitoring Team agreed with the proposals and suggested the ISH11 Team to refer to the detailed comments during the Technical Meeting. It was also suggested to continue with the present parameters and to add another parameter (phytoplankton) to have complete set.

Response: The suggestions from the Cambodian team made during the technical meeting in August were integrated as much as possible in the AE proposals. Phytoplankton is outlined in proposal AE2.

---

4 Minutes of Lao PDR 1st National Consultation 9-10/05/2013

Lao PDR mentioned: “On Aquatic Ecology, most of suggested ~~macro-invertebrates~~ [aquatic biota] (except macrophytes and maybe phytoplankton) were collected once per year by the Faculty of Science of the National University of Laos during 2008-2011 with the support from the MRC and IUCN. Littoral macro-invertebrate samples were also collected during 2003-2011 by the Faculty of Science. Most of the data were analysed by the university team and the data were regularly sent to MRCS for publication. The data was recorded in Excel files.”

Response: The ISH11 team is appreciative of this advice. Data from EHM are available to ISH11 via EP. NUOL team advised to ask IUCN if data collected outside of EHM (as mentioned above) would be available to MRC. Contact details were provided by Dr. Chanda Vongsombath. The request to IUCN is under preparation.

5 Minutes of Lao PDR 2nd National Consultation 31/10-01/11/2013

Lao PDR mentioned: "Agree with the proposals in principle. On proposal [AE2 *"Phytoplankton"*], it requires high-specific equipment to perform the sampling which the cost is very high. There are a few experts in this field who can conduct the sampling but would need support on equipment."

Response: The AE proposal for integration of phytoplankton suggests initiating trialling and a first stage of learning by doing in Vietnam. The trial event may test and discuss applicability, data generation and meaningfulness for Mekong mainstream phytoplankton sampling before a decision is made on integration into EHM and the need for additional equipment.

Lao PDR mentioned: "on [proposal AE3 Strengthening the Biomonitoring Database for Hydropower Information], it was suggested to gather experts from member countries to have discussions for agreement on the principles of biologic classification."

Response: Involving experts from the Member Countries in the discussion on application of EHM method, and classification principles etc as well as updates of taxa catalogues used in EHM, is a must also from the ISH11 perspective, and thus incorporated in the AE improvement proposals.

Lao PDR mentioned: "Not sure if it is necessary to have sampling activities at the same monitoring stations together with other disciplines."

Response: As highlighted in Section 1 of this Annex, there are a number of inter-linkages and combined data can assist interpretation of findings for all disciplines. However it may not be necessary to have the exact same sites as long as the general locations are similar.

Lao PDR mentioned: "Need to collaborate with other discipline information in order to have in-depth understanding of the hydropower related changes in the aquatic ecology presented in different environment.

Response: The proposal to have "integrated sampling" of several disciplines at one monitoring station would be one approach for such a collaboration. Linking data from different disciplines may provide additional information to underpin hydropower information needs.

6 Thailand 1st National Consultation 04/07/2013

The comments received in the minutes of this consultation are related to the whole project and are responded to in an attachment to the ISH11 Phase 2 Main Report. There is no specific comment relating to Aquatic Ecology in the minutes.

7 Vietnam 1st National Consultation 18/04/2013

Vietnam mentioned: "Some participants from concerned line agencies related to the environment, hydropower sectors indicated that some outputs from their colleague project activities could be certain inputs for MRC ISH 11 work, closer cooperation and more contacts should also be suggested at national levels."

Response: For Aquatic Ecology, close cooperation is foreseen in all AE proposals and was discussed in some detail during the ISH11- Vietnam Line Agency workshop in Hoa Binh City in July 2013. An example would be integration of Vietnam experts as trainers for field and lab work in the area where they have specific knowledge. Especially in integration of phytoplankton monitoring, colleagues from Vietnam agreed to host initial sampling and trialling and to provide their expertise in capacity-building workshops for all Member Countries.

8 Minutes of Vietnam 2nd National Consultation 3-4/10/2013

Vietnam mentioned: "Themes on biodiversity, wetland mapping, salinity and soil erosion could be considered in data updating activities."

Response: ISH11 agrees that all those topics are important, but they are to a large extent beyond the scope of the ISH11 study. Biodiversity aspects are integrated in both Aquatic Ecology and Fisheries proposals. Several specific biodiversity topics are subject to future research activities. Some aspects are part of the Council and the Delta study.

9 Minutes of Cambodia Line Agency Technical Workshop on Hydrology, Sediment, Water quality and Aquatic Ecology 21-22/08/2013

Cambodia raised "some difficulties faced during their [EHM] monitoring works below:

Identification of taxa down to species or genus level is very problematic due to limited technical knowledge and lack of good taxonomic keys for the region; several taxa for Cambodia missing in keys; Update of invertebrate key needed; Keys for other groups needed; Lack of budget."

Response: Issues in taxonomic identification will best be clarified in a series of capacity-building workshops, as proposed in proposal AE1. Proposals for update/generation of keys, a common database, and related taxa catalogues are integrated in the proposals AE2 and AE3. For more details see the ISH11 Phase 2 Main Report and Section 5 of this Annex.

Cambodia asked "on the number of sites that will be covered in the trial period, location and timing".

Response: Monitoring sites in ISH11 Phase 3 (trialling) were foreseen to be two per country. For Cambodia, these were proposed to be on the Mekong mainstream at Stung Treng and on the Tonle Sap River at Prek Kdam with the same sample and same biological groups as in EHM. The site on the

Tonle Sap River was selected because its flow depends on the mainstream Mekong and it is important for the fisheries resources. The proposed time would be low flow (March) as in EHM. The approach and activities in ISH11 Phase 3 are dependent on the MRC Programme and Member Country response to this Phase 2 Report.

Cambodia proposed "to add more sites, as two sites will not provide enough information. At least one on Stung Sen River for the Tonle Sap and another one on the Mekong mainstream at a point above Phnom Penh, e.g. where the mainstream flow enters into Phnom Penh at Chaktomouk to be added. Based on suggestion of the AE and WQ/Sed/Hydro Specialist, the existing monitoring site on the Stung Sen River for the Tonle Sap can be added as: i) there is a planned hydropower project on this river; and ii) the existing monitoring site downstream of the project already has hydrology and sediment monitoring."

Response: The two sites per country proposed by ISH11 for Phase 3 (e.g. in the ISH11 Discussion Points, August 2013) were proposed as an initial set for trialling integrated sampling and /or additional methods. The locations identified as important for hydropower information needs (ISH11 Phase 2 Main Report, Tables 3 and 19 and Figure 6) include several more sites of specific importance for hydropower information. The integration of the above mentioned sites in EHM is recommended to be discussed with EP for further consideration.

Cambodia requested to: "i) continue with the on-going EP monitoring Programme; and ii) additional sites can be considered up on the results of the trial; and iii) all sites of existing EHM be operated in the same way as prioritized sites for ISH11 Project in order to have the same level of information. Cambodia as the country most concerned by the hydro power plants is interested in having more site to be investigated and long-term information."

Response: The AE proposal have a strong focus on enhancing existing EHM by capacity-building, update of taxa catalogues and database, trials for additional indicators regarding hydropower information and integration of additional parameter groups in EHM. All this supports the request above. For more details see Aquatic Ecology proposals. Agreement on and implementation of the ISH11 improvement proposals is subject to consideration and discussions by MRC Programmes and Member Countries.

Cambodia fully supported "[phytoplankton integration in EHM], and *raised* the need to build more capacity. The representative from Tonle Sap Authority asked to include biologists from Tonle Sap Authority in the capacity building plans and also in the EHM activities."

Response: The need for capacity-building in the phytoplankton field and lab work is part of the ISH11 improvement proposal AE2. The integration of experts from Tonle Sap is supported by ISH11 IC as it strengthens Cambodian capacity and is mentioned in the improvement proposal.

Cambodia mentioned: "For long–term implementation of phytoplankton monitoring Cambodia needs equipment (financed by ISH), personnel capacity and long-term fund."

Response: ISH11 will discuss these issues with NMCs and Programmes at consultations.

Cambodia mentioned: "AE proposal for design of mid-term Capacity building, identification of keys, etc., are completely agreed by the national team. However, the national team requested for additional capacity in updating EP's identification keys. Some new taxa are not included, existing keys

cannot cover all species in Cambodia. Zooplankton keys have not been agreed by the four countries yet. If ISH or EP can provide support for production of keys for / in the region this would be very useful (as the team had difficulties to find the keys in the websites)."

Response: ISH11 IC for Aquatic Ecology has integrated these issues in the improvement proposal AE4. Options for production of taxonomic keys need to be discussed with EP. Input from experts from other Member Countries and possible international taxonomic specialists will be needed,

---

10 Minutes of Lao Line Agency Technical Meeting on Aquatic Ecology 23/10/2013

An overview on aquatic ecology and respective proposals were discussed in detail. Comments given during the technical workshop were answered directly at the workshop and several details were clarified. Full information is available in the Minutes of the meeting. Comments related to the AE proposals are repeated below:

Lao mentioned "that equipment used to sample and identify the Phytoplankton is not in good quality in Laos. Especially good microscope would be required. The same is true for all other EHM field equipment, which has to be renewed very soon…. It was also discussed that currently there is no much phytoplankton in the upstream areas of Mekong mainstream, rather in Cambodia and Vietnam. Participants expressed their view, that with increased impounded sections, this biological group may become more relevant and should be considered in term of hydropower information…."

Response: It was agreed that all those points provide good advice to be considered in the proposals. Equipment needs should be bilaterally discussed between NUOL/LNMC and EP.

Lao mentioned regarding taxa lists used in EHM: "… they [NUOL] add the names of the new findings in the [EHM] excel lists they use for data storing and calculation of EHM classes. Same is done by teams in other countries in their lists…."

Response: Based on discussions of this point, it became clear that each country meanwhile uses a different list and that there is no real consistent taxonomy system / taxa list used among the Member Countries. Improvement proposal AE4 proposes to have a single list of taxa to avoid confusion and typing errors, managed and updated by EP and distributed regularly to the Member Countries. Quality assurance and quality control mechanisms need to be initiated.

Lao mentioned: "Participants welcomed the idea of a joint field workshop with participants from all member countries, with the purpose to refresh and enhance field work capacities and train young experts in EHM application. NUOL sees great value in such a workshop, especially in preparation of handing over activities to younger professionals in the next years. Also, the proposals of joint identification workshops with samples taken earlier on Mekong sites (experts from each biological groups, i.e. 3 different workshops on invertebrates, zooplankton, diatoms) was discussed in detail and supported by NUOL.

Response: The approaches mentioned above are part of proposal AE1.

11 Minutes of Vietnam Line Agency Technical Workshop 03-04/07/2013

Vietnam recommended "to review and improve the existing EHM method for the Viet Nam delta context; Viet Nam researchers expressed their view that sometimes classifications are questionable. Integration of new indicators relevant to hydropower is possible but needs further discussion and research."

Response: This recommendation may further be discussed with EP and the ISH11 IC during implementation of proposal AE1 and the workshops proposed there.

Vietnam mentioned: "It would be possible to integrate phytoplankton into existing monitoring, and the Vietnamese specialist could conceivably give this training to other countries. Phytoplankton sampling is recommended for 2014 trails 2 to 3 times per year."

Response: This advice is integrated in proposal AE2.

Vietnam mentioned: "Locations near the Cambodian border were suggested for the ISH11 2014 trials."

Response: This advice is integrated in the identified locations for hydropower information needs shown in the ISH11 Phase 2 Main Report (Tables 1 and 17 and Figure 6).

Vietnam mentioned: "It is hoped that the Delta Study can use the same EHM biological groups and methods including phytoplankton at additional delta sites." …. "Macrophytes and riparian vegetation are recommended for inclusion in the Delta Study...".

Response: ISH11 also sees great value in these approaches. If ISH11 has the option to discuss methods with the Delta Study, both EHM methods and integration of macrophytes / riparian vegetation will be proposed.

12 Thailand Working notes provided in June 2013

Thailand mentioned: "Thai expert had study the Mollusca, Fresh water insect larvae and Macrophyte by the (Lecture) from Chiang Mai University, Khon Kaen University and Kasetsart University.

Response: Thai experts are well known to have a very good knowledge in several field of aquatic ecology. Many publications in this field from Thai colleagues are known to the IC and several are mentioned in the Annotated Bibliography. More information and details provided by experts from Thailand on the above mentioned studies and their context to hydropower information would be very welcome. Important studies may be available only in Thai language and thus the IC is looking forward to having personal discussion options and meetings with Thai experts.

13 Thailand comments on "Desk Study"

The following comments on Aquatic Ecology were received by IHS11 from TNMC.

Thailand mentioned: "Monitoring site should be the stations from Ecological Health Monitoring Activity".

Response: One of the key principles of ISH11 is to use existing sites where possible and suitable. One of the observations of the existing monitoring work done by the MRC Programmes is its lack of ability to meet hydropower information needs at important locations. The 12 existing EHM monitoring sites along Mekong mainstream are not sufficient on their own to inform hydropower planning, management and decision-making needs in the long-term. Integration of more sites at specific locations is proposed and can be found in the ISH11 Phase 2 Main Report.

Thailand mentioned: "We propose additional parameter group i.e. fish, shellfish, larvae (these are on FP's future plans for data collection)".

Response: The ISH11 study has one discipline specifically dealing with Fisheries. Thus, fish and fish larvae are part of the Fisheries discipline and are not dealt with in the ISH11 discipline Aquatic Ecology, but both disciplines work closely together. The ISH11 IC for Aquatic Ecology would be happy to discuss with experts from Thailand which parameter group exactly is meant with "shellfish", and how this group can specifically be used for hydropower information.

Thailand mentioned: "MRCS/ISH should clarify why it proposes to use a sensitive organism in Europe for the Mekong River".

Response: The rationale for the proposals for aquatic ecology parameter groups is given in the ISH11 Phase 1 and Phase 2 Report Aquatic Ecology Annex. Macroinvertebrates are part of the Ecological Health Monitoring in the LMB and may be used for further evaluation e.g. as flow indicators as already proposed in the IBFM reports. Such information on aquatic invertebrates will support hydropower information needs. The ISH11 Phase 1 Report Aquatic Ecology Annex thus proposed macroinvertebrates as one sensitive group of organisms often indicative of hydropower-related changes. The ISH11 IC will be happy to receive further advise on this comment in discussion with experts from Thailand and information why experts from Thailand consider invertebrates only sensitive in Europe and not sensitive in Asia.

14 Minutes of MRC Programme Consultation – 15/05/2013

Timing of sampling

EP advised that the EHM monitoring follows a 2-yearly cycle, collecting in 2013 and again in 2015, which means there would be no planned EP field monitoring during 2014 onto which ISH11 initiatives could be linked.

Response: Phase 3 earlier had been proposed to consist of capacity-building trial events in 2014 (as per the ISH11 Discussion Points August 2013). This would have been done additional to routine EHM

monitoring. For EHM, the low flow period is needed for sampling and based on the present timing March 2014 is not realistic. Options have to be discussed with EP. One option is to have capacity-building events in 2014 and to add more locations of specific hydropower relevanceto the next EHM monitoring in 2015 (also mentioned in proposal AE1).

Importance of aquatic ecology monitoring

Questions were asked about how to emphasise the importance and relevance of collected aquatic ecology data with respect to hydropower, and about whether it is absolutely necessary for Ilse to go to the field to get data.

Responses were that aquatic ecology is a critical knowledge component not only in its own sake with respect to ecosystem health, but also with respect to interpreting and understanding other environmental and socio-economic conditions. FP advised that aquatic ecology information is very important for the FP, and in fact the information from all the disciplines collated will be very useful for understanding fisheries.

Offshore plankton

CCAI asked whether offshore plankton monitoring was being considered.

Response: They were advised that no it is not at this stage, that the geographic scope of the ISH11 project is the mainstream river and not offshore. More understanding of aquatic ecology monitoring in the delta and offshore will be obtained once the ISH11 team is able to liaise more directly with those undertaking the Viet Nam Delta Study.

Phytoplankton

FP was interested in why phytoplankton was not included in the aquatic ecology parameters, which they felt was an important area of knowledge need for fisheries. EP advised that it was trialled early on in EHM, but was not continued. It was suggested that Ilse should discuss with Dr. Malasri and EP as to why phytoplankton was not progressed in EHM, and with FP to better understand their interest.

Response: Phytoplankton was mentioned in the Phase 1 Report Aquatic Ecology Annex as an option. It has since been discussed with EP, FP and NMCs which lead to proposal for phytoplankton trials (see improvement proposal AE2 in Section 5 of this Annex).

---

15 Environment Programme Comment on Phase 1 Report and Aquatic Ecology Annex (received by email)

EP comment: “Main report p.20 and p. 55: For biomonitoring it is mentioned that “only a few sites in the Mekong mainstream“ are monitored and “only few sites from Mekong River are in EHM”. The number of mainstream stations for the Ecological Health Monitoring is 15 (as mentioned in the Annex).”

Response: The number of sites along Mekong Mainstream and tributaries has been clarified since and the numbers are corrected both in Phase 2 Main Report and this Annex. (The number of Mekong mainstream is 12, as some are in junctions of tributaries and mainstream)

EP comment: "Aquatic Ecology Annex p. 7: "One limitation to the interpretation of results from the current monitoring programme is the lack of the above mentioned set of information". What is the above-mentioned information referred to?"

Response: The EHM classes refer to "general ecological health". Data interpretation with respect to cause and effect is currently not done or foreseen, which is not a specific problem of EHM but a more general one in rivers worldwide due to lack of cause-effect-chain knowledge.

EP comment: "Aquatic Ecology Annex: It is not clear whether and to what extent monitoring for hydropower impacts should be different from general ecological health monitoring"

Response: It was discussed intensively and clarified that there should not be two different monitoring systems, but all AE topics should be integrated in and implemented via EP and EHM. The content of this Annex addresses what additional measures could be implemented to enable the EHM to better inform hydropower planning and management information needs.

Attachment 5 - Annotated bibliography for Aquatic Ecology (focus on invertebrates, algae/diatoms, plankton)

Year	Reference	Comment
2000	**Amornsakchai S, Annez P, Vongvisessomjai S, Choowaew S:** Thailand Development Research Institute (TDRI), Kunurat P, Nippanon J, Schouten R, Sripapatrprasite P, Vaddhanaphuti C, Vidthayanon C, Wirojanagud W and Watana E (2000) Pak Mun dam, Mekong river basin, Thailand. WCD case study. Cape Town: World Commission on Dams	Case Study on Pak Mun Dam, summarises pros and cons along several guiding questions; does not contain raw data on aquatic ecology; extendend summary available
	Biomonitoring database (MRC-IKMP)	Access database; provides information on benthic and littoral invertebrates, phytobenthos and zooplankton per sampling site and year for Thailand, Lao PDR, Cambodia, Viet Nam from 2004 -2008 EHM; was compiled by IKMP from existing data provided by Environment Programme.
2007	**Bird P, J Haas, L King:** The Current Status of Environmental Criteria for Hydropower Development in the Mekong Region: A literature compilation. Consultants Report to ADB, MRCS and WWF, 171 pp	Gives literature based overview on Mekong dams, gathers background information for consultation processes
2006	**Boonsoong B. and Sangpradub N.:** Diversity of Stream Benthic Macroinvertebrate at the Loei River and Adjacent Catchments, Northeastern, Thailand. In: The first International Conference on Science and Technology for Sustainable Development of the Greater Mekong Sub-region, Khon Kaen, Thailand, 15-16 August 2006.	Provides information on occurrence and distribution of benthic invertebrates,
2009	**Boonsoong, B., Sangpradub, N. & M.T. Barbour:** Development of rapid bioassessment approaches using benthic macroinvertebrates for Thai streams. Environmental Monitoring and Assessment 155:129-147.	Method development for invertebrates in Thai streams in line with international up to date practice
2007	**Campbell, I. C.:** Perceptions, data and river management - lessons from the Mekong River. Water Resources Research 43: doi: 10.1029/2006WR005130	Gives summary and views on Mekong River management
2009	**Campbell I.C., Chessman B.C, Resh V. H.:** The development and application of biomonitoring in the Lower Mekong River System. In: Campell I.C. (ed), The Mekong: Biophysical Environment of an International River Basin. Chapter 13: 321-334, Aquatic Ecology Series, Elsevier, ISBN 978-0-12-374026-7.	Gives an overview on biomonitoring development and overview for LMB

Year	Reference	Comment
2006	**Campbell I.:** IBFM Phase 2/3 Pilot-Specialist Report on Aquatic Invertebrates. Unpublished manuscript	Describes WUP/IBFM activities for aquatic invertebrates and gives overview on possibility for use of flow indicators
2011	**Campbell L:** The Use of Environmental Impact Assessment in Laos and its Implications for the Mekong River Hydropower Debate. MSc study, Nicholas School of the Environment of Duke University, 36pp.	Gives overview on Mekong River Hydropower EIA and debate with special emphasis on Lao PDR
1989	**Chantaramongkol Porntip, Malicky Hans:** Some Chimarra (Trichoptera: Philopotamidae) from Thailand. Studies on caddisflies from Thailand, No.2. - Aquatic Insects 11:223-240	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
2010	**Chessman B, Dao Huy Giap:** Biological metrics calculation. p. 57- 60 in: MRC (2010a) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes calculation procedure of "metrics" (indicators) developed for use in LMB biomonitoring methods
1876	**Crosse H, Fischer P:** Mollusques fluviatiles, recueillis au Cambodge, par la mission scientifique française de 1873. Journal de Conchyliologie 24: 313-334.	Summarises scientific findings and description of snails from Cambodia; cited in Srum Lim Song, Neou Bonheurm, Uy Ching (2002)
1980	**Dang, N.T, Thai, T.B. & V.M. Pham**: Classification of freshwater invertebrate zoology in North Viet Nam. Science and Technology Publisher.	Provides information for plankton identification
2010	**Dao Huy Giap, Tatporn Kunpradid, Chanda Vongsombath, Do Thi Bich Loc, And Prum Somany:** Report on the 2008 biomonitoring survey of the lower Mekong River and selected tributaries, MRC Technical Paper No. 27. Mekong River Commission, Vientiane.69 pp. ISSN 1683-1489	Provides overview and short description on sampling sites, sampling and lab methods, classification of 32 sites for Ecological Health Monitoring 2008 in Lao PDR, Thailand, Cambodia, Viet Nam; shows some comparisons for data 2004-2008
2004	**Davison Supatra Parnrong:** Primary Production and Phytoplankton Composition. Report submitted to Thai National Mekong Committee;Mekong River Commission - Environment Programme, 32 pp.	Study on applicability of phytoplankton composition indicating primary production and ecological health for the Mekong River system

Year	Reference	Comment
2010	**Davison Supatra Parnrong and Sok Khom:** Environmental variables. p.21-24 in : MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes environmental (physical and some chemical) variables and methods for measurements in short for use in LMB biomonitoring methods
2006	**Davison Supatra Parnrong, Tatporn Kunpradid, Yuwadee Peerapornisal, Nguyen Thi, Mai Linh, Bounnam Pathoumthong, Chanda Vongsambath And Anh Duc Pham:** Biomonitoring of the Lower Mekong and selected tributaries. MRC Technical Paper No.13, Mekong River Commission, Vientiane. 100 pp. ISSN: 1683–1489.	Provides overview on biomonitoring in 2004 for 20 sites in Lao PDR, Thailand, Cambodia, Viet Nam; gives description on sampling sites, sampling and lab methods, statistical analysis etc.
2006	**Duong T.T., Coste M., Feurtet-Mazel A., Dang D.K., Gold C., Park Y.S. and Boudou A.:** Impact of urban pollution from the Hanoi area on benthic diatom communities collected from the Red, Nhue and Tolich Rivers (Vietnam). Hydrobiologia 563: 201-216	Study on benthic diatoms in three rivers in Viet Nam, may provide biological background information
	Eriksson, L. & S. Smith (Undated, estimated year 1988): The chironomid fauna in the Mekong River and its tributaries in the Plain of Reeds. Report to the Interim Mekong Committee. 9p, plus Annexes	Study on non-biting midges in the Mekong basin, may provide input to fauna inventory of LMB, contains drawings of taxonomic identification characteristics of some Chironomids
1971	**Foged N.:** Freshwater Diatoms in Thailand. Odense Publisher. Denmark	Gives overview on freshwater diatoms in Thailand as of 1971
2001	**Gallacher, D.:** The application of rapid bioassessment techniques based on benthic macroinvertebrates in East Asian rivers (a review). Internationale Vereinigung für Theoretische Angewandte Limnologie Verhandlungen 27:3503-3509.	Gives overview on biological methods, no data
2008	**Getwongsa P, Sangpradub N:** Preliminary Study on Development of Biotic Index for Rapid Bioassessment in Mekong II Basin (Thailand). KKU Sci. J.36 (Supplement) 122-136 (2008).	Describes method development for using aquatic invertebrates as indicator group for bioassessment in Thailand; 20 streams investigated 2005-2006; no raw data; provides example on best practice and options for method development for the Mekong mainstream (e.g. under guidance of Thai scientists)

Year	Reference	Comment
1988	**Grimas U:** Water quality investigations in the Lower Mekong Basin. Biological Monitoring – an Evaluation. Report to the Interim Mekong Committee, 25 pp plus Annexes.	Provides insight in early attempts to combine chemical water quality monitoring with biological parameter (invertebrates), does not contain species lists
2001	**Hart BT, Jones MJ, Pistone G:** Transboundary Water Quality Issues in the Mekong River Basin. Report to the Mekong River Commission, 65 pp plus Annex.	Analysis ongoing activities in LMB re water quality and transboundary issues; report was previous to biomonitoring /EHM, thus suggests biological monitoring activities; deal also with risk assessment
1967	**Hirano M:** Freshwater Algae Collected by the Joint Thai-Japanese Biological Expedition to Southeast Asia 1961-1962. In: Kira, T. and K. Iwata (eds.), Nat. Life Southeast Asia, pp: 1–71. Fauna and Flora Research Society, Kyoto, Japan	Describes and lists algae (diatoms) from an floristic expedition in the 1960ies; may provide input to biological background information
2010	**Hirsch P:** The changing political dynamics of dam building on the Mekong. Water Alternatives 3(2): 312-323	Provides review on geopolitical and eco-political discussion and plans for Mekong dams
2004	**Hortle K, Chea T, Bun R, Em S,and P. Thac:** Drift of fish juveniles and larvae and invertebrates over 24-hour periods in the Mekong River at Phnom Penh, Cambodia. p 19-33, Proceedings of the 6th Technical Symposium on Mekong Fisheries, Pakse, Lao PDR 26-28 November 2003	Investigates drift fauna at different times during the day at a single location over three days in July 2003; besides fish larvae drift it contains info on 28 invertebrate taxa, e.g Macrobrachium, Hydropsychidae, Odonata, Hemiptera etc.
2006	**IBFM Report**, Overview of Biotic Aspects and Impacts from Changes of Flow Regime to Mekong Delta Water Utilization Program/Environment Program, Integrated Basin Flow Management – IBFM3 , Mekong River Commission, 55pp.	Gives overview of natural condition, current flow and tide regimes, number of wetlands, and component and number of fauna and flora species in Zone 6 (South of Phnom Penh to the sea of Vietnam). Relationships between estuarine organism species with changes of flow regime are described.
2010	**ICEM:** MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream, Hanoi, Viet Nam, 198 pp.	Summarises approach of EA in context with Mekong dams

Year	Reference	Comment
2010	**Kunpradid Tatporn, Yuwadee Peerapornpisal, and Sutthawan Suphan:** Benthic diatoms. p.27-33 in : MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes benthic diatom sampling and laboratory methods developed for use in LMB biomonitoring methods
2005	**Lana G:** Review of the water quality assessment (EAMP) Proposed Nam Theun 2 Hydroelectirc Project. International Rivers Network 12pp.	Reviews and comments EAMP for Nam Theun 2
2011	**Leelahakriengkrai, P. and Y. Peerapornpisal:** Diversity of benthic diatoms in six main rivers of Thailand. Int. J. Agric. Biol., 13: 309–316	Provides information on diatoms in 6 in Thailand; may provide input to biological background information
2009	**Leelahakriengkrai, P., S. Pruetiworanan and Y. Peerapornpisal:** Diversity of Benthic Diatoms and Macroalgae and Water quality in the Mekong River Passing Chiang Rai Province, Thailand. KKU Sci. J., 37: 143–152	Studies occurrence of freshwater algae in Chiang Mai Province and provides info on water quality in the investigated area; may provide input to biological background information
1995	**Lewmanomont, K., L. Wongrat and C. Supanwanid:** Algae in Thailand. Office of Environmental Policy and Planning, Bangkok, Thailand	Summary of Information on freshwater algae across Thailand; may provide input to biological background information
2002	**Luadee. P., Nuntakwang, A., Prommi, T. et al.:** Aquatic insects and their application to environmental bioassessment in lotic water of Northern Thailand. ASEAN Regional Center for Biodiversity Conservation, Laguna, Phillippines.	Provides information on use of invertebrates for assessment of biological conditions of freshwater; serves as background information
1995	**Malicky H:** Neue Köcherfliegen (Trichoptera, Insecta) aus Vietnam. - Linzer biol.Beitr. 27:851-885	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
1993	**Malicky H, Chantaramongkol P:** Neue Trichopteren aus Thailand. Teil 1: Rhyacophilidae, Hydrobiosidae, Philopotamidae, Polycentropodidae, Ecnomidae, Psychomyidae, Arctopsychidae, Hydropsychidae. - Linzer biol.Beitr. 25:433-487	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
1999	**Malicky H. & P. Chantaramongkol:** A preliminary survey of the caddisflies (Trichoptera) of Thailand. – Proc. 9th Int.Symp.Trich.: 205-216.	Summary on caddisflies occurring in Thailand; may provide input to biological background information for fauna catalogue

Year	Reference	Comment
1989	**Malicky H.** Odontoceridae aus Thailand (Trichoptera). Studien über thailändische Köcherfliegen Nr.4. - Opusc.zool.flumin. 36:1-16.	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
1989	**Malicky H, Chantaramongkol Porntip:** Einige Rhyacophilidae aus Thailand (Trichoptera). Studien über thailändische Köcherfliegen Nr.3. - Ent.Z.(Essen) 99:17-24.	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
1991	**Malicky H, Chantaramongkol Porntip:** Beschreibung von Trichomacronema paniae n.sp. (Trichoptera, Hydropsychidae) aus Nord-Thailand und Beobachtungen über ihre Lebensweise. Arbeit über thailändische Köcherfliegen Nr.9. - Ent.Ber.Luzern 25:113-122.	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
2000	**Malicky H, Chantaramongkol Porntip, Chaibu Prachuab, Thamsenanupap Penkhae, Thani Isara:** Acht neue Köcherfliegen aus Thailand. – Braueria 27:29-31.	Faunistic paper on Trichoptera from Thailand, provides input for fauna inventory (example, several more on Trichoptera of Thailand published)
1931	**Martynov AB:** Report on a collection of insects of the order Trichoptera from Siam and China. Proceedings of the United States National Museum 79: 1-20	Summary for the 1930ies on caddisflies occurring in Thailand and parts of China; may provide input to biological background information for fauna inventory of LMB
2009	**Molle, F, Foran T, Käkönen M (eds):** Contested waterscapes in the Mekong region: Hydropower, livelihoods and governance, pp. 81-114. London: Earthscan	Consists of several chapters about Mekong and hydropower; no specific data or methods on aquatic ecology
2011	**MRC:** Prior Consultation Project Review Report for the Proposed Xayaburi Dam Project. Mekong River Commission, Vientiane, Lao PDR. 99 pp	Details on a set of impacts associated with the construction of the Xayaburi Dam on e.g. sediments, nutrients, fisheries, details on aquatic ecology missing
2005	**MRC:** Overview of the present knowledge of the lower Mekong River ecosystem and its users. IBFM Report 7, Vientiane, 10 November 2005	Copy not available to date but highly appreciated

Year	Reference	Comment
2008	**MRC:** Biomonitoring of the lower Mekong River and selected tributaries 2004-2007. MRC Technical paper No. 20, ISSN 1683-1489. Mekong River Commission, Vientiane.	Provides summary overview and short description on sampling sites, sampling and lab methods; statistical analyses and guidelines for classification of sites for Biomonitoring 2004-2007 in Lao PDR, Thailand, Cambodia, Viet Nam
2008	**MRC:** The Mekong River Report Card on aquatic ecological health (2004-2007).	Provides overview on sites and ecological health classes from EHM 2004 to 2007
2009	**MRC:** The Mekong River Report Card on aquatic ecological health 2008.	Provides overview on sites and ecological health classes from EHM 2004 to 2008
2010	**MRC:** Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes method development and details for methods used in biomonitoring / Ecological Health Monitoring in the LMB (see also references on single chapters)
2011	**MRC:** Planning Atlas of the Lower Mekong River Basin. Mekong River Commission BDP Program, 101 pp. River Commission, Vientiane, Lao PDR.	Provides summary on various topics of the LMB including environmental aspects
1999	**Mustow, S.E.:** Lotic macroinvertebrate assemblages in northern Thailand: altitudinal and longitudinal distribution and the effects of pollution. Natural History Bulletin of the Siam Society 47: 225-252.	Provides information on invertebrates in streams of Thailand and their reaction on pollution; provides kind of ecological background information which may also be valid for LMB
2002	**Mustow, S.E.:** Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score. Hydrobiologia 479:191-229	Describes British Biological Monitoring Working Party Score adapted to Thailand and its application; method will be tested for Mekong invertebrate fauna

Year	Reference	Comment
1997	**Mustow, S.E., Wilson, R.S. & Sannarm:** Chironomid assemblages in two Thai water courses in relation to water quality. Natural History Bulletin of the Siam Society 45: 53-64.	Provides information on non-biting midges and their use for biological water quality indication in two Thai streams; provides information on fauna and some ecological background for this Dipteran family which may also be important for LMB
2010	**Nguyen Thi Mai Linh, Phan Doan Dang, and Do Thi Bich Loc:** Zooplankton. p. 35-40 in : MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes zooplankton sampling and laboratory methods developed for use in LMB biomonitoring methods
2000	**Nguyen, X.Q., Mai, D.Y., Pinder, C. & S. Tilling:** Biological surveillance of freshwaters using macroinvertebrates. A practical manual and identification key for use in Vietnam.Field Studies Council	Provides information for field and lab work in context with invertebrates used as biological group to indicate river status in the LMB; info prior to development of biomonitoring methods for LMB
2005	**NT2 WMPA SEMFOP:** Part 4: Biodiversity Management & Conservation Framework. 48 pp.	Describes strategies for Nam Theum biodiversity management; does not give details or data on aquatic ecology except reference to one week study on aquatic snails from 1997
1902	**Oestrup E:** Freshwater diatoms. In J. Schmidt (Ed.), Flora of Koh Chang contributions to the knowledge of the vegetation in the gulf of Siam Part VII, Botanik Tidsskrift, 1902.	Gives historic information on diatom algae, can provide some biological background information
1971	**Ohno M, Fukushima H and Ko-Bayashi T:** Diatom flora of the Mekong water system, Cambodia. Natural Science 20: 1-24.	Provides information on diatoms in the LMB, can provide biological background information
2002	**Pan Van Niem:** Draft Report on Review of Biological Assessment of Freshwater Ecosystems in Viet Nam. Report submitted to Viet Nam National Mekong Committee Environment Program, 30 pp.	Summarises information available on biological assessment in Viet Nam ahead of biomonitoring development for LMB; does not contain data or detailed ecological information as this was not the purpose of the paper

Year	Reference	Comment
2002	**Parnrong Supatra:** A Review of Biological Assessment of Freshwater Ecosystems in Thailand. Report submitted to Mekong River Commission – Environment Program, 36 pp.	Summarises information available on biological assessment in Thailand ahead of biomonitoring development for LMB; does not contain data or detailed ecological information as this was not the purpose of the paper
1936	**Patrick R.:** A taxonomic and distributional study of some diatoms from Siam and the Federated Malay States. Proc. Acad. Nat. Sci. USA, 88: 367–470	Provides historic information on diatom algae, may provide biological background information, although not LMB specific
2004	**PCD:** Standard Surface Water Quality for Thailand. Pollution Control Department, Ministry of Natural Resources and Environment, Thailand, Bangkok. (http://www.pcd.go.th/info_serv/en_reg_std_water05.html#s3)	Detailed information on WQ standards from Thailand
2005	**Peerapornpisal Y.:** Fresh Water Algae in Northern Thailand. The Biodiversity Research and Training Program (BRT). Chiang Mai: Chotana Print Co., Ltd.	Provides overview but not tailored to LMB; some info maybe useful as biological background
2002	**Pekthong T. & Y. Peerapornpisal:** Fifty one new record species of freshwater diatoms in Thailand. Chiang Mai Journal of Science, 2002; 28(2): 97-112.	Provides information on diatom species new for Thailand (as of 2002); contributes to knowledge of diatom species in the LMB
2010	**Pham Anh Duc and Narumon Sangpradub:** Benthic macroinvertebrates. p.51-54 in : MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes benthic invertebrate sampling and laboratory methods developed for use in LMB biomonitoring methods
2013	**Phan Doan Dang, Nguyen Van Khoi, Dang Ngoc Thanh, Ho Thanh Hai and Le Thi Nguyet Nga**. Identification of Freshwater Zooplankton of the Mekong River and its Tributaries. Mekong River Commission, Vientiane. **Error! Bookmark not defined.**pp.	Identification key for LMB zooplankton
1999	**Pinder, L.C.V.:** Biological surveillance of freshwaters using macroinvertebrates and its application in South East Asia. Proceedings of International Conference on Water Resources Management in Intermontane Basins. Chiang Mai University, Thailand	Overview on some methods used for biomonitoring in South East Asia,provides info prior to development of biomonitoring methods for LMB

Year	Reference	Comment
2001	**Pollution Control Department:** A study and development of biological indicatorsfor pollution in Petchburi River. Pollution Control Department, Ministry of Science, Technology, and Environments. Bangkok. 4 vols.	Cited in Davidson 2004, copy not available to date but highly appreciated
2008	**Pruethiworanon S:** Diversity of macroalgae and benthic diatoms in Mekong River passing Thailand and their application for water quality. MS Thesis, Chiang Mai University, Thailand, 2008.	Provides information on occurrence of aquatic flora in Thailand and their use for indicating pollution; contributes to knowledge of algal distribution in the LMB
2010	**Resh V:** Biological, chemical and physical indicators of the ecological health of the Mekong. p.9- 12 in : MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Gives overview on and describes reason for selection of biological, chemical and physical parameters selected for LMB biomonitoring method development
2010	**Resh V:** Habitat assessment and the calculation of a site disturbance score. p.13-17 MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes habitat assessment procedure developed for use in LMB biomonitoring methods
2010	**Resh V, Chessman B:** Designation of reference sites. p. 61- 65 in: MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes selection and criteria for references sites for use in LMB biomonitoring methods
2007	**Resh V.:** Multinational freshwater biomonitoring programmes in the developing world: lessons learned from African and Southeast Asian river surveys. Environ. Manage. 39: 737-748.	Provides review on some monitoring activities including Mekong
2005	**Revenga C, I Campbell, R Abell, P de Villiers and M Bryer:** Prospects for monitoring freshwater ecosystems towards the2010 targets Phil. Trans. R. Soc. B 2005 360, doi: 10.1098/rstb.2004.1595	Describes biomonitoring approaches in different basins in the world, including Mekong River Basin
2010	**Richter B D, Postel S, Revenga C, Scudder T, Lehner B, Churchill A and Chow M:** Lost in development's shadow: The downstream human consequences of dams. Water Alternatives 3(2): 14-42	Summary paper on dam development worldwide, contains also some general information on Mekong basin
2006	**Sangpradub N, Boonsoong B:** Identification of freshwater invertebrates of the Mekong River and its tributaries. Mekong River Commission, Environment Programme, Vientiane, Lao PDR. ISBN 978-92-95061-01-9.	Detailed identification key tailor-made for LMB, provides inevitable information for laboratory work on invertebrates; is updated at present; avaiable as book and CD

Year	Reference	Comment
1996	**Sangpradub, N., Inmuong, Y., Hanjavanit, C. & U. Inmuong:** A correlation study between freshwater benthic macroinvertebrate fauna and environmental quality factors in Nam Pong Basin Thailand. Part I. A research report to the Thailand research fund. Khon Kaen University, Khon Kaen, Thailand.	Provides information and analyses on relationship of invertebrates and environmental parameters; serves as information concerning method development
1998	**Sangpradub, N., Y. Inmuong, C. Hanjavanit and U. Inmoung:** Biotic indices for biological classification of water quality in the Pong catchment using benthic macroinvertebrate. Journal of Science, Khon Kaen University, Khon Kaen	Provides information on benthic invertebrate assessement; copy not available to date but highly appreciated
1988	**Smith SH:** Bottom Fauna Monitoring in the Lower Mekong Basin, Part III, Mekong River Commission, Phnom Penh, Cambodia, 25 pp plus Annexes	Provides overview on invertebrate fauna from the 1980ies; but does not contain species lists but might provide some input to fauna overview if old samples are available at MRC and could be determined once again
(1988)	**Smith SH** (undated)**:** Bottom Fauna Monitoring in the Lower Mekong Basin, October 1987 – January 1988, Mission report to Mekong River Commission, Phnom Penh, Cambodia, 15 pp plus Annexes	Provides insight in early biological monitoring attempts; does not contain species lists
2002	**Srum Lim Song, Neou Bonheurm, Uy Ching:** A Review of Biological Assessment of Freshwater Ecosystems. Report submitted to Mekong River Commission, Final Draft, 38 pp. (CAMBODIA)	Summarises information available on biological assessment in Cambodia ahead of biomonitoring development for LMB; does not contain data or detailed ecological information as this was not the purpose of the paper
2010	**Suphan S. & Y. Peerapornpisal:** Fifty Three New Record Species of Benthic Diatoms from Mekong River and Its Tributaries in Thailand Chiang Mai J. Sci. 2010; 37(2): 326-343.	Provides biological/ecological information on diatom species important for list of aquatic flora as background info on further method possible method developments by scientists for LMB
2009	**Suphan S.:** Benthic diatoms and their application in water quality monitoring of Mekong River in the part of Thailand. Ph. D. Thesis, Chiang Mai University, Chiang Mai, Thailand	Provides biological/ecological information on diatom species and their relation to water quality; info on further method possible method developments by scientists for LMB

Year	Reference	Comment
1997	**Thorne, R. St. J. & W.P. Williams:** The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. Freshwater Biology 37:671-686.	Describes method development possibilities to detect organic pollution; serves as background information
2011	**Uttaruk P, Pravat Voharndee, Phuttipong Jusanit, Panya Bunyaadunyakit, Sutep Suriya, Thongman Jaengjaithum, Kanchana Nittayaand Narumon Sangpradub:** Development of biotic index based on rapid bioassessment approaches using benthic macroinvertebrates for Chi and Mun headwater streams, northeast Thailand AES Bioflux, 2011, Volume 3, Issue 1: 29-43.	Describes method development (invertebrates) for Thai rivers in line with international best practice; provides good example for further LMB method developments
2013	**Vogel B, Koehnken L, Quibell G, Phoumin Han.** Significant Tributaries to the Mekong River System - Draft Synthesised Study. Second Draft, MRC IWRM Technical Report	Provides information about selections and several evaluations and characteristics of "main tributaries" in the LMB
2010	**Vongsombath Chanda, Bounnam Pathoumthong, and Narumon Sangpradub:** Littoral macroinvertebrates. p.43-47 in: MRC (2010) Biomonitoring methods for the Lower Mekong Basin. Mekong River Commission, Vientiane, 65 p.	Describes littoral invertebrate sampling and laboratory methods developed for use in LMB biomonitoring methods
2009	**Vongsombath Chanda, Pham Anh Duc, Nguyen Thi Mai Linh, Tatporn Kunpradid, Supatra Parnrong Davison, Yuwadee Peerapornpisal, Sok Khom, Meng Monyrak:** Report on the 2006 biomonitoring survey of the lower Mekong River and selected tributaries, MRC Technical Paper No. 22. Mekong River Commission, Vientiane. 124 pp.	Provides overview and short description on 21 sampling sites, sampling and lab methods, classification of sites for Biomonitoring / Ecological Health Monitoring 2006 in Lao PDR, Thailand, Cambodia, Viet Nam; contains several raw data and calculated metrics as well as summaries on finding from 2004 and 2005.
2009	**Vongsombath Chanda, Pham Anh Duc, Nguyen Thi Mai Linh, Tatporn Kunpradid, Supatra Parnrong Davison, Yuwadee Peerapornpisal, Sok Khom, Meng Monyrak:** Report on the 2007 biomonitoring survey of the lower Mekong River and selected tributaries, MRC Technical Paper No 23. Mekong River Commission, Vientiane. 75 pp.	Provides overview and short description for 20 sampling sites, sampling and lab methods, classification of sites for Biomonitoring / Ecological Health Monitoring 2007 in Lao PDR, Thailand, Cambodia, Viet Nam

Year	Reference	Comment
2000	**Wirojanagud Wanpen, Prasit Kunurat, Ek Watanam, Jaruwan Nippanon:** Ecological aspects of Pak Mun dam. Working paper for World Commission of Dams, 35 pp.	Study on post-facto assessment of Pak Mun project; covers several aspects like soil, river bank vegetation, forest, wildlife, natural rapids…, but has not specific point on aquatic ecology
2007	**Wong C.M., Williams C.E., Pittock J., Collier U., Schelle P.:** World's top 10 rivers at risk. WWF International. Gland, Switzerland	Short overview, includes some info on Mekong River
2009	**Yana, E. and Y. Peerapornpisal:** Diversity of benthic algae and water quality in tributaries of the Mekong river passing Thailand and some parts of Lao PDR. KKU Sci. J., 37: 30–41	Provides information on diatoms and their use for indication of water quality

Attachment 6 - Effects of Pressures on Aquatic Ecology that may be Caused by Hydropower Plants – Example Macroinvertebrates

Hydromorphological alterations arising from dams such as hydrological and habitat changes, disconnected floodplains, altered sediment transport regimes, and changes in river structures such as river depth, width and flow regimes, may have particular implications for aquatic ecology.

Hydropower leads to a loss of typical habitats and thus of typical species. The alteration of the flow regime reduces flow velocities in the impounded section. The longitudinal continuum is interrupted, which is especially important for fish migration but also migration of some invertebrates. In impounded sections with stagnant flowing conditions – depending on the length and size of the impoundment - the type of waterbody may change from a running section with riffles to a section which is more comparable to a lake with subsequent alteration of the species composition.

Further effects in impounded sections caused by the construction of dams include sediment and nutrient trapping in the impoundments. Sediment trapping after several years often leads to the necessity of reservoir flushing which then may cause high impacts on the biota in the downstream area. Nutrient retention, retention / accumulation of organic matter, alteration of oxygen content due to higher water depth together with reduced light and decreased flow velocity are also reasons for changes in the biotic communities. Such changes can be detected by, for example, monitoring levels of decomposition of organic materials.

Depending on the operation of the hydropower plant, the downstream reach can be affected by periodic flushing, higher than average base flows, or too little residual water, each with consequent impacts on aquatic habitats and species.

The scheme below gives some examples of pressures related to the driver “hydropower” (run-of-river types), effects on rivers that may result from such pressures and the related sectors – all with a focus on macroinvertebrates, whereby the effects are of different spatial dimension.

The scheme is not intended to be exhaustive.

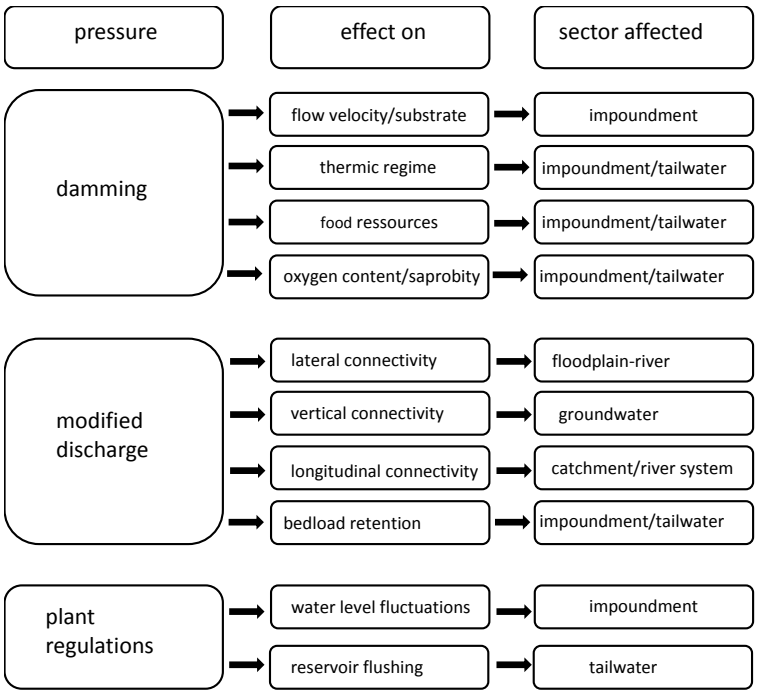


Figure 11 - Examples of Pressures Related to the Hydropower, Ofenboeck et al. (2010), modified

Ofenboeck T, Graf W, Hartmann A, Huber T, Leitner P, Stubauer I, Moog O, (2010) (in German; Expert assessment /estimation of the ecological status of impoundments based on abiotic factors). Study for the Austrian Ministry for Agriculture, Forestry, Environment and Water Management, 102 pp.

Attachment 7 – Description of Multi Habitat Sampling Approach as an Example for Best Practice Field and Lab Work for Invertebrates Used in Several Countries Worldwide

The following approach describes in short the principles of Multi Habitat Sampling (MHS) for macroinvertebrates. It is suggested to apply this approach in parallel to the littoral invertebrate sampling to test applicability for the Mekong River.

The recommended procedures focus on the Multi-Habitat Sampling (MHS) of macroinvertebrates in wadeable areas of streams (e.g. “littoral” zones). The MHS methodology is based on the Rapid Bioassessment Protocols (Barbour et al. 1999), the AQEM sampling manual (2002), the AQEM & STAR site protocol (2002) and the ASSESS-HKH manuals (2008, www.assess-hkh.at).

1 Description of Sampling Approach

The method focuses on a multi-habitat scheme designed for sampling major habitats in proportion to their presence within a sampling reach. A sample consists of 20 "sampling units" taken from all habitat types at the sampling site, each with a share of at least 5 % coverage. If habitats are very uniform, an alternative approach with less sampling units e.g. 10 units can be used.

A "sampling unit" is a sample taken by positioning the net at the bottom of the stream and disturbing the substrate in a quadratic area that equals the frame-size upstream of the net. Sediments must be disturbed to an adequate depth that ensures capture of all species present depending on substrate diameter and compactness. Fine substrates like sand and silt should e.g. be disturbed to a depth of approximately 5-10 cm, intermediate sized substrates like gravel to 10-15 cm.

20 sampling units proportional to the share of habitats are taken (e.g. if the total habitat in the sampling area consists of 50 % sand, then 10 "sampling units" will be taken from this substrate). The categories of habitat composition are shown in the site protocol (taken from www.assess-hkh.at).

2 Estimation of Habitat Composition and Allocation of Sampling Units

Before sampling, the site protocol - especially the estimation of the coverage of habitats - must be completed. Whenever possible, the sampling area should not be disturbed before sampling. If the estimation of the coverage of habitats needs to be corrected, e.g. due to hardly visible parts of the river bottom, this can be done during the sampling procedure. After sampling, the estimated coverage of substrates should be reviewed for accuracy and completeness. For the Mekong River this will be an important step due to the turbidity of the river. Based on the habitats listed, the coverage of all habitats in the river channel with at least 5% cover is recorded to the nearest 5% interval. This approach may need refinement in terms of application on littoral areas in the Mekong.

Site name	date sample code	investigator	

	1	2	3	4
MINERAL HABITATS 5% steps; indicate microhabitats <5% with 'X', indicate artificial microhabitats with 'X' in column 'man-made'	% of coverage - 5% steps	SU (number of sampling units)	Comments	'man-made'
Hygropetric Sites water layer on solid substrates				☐
Megalithal >40 cm large cobbles, bolders and blocks, bedrock				☐
Macrolithal >20 cm to 40 cm coarse blocks, head-sized cobbles (with variable percentages of cobbles, gravel and sand)				☐
Mesolithal >6 cm to 20 cm fist to hand-sized cobbles (with variable percentages of gravel and sand)				☐
Microlithal >2 cm to 6 cm coarse gravel (size of a pigeon egg to child's fist) (with variable percentages of medium to fine gravel)				☐
Akal >0.2 cm to 2 cm fine to medium-sized gravel				☐
Psammal >6 µm to 2 mm sand				☐
Psammopelal mixture of sand with mud				☐
Pelal <6 µm mud (including organic mud and sludge)				☐
Argyllal silt, loam, clay (inorganic)				☐
sum=	**100 %**			
BIOTIC HABITATS 5% steps; indicate microhabitats <5% with 'X', indicate artificial microhabitats with 'X' in column 'man-made'	only biotic habitats			
Micro-algae diatoms and other algae				☐
Macro-algae filamentous algae, algal tufts				☐
Submerged macrophytes macrophytes, including moss and Characeae				☐
Emergent macrophytes e.g. *Thypha, Carex, Phragmites*				☐
Living parts of terrestrial plants fine roots, floating riparian vegetation				☐
Xylal (wood) tree trunks (dead wood), branches, roots				☐
CPOM deposits of coarse particulate organic matter, as e.g. fallen leaves				☐
FPOM deposits of fine particulate organic matter, detritus				☐
Debris organic and inorganic matter deposited within the splash zone area by wave motion and changing water levels, e.g. mussel shells, snail shells				☐
Sewage bacteria and -fungi e.g. *Sphaerotilus, Leptomitus*, sulfur bacteria (e.g. *Beggiatoa, Thiothrix*), sludge				☐
sum =	**variable**			

Figure 12– Part of site protocol for MHS as used in ASSESS-HKH (www.assess-hkh.at)

Following the AQEM procedure (2002) with a square net of 25 x 25 cm, sampled area equals approximately 1.25 m^2 of the stream bottom. If different gears are used – which needs to be discussed on forehand – the sampled area has to be calculated. It is important to define the net and to use exactly the same type of gear for each sampling.

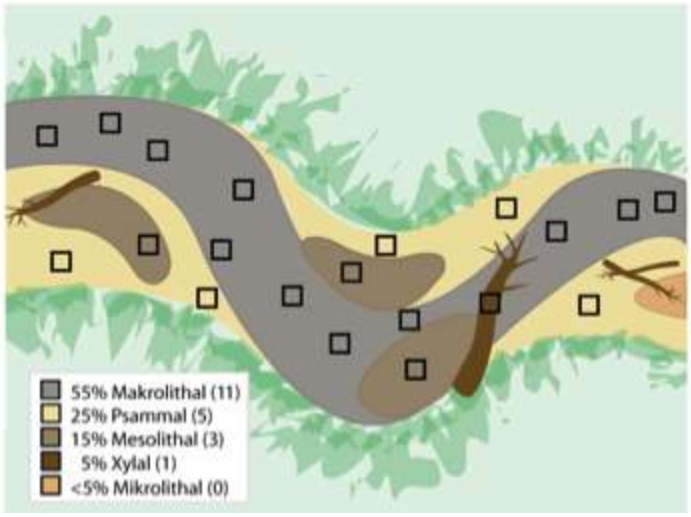


Figure 13 - Example of sampling unit position in a theoretical sampling site according to the "multi habitat sampling" method (taken from AQEM sampling manual 2002).

3 Sampling Gear

The proposed sampling gear to be applied in wadeable rivers is the **AQEM/STAR net sampler**:

- Shape of the frame: rectangular. A frame in front of the hand net of 625 cm2 area is recommended to enable the sampling of a distinct area.
- Dimensions of the frame: 0.25 m width by >0.25 m height. The frame attaches to a long handle.
- Shape of the net: cone or bag shaped for capturing organisms. Mesh size of the net: standard mesh size of 500 µm nytex screen.

Figure 14 - Standard net for sampling (taken from AQEM sampling manual 2002).

A grab, like for benthic invertebrate sampling for EHM can also be used to take soft sediment samples from the river bottom.

Further details on sampling are given in standard manuals (e.g. www.assess-hkh.at). The description above should give a first overview on the MHS sampling.

4 Sorting

The whole sample is preserved with formalin, which has the advantage to "stabilize" invertebrates in contrast to alcohol which is used as preservative in many methods and also in EHM sampling. After preserving with formalin, samples have to be stored for at least 2 weeks.

A standardised sorting approach is applied to the samples (www.assess-hkh.-at). The complete sample must be rinsed through a set of sieves to gently remove the fine material from the sample under running water. By sieving, the sample is split up into different portions from coarse to fine fractions. For samples from soft-bottom streams (sand) sieves from 1000 µm to 500 µm mesh size are used.

The sample is transferred into white trays and must be sorted completely in the lab. All specimens should be removed. The animals sorted in the lab should be separated into "systematic units". The systematic units correspond to highest potential taxonomic level that can be identified by the sorting personnel. One Petri dish per each systematic unit is used. This process is a method of pre-determination. While separating the animals into systematic units, the number of sorted specimens must be counted and recorded (number of specimen per systematic unit).

The whole process provides several options for quality assurance and quality control (labelling, protocol, recording sheets, pre-determination, enumeration…). Using formalin instead of alcohol also provides the possibility to measure biomass per systematic unit, which provides additional options for data evaluation.

5 References

AQEM & STAR Site Protocol (2002) www.eu-star.at

AQEM consortium (2002) Manual for the application of the AQEM system. A comprehensive method to assess European streams using benthic macroinvertebrates, developed for the purpose of the Water Framework Directive. Version 1.0. (www.aqem.de).

ASSESS-HKH manuals (2008) www.assess-hkh.at

Barbour MT, Gerritsen J, Snyder BD, Stribling JB (1999) Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. 2nd edn. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.