Mekong River Commission
For Sustainable Development

REPORT ON THE 2015 BIOMONITORING SURVEY OF THE LOWER MEKONG RIVER AND SELECTED TRIBUTARIES

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Mekong River Commission

Report on the 2015 Biomonitoring survey of the lower Mekong River and selected tributaries

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ACRONYMS

ATSPT	Average Tolerance Score Per Taxon
BDP	Basin Development Programme of the MRCS
EHM	Ecological Health Monitoring
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NMC	National Mekong Committee
SDS	Site Disturbance Score

GLOSSARY OF BIOMONITORING TERMS

Glossary of biomonitoring terms

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

Average richness – The average number of taxa (types) of plants or animals belonging to a particular biological indicator group (e.g. diatoms, zooplankton) counted in the samples from a site.

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

Benthic macroinvertebrates – In this report, this term refers to animals that live in the deeper parts of the riverbed and its sediments, well away from the shoreline. Because many of these species are immobile, benthic macroinvertebrates respond to local conditions and, because some species are long-living, they may be indicative of long-standing environmental conditions.

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

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

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

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

Littoral organisms – Organisms that live near the shores of rivers, lakes, and the sea.

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

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

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

Primary productivity – Total organic material made by primary producers over a given period of time.

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

Sampling sites: These are sites chosen for single or repeated biological and environmental sampling. Although locations of the sites are geo-referenced, individual samples may be taken from the different habitats at the site that are richness, and Average Tolerance Score per Taxon (ATSPT). Signs of a healthy ecosystem can be defined through high abundance, high average richness, and low ATSPT (signifying scarcity of pollution-sensitive species) of species. The assessed sites were graded into four classes (A: Excellent; B: Good; C: Moderate; and D: Poor) according to the compliance of their 12 indicators (three for each groups of organisms) with the guidelines.

The study on diatoms found that three sites (LMX, LBH, and LBF) in Lao PDR showed signs of a poor ecosystem since the three metrics as outlined above could not fulfill the corresponding guidelines. For the study on zooplankton, it was noticed that two sites (TNP and TNK) in Thailand showed a low average abundance, low average richness and high ATSPT, which is also a sign of a degrading and poor ecosystem. Also, the study on littoral macroinvertebrates indicated that nine sites – three sites in Lao PDR (LMX, LBF, LBH), one site in Thailand (TCS), three sites (CSK, CSJ and CPP) in Cambodia, and one site (VTP) in Vietnam – had low average abundance, low average richness and high ATSPT. In relation to benthic macroinvertebrates, the majority of sites could not meet the required threshold value of the ATSPT, suggesting that the local riverbed may be disturbed or in a stressed condition.

After the combination of the scores for the three metrics of the four biological indicator groups – diatoms, zooplankton, littoral macroinvertebrates, and benthic macroinvertebrates – it is concluded that 8 sites were classed as Excellent (A), 27 sites as Good (B), and 6 sites as Moderate (C). Overall, the ecological health of the Mekong River is relatively stable with about 64% in good condition, 16% in moderate condition, and 20% in excellent condition.

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

Taxon/taxa (plural) – A group or groups of animals or plants that are related through evolution. Examples include species, genera, families up to phylum or even kingdom.

Total richness – The total number of taxa (types) of plants or animals belonging to a particular indicator group (e.g. diatoms, zooplankton) collected at a site.

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

ABSTRACT

This report describes the biomonitoring survey conducted in 2015 in the Lower Mekong Basin, which contributes to the evaluation of the overall ecological health of the river. The objectives of the report are to: (i) describe the biological indicator groups sampled during 2015; (ii) use this information to derive biological indicators for the sites examined in 2015; and (iii) use biometric indicators to evaluate these sites.

A total of 41 sites – the same 41 sites assessed for the EHM 2011-13 surveys – were assessed, ranging from rocky rapids, sandy-alluvial areas of tributaries and the mainstream, Tonle Sap Lake and adjacent rivers, including estuaries of the delta areas. The 2015 EHM was conducted based mainly on an agreed and standardized methodology. Three biological metrics of the aquatic ecological health were calculated for each of four groups of organisms, including benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. The biological metrics were: average abundance, average richness, and Average Tolerance Score per Taxon (ATSPT). Signs of a healthy ecosystem can be defined through high abundance, high average richness, and low ATSPT (signifying scarcity of pollution-sensitive species) of species. The assessed sites were graded into four classes (A: Excellent; B: Good; C: Moderate; and D: Poor) according to the compliance of their 12 indicators (three

1. INTRODUCTION

1. INTRODUCTION

The Mekong River is recognized as one of the largest rivers in the world and also one of the richest areas for biodiversity since it is home to more than 800 fish species (So, et al., 2016). In addition to fish, it provides supporting services to a large number of crabs, snails, frogs, snakes, algae and higher plants. These species are one of the main sources of livelihood and food supply for about 70 million people living in the Lower Mekong Basin (So, et al., 2016). Due to development goals of the four Member Countries (MCs), the revenue from development projects, such as hydropower, irrigation, navigation, and tourism has been used for poverty alleviation and to enhance the standard of living for their people; however, these development projects may be a major risk to the river ecosystem and may negatively impact people's livelihoods and food security. Hence, since 2003 the governments and line/implementing agencies have made serious efforts to support the establishment of a monitoring system. This monitoring system will provide the necessary reports of changes in the river's ecosystem in order for the stakeholders to take remedial action if necessary.

In 2003, pilot studies were conducted to identify which biological indicators should be employed to assess the ecological health of the river (MRC, 2009). The results of each site were compared and analysed on their biological variability in the following year. The analysis confirmed that within-site variability is comparatively low, and that the sampling effort used in the pilot studies was sufficient to characterize each site. In 2005, the study focused on testing the performance of assessment metrics developed and widely used elsewhere to describe community structure (abundance, species richness, a species diversity index, and a dominance index) when these assessment metrics are applied to data from the Mekong River system (MRC, 2005b; MRC, 2006). In a majority of these metrics the performance was limited. In 2006, the development of tolerance values was emphasised for each taxon (which included organisms identified to species, genus or family) that is specifically applicable to the Mekong River system. Furthermore, the other metrics were re-tested with a larger data set that had become available.

In 2007, the study focused on three biological metrics (abundance, richness and Average Tolerance Score Per Taxon). Regression analyses were used to examine relationships between biological metrics and environmental variables. The results of the development of the biomonitoring survey were published in a series of MRC Technical Papers (MRC, 2005a; MRC, 2005b; MRC, 2006; MRC, 2008; MRC, 2010b). In 2008, the biomonitoring programme was transferred to the MRC Member Countries, and with support from the MRCS, a national team in each Member Country conducted the sampling, identification, analysis and reporting at all sites in their respective countries.

To date, EHM is conducted on a biennial basis and three indicator metrics of the health of the Mekong aquatic ecosystem are calculated for each of the four groups of organisms: benthic diatoms, zooplankton, littoral macroinvertebrates, and benthic macroinvertebrates. The metrics are: average abundance, average richness and Average Tolerance Score Per Taxon (ATSPT) of each of the four groups. A healthy ecosystem is indicated by high abundance, high average richness, and low ATSPT. Each metric was calculated for individual samples of each group of organisms. Also, three identification handbooks for these biotas were published as tools to support the EHM (Sangpradub & Boonsoong, 2006; Dang, Khoi, Nguyen Nga, Thanh, & Hai, 2015; Kunpradid, Leelaharrangkri, Supan, & Peerapornpisal, 2014).

The purpose of this report is to: (i) describe the biological indicator groups sampled during 2015; (ii) use this information to calculate biological metrics for the sites examined in 2015; and (iii) use biological metrics to evaluate the sites. Finally, this report has mainly been written based on the national reports provided by the national teams in each Member Country; thus the detailed information and analysis within this report may differ from the individual national reports.

2. MATERIALS AND METHODS

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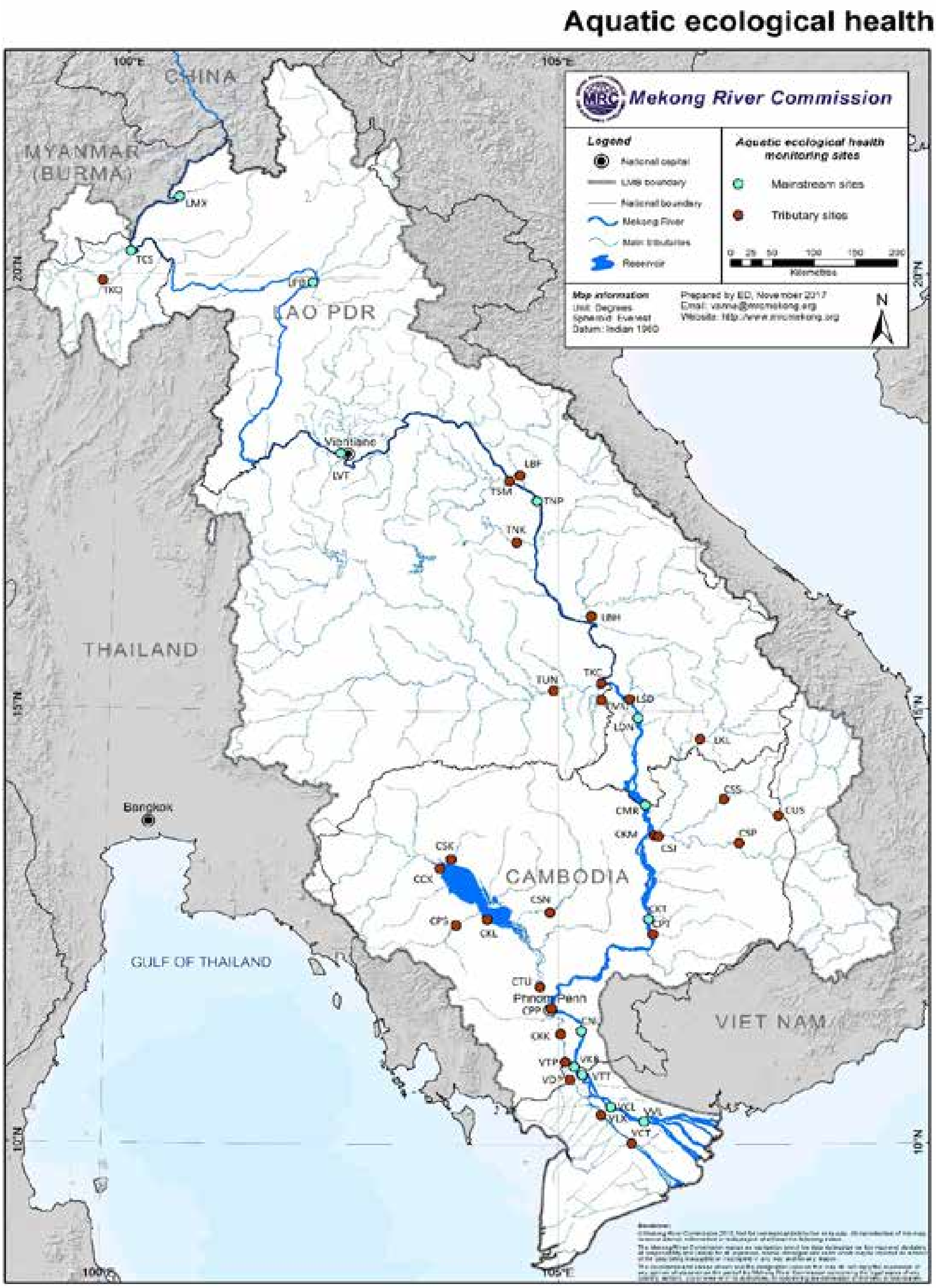
2.1 SAMPLING SITES

In the 2015 survey, four teams of national experts from each MC, in consultation with the MRCS and its respective National Mekong Committees (NMCs) sampled a total of 41 sites during March - April 2015. Eight sites each were surveyed in Lao PDR, Thailand, and Viet Nam, while Cambodia surveyed 17 sites. These sites are the same as those assessed in the monitoring study conducted in 2013. Site details and survey activities are given below and are summarized in Tables 1 to 4 and Figure 1. Sites are presented in sequence from upstream to downstream.

Figure 1 Sampling sites of ecological health monitoring in 2015



Sites in Lao PDR

Sampling sites in 2015 (Figure 1) included localities on the Mekong and its major tributaries in Lao PDR. The sampling sites cover a range of river settings varying from bedrock-confined channels in the north to alluvial channel systems in central and southern regions. Some sites also showed a varying number of disturbing human activities. Most sites are located in or close to villages or towns, such as LMX, LVT, LSD, LBF, LBH and some are next to fields where crops are grown. Other sites are variously located: for example, upstream of dams, and close to gold-sieving areas, eroded banks (LKL), sand or gravel collection areas (LPB), and fishing and navigation activities (LDN and LSD). Details of the 2015 survey sites are described below and summarised in Table 1. Detailed site descriptions are also available in the annex.

Table 1. Sites sampled in 2015 and earlier biomonitoring surveys in Lao PDR

Site	Location	Mekong River/ Tributary	2007	2008	2011	2013	2015	Date of collection
LMX	Ban Xiengkok, Luangnamtha	Mekong River		x	x	x	x	3 April 2015
LPB	Done Chor, Luang Prabang	Mekong River		x	x	x	x	30 March 2015
LVT	Ban Huayhome, Vientiane	Mekong River	x	x	x	x	x	24 April 2015
LBF	Se Bang Fai, Khammouan	Tributary, Se Bang Fai River	x	x	x	x	x	7 April 2015
LBH	Songkhone, Savannakhet	Tributary, Se Bang Hieng River	x	x	x	x	x	9 April 2015
LSD	Ban Hae, Pakse	Tributary, Se Done River	x	x	x	x	x	19 April 2015
LKL	Ban Somsanouk, Attapeu	Tributary, Se Kong River	x	x	x	x	x	21 April 2015
LDN	Done Ngiew, Champasak	Mekong River	x	x	x	x	x	17 April 2015

LMX, Mekong River, Ban Xiengkok, Luangnamtha

LPB, Mekong River, Done Chor, Luang Prabang

LVT, Mekong River, Ban Huayhome, Vientiane

LBF, Se Bang Fai River, Se Bang Fai, Khammouane

LBH, Se Bang Hieng River, Songkhone, Savannakhet

LSD, Se Done River, Ban Hae, Pakse

LKL, Se Kong River, Ban Somsanouk, Attapeu

LDN, Mekong River, Done Ngiew, Champasak

X (Mekong River, Ban Xiengkok, Luangnamtha)

The sampling site is on the Mekong River, 200 metres north of Ban Xiengkok in Long District, Luangnamtha Province. Here, the right riverbank belongs to Myanmar while the left side is part of Lao PDR. The villages are located on the left riverbank with a few guesthouses, the migration office and a port. In general, this site experiences strong currents and is highly disturbed by human activities, including gold sieving at the right-hand side and navigation. The substrata close to the bank are clay and sand with more cobbles and pebbles found prograding into the river (about 5 m from the bank).

LPB (Mekong River, Done Chor, Luang Prabang)

This island is in the middle of the Mekong River, about 1.5 km north of Souphanouvong University. It shows secondary forest on the right side of the island with some grass, minor shrubs and sandy areas. Villages, roads, and sand and gravel extraction activities are found on the left side of the island. The substratum of the river is a mix of bedrock, boulders, and gravel with algae. A pool south of the island has a standing water habitat with a substratum composed of clay, mud and sand. In general, this site experiences a high level of disturbance from human activities, such as sand and gravel exploitation, water extraction, and river traffic.

LVT (Mekong River, Ban Huayhome, Vientiane)

The sampling site is in Ban Huayhome, Sikhottabong District, around 5 km upstream from Vientiane. Thailand is on the right bank and Lao PDR on the left with large vegetable gardens and a dock. The collection of samples was only taken from the left side, on Lao PDR territory. The main substrata were sand and mud. This site is frequently disturbed by agricultural and domestic waste, fish farming and river traffic.

LBF (Se Bang Fai River, Se Bang Fai, Khammouan)

The sampling site is located in Ban Se Bang Fai, Se Bang Fai District, Khammouan Province, next to the bridge on National Route 13 over the Se Bang Fai River. The Se Bang Fai River is a tributary of the Mekong. Vegetable gardens and houses are found on both river banks. The substratum is comprised of mixed boulders, concrete, sand, mud, and debris. While sampling, the water level was high and the water had a strong current, probably due to the drainage of the Nam Theun II Hydropower Plant. This location is frequently disturbed by village activities.

LBH, (Se Bang Hieng River, Songkhone, Savannakhet)

This sampling site is located next to the bridge at the Se Bang Hieng River in Ban Se Bang Hieng, Songkhone District, Savannakhet Province, a tributary of the Mekong. Vegetable gardens and houses are located on both banks. The substratum is comprised of a mix of boulders, concrete, sand, mud, and debris. This location was moderately disturbed by village activities. The water level in 2015 was relatively low, resulting in the emergence of small sandy islands.

LSD (Se Done River, Ban Hae, Pakse)

This site is on the Se Done River, a tributary of the Mekong in Ban Hae, Pakse Town, and it is about 4 km upstream from the confluence of Se Done River with the Mekong. The right bank showed vegetable gardens, and the left was comprised of houses, a school and gardens. This site is often disturbed by fishing and water-pumping activities. Substrata of the site are bedrock with sandy and muddy areas.

LKL (Se Kong River, Ban Somsanouk, Attapeu)

This site is on the lower Se Kong River, a tributary of the Mekong River in Ban Somsanouk, Sanamxay District, Attapeu Province. The right bank has a town, fruit gardens and a boat pier, with many eroded stretches along the river bank. On the left bank, banana orchards and bamboo are found with some eroded stretches of the river bank. The area was flooded in 2010 and the channel has now changed its shape around an island in the middle of the river. This site is moderately disturbed by domestic waste and fishing activities. Before 2013, the site was disturbed by gold collection, but that activity stopped in 2013. However, between 2014 and 2015 gold collection reoccurred and led to a decrease in channel width of the river compared to 2013. Substrata present in the faster-flowing current are pebbles and gravel, with sand and debris accumulating in the pool where the current is slower.

LDN (Mekong River, Done Ngiew, Champasak)

This sampling site is on the Mekong River at Done Ngiew in Ban Muang, Pathumphone District, Champasak Province. The sampling point is about 800 m upstream of the ferry crossing to Wat Phu. The environment of both banks has changed slightly since 2008. A steep slope showing bank erosion is found on the right bank where maize gardens, vegetables and riparian shrubs (dominated by *Homonoia riparia*) can also be seen. Plantations and rice fields are scattered along the bank at a distance of 100-200 m with single households in between. This location is slightly disturbed by fishing and navigation activities. Substrata of the site are mainly bedrock with some sand patches and some small islands in the channel.

Sites in Thailand

Sampling sites in Thailand include localities on the Mekong and its major tributaries, with two sites in the north and six in the northeast. The sites exhibit various disturbances reflecting low to high human-activity impacts. Some sites are in or close to villages or towns; some are next to farmland and ranches; some are upstream or downstream of dams or weirs, and some are exposed to moderate to heavy river traffic. All eight sites were sampled during 1-8 April 2015.

Table 2. Sites sampled in 2015 and earlier biomonitoring surveys in Thailand

Site	Location	Mekong/ Tributary	2007	2008	2011	2013	2015	Date of Collection
TCS	Chiang San, Chiang Rai	Mekong River		x	x	x	x	7 April 2015
TKO	Chiang Rai City	Tributary, Kok River		x	x	x	x	8 April 2015
TSM	Songkram and Mekong River junction, Nakorn Phanom	River junction	x	x	x	x	x	2 April 2015
TNP	Nakorn Phanom City	Mekong River		x	x	x	x	1 April 2015
TNK	Na Kae Mukdaharn	Tributary, Nam Kham River	x	x	x	x	x	3 April 2015
TUN	Ubon Rachathani City	Tributary, Mun River		x	x	x	x	5 April 2015
TMU	Kong Chiam Ubon Rachathani	Tributary, Mun River		x	x	x	x	4 April 2015
TKC	Mun and Mekong River junction, Ubon Rachathani	River junction		x	x	x	x	4 April 2015

TNP, Thailand Mekong river at Nakorn Phanom City

TSM, Thailand Songkram and Mekong River junction at Nakorn Phanom

	
TNK, Thailand Tributary of Nam Kham River at Na Kae, Mukdaharn	TUN, Thailand Tributary of Mun River at Ubon Rachathani City
	
TKC, Thailand Mun and Mekong River junction at Ubon Rachathani	TMU, Thailand Tributary of Mun River at Kong Chiam, Ubon Rachathani
	
TCS, Thailand Mekong River at Chiang San, Chiang Rai	TKO, Thailand Tributary of Kok River at Chiang Rai City

TCS (Mekong River, Chiang Saen, Chiang Rai)

This site is located on the border between Thailand and Lao PDR in Chiang San District. The most important dock for navigation, import and export transport between Thailand and the upper Mekong countries is found here. There is a flat sand bar on the left (Lao PDR) side, and an artificial bank comprised of a concrete wall with stairs on the right side. The site is surrounded by large communities, with about 10,000 households, mainly on the Thailand side. The riparian zone is comprised of some plots of forest, cattle-grazing areas and a local market. Stretches of erosion and sand are present on the bank in addition to algae and aquatic plants. The substratum is sand, clay, mud and gravel. The human impact at this site is heavy due to road construction on the Lao PDR side, boat navigation, domestic waste, and disposal from transport and other activities.

TKO (Tributary, Kok River, Chiang Rai City)

This site is on the tributary of Kok River at Chiang Rai. The left bank has a 30 degree slope, while the right bank is flat. Both banks are eroded, and riparian areas are cleared of forest with advanced agricultural development on the left bank, while a resort and a tourist recreation area are found on the right side. A cobble and gravel island is in the centre of the river. Human influences include agricultural runoff and navigation in the form of large tourist boats and ships causing the bank to erode due to waves. The substrata are made up of sand, cobbles and gravel.

TSM (Songkram River at Mekong junction, Nakorn Phanom)

This site is on the border between Thailand and Lao PDR. The left bank is a flat sand bar, while the right bank slopes at 40 degrees. The site is surrounded by medium-sized villages, with a total of about 500 inhabitants. The riparian zone consists of some forest, landslides, aquatic plants and algae such as river weed ('Kai' or *Cladophora glomerata*), a few houses, small-scale agricultural plots, piers, floating houses and fish cages. Also, bamboo is found in the river. Most of the substrata at the site are sand and clay, firm mud and firm sand. Human impacts are high due to human waste from restaurants, fish cages, solid- and farm waste, and agricultural runoff. Furthermore, the banks have been damaged by livestock.

TNP (Mekong River, Nakorn Phanom City)

This site is located on the border between Thailand and Lao PDR about 1.5 km upstream of Nakorn Phanom City. It is surrounded by small villages, with a total of about 200 households. The left bank, on the Lao PDR side, is steep with a 30 degree slope and the right bank (Thailand side) is also steep with a 45 degree slope. The riparian zone consists of a few agricultural plots, floating houses, a shoreline, some trees on the bank, and small-scale fish farms. Disturbance through human activities are moderate with rubbish disposal, agricultural runoff, fish farming, and bank erosion the most dominant.

TNK (Tributary, Nam Kham River, Na Kae, Mukdaharn)

This site is located about 5 km downstream of a water supply station. The river here is shallow (<0.5–1.5 m depth) and both banks have a slope of 40-50 degrees. The vegetation on the right bank is bamboo and grass. The substratum is comprised of wood and leaf debris, sand, clay, gravel, and mud. The site shows severe bank erosion and landslides. Disturbances are moderate as a result of human waste disposal and rubbish from upstream.

TUN (Tributary, Mun River, Ubon Rachathani City)

This site is located about 10 km from Ubon Rachathani City and is surrounded by a few fishermen's houses. Both banks slope at a 15 degree angle. The riparian zone consists of a cattle-grazing area, algae, and aquatic plants and shows signs of soil erosion. The substratum is made up of mud, aquatic plants, sand, clay and firm sandy gravel. Disturbances are moderate and due to disposal of human and animal waste, navigation activities and agriculture.

TMU (Tributary, Mun River, Kong Chiam, Ubon Rachathani.)

This site is located downstream from the Pak Mun Dam and about 2 km above the confluence of the Mun and Mekong Rivers in Ubon Rachathani Province. It is surrounded by a small fishing village of about 180 households. The banks have a 30 degree slope and the riparian zone consists of vegetable orchards, farmland, houses, and floating houses, and stretches of soil erosion are visible. Human activities include cattle herding and fish farms with floating cages. The substratum is mostly sand and gravel. This site is highly disturbed from disposal of human and animal waste, including agricultural and urban runoff.

TKC (Mun and Mekong River junction, Ubon Rachathani)

This site is located on the border between Thailand and Lao PDR and is at the confluence of the Mun and Mekong Rivers. The banks are formed by sand bars. The left bank (Lao PDR) of the Mekong River is steep, with a 40 degree slope, while the right bank (Thai side) slopes at a 45 degree angle. The riparian vegetation is made up of bamboo woodlands and the site is surrounded by fishing villages, with a total population of about 800. The banks are eroded due to human activities including tourism facilities, a pier, a floating house, and floating fish cages. The substrata are bedrock, sand and clay, firm mud, and firm sand. This site is moderately disturbed by rubbish disposal and animal/fish farm waste.

Sites in Cambodia

The sites were selected in an attempt to include a diversity of habitats in the Cambodian Mekong within different types of ecosystems, comprising the mainstream of the Mekong, the Bassac River, Tonle Sap River, and Tonle Sap Lake and its tributaries. Each ecosystem is characterized by specific types of substrata. The substrata of the sampling sites are characterized by sandy rock, sandy clay, mud, sand, clay, boulders and gravel.

Table 3. Sites sampled in 2015 and earlier biomonitoring surveys in Cambodia

Site	Location	Mekong/ Tributary	2007	2008	2011	2013	2015
CMR	Ramsar Site, Stung Treng	Mekong River	x	x	x	x	x
CKM	Kbal Koh, Stung Treng	Tributary, Se Kong River	x	x	x	x	x
CUS	Dey It Rattanakiri	Tributary, Se San River	x	x	x	x	x
CSS	Veunsai, Ratanakiri	Tributary, Se San River			x	x	x
CSP	Phik, Rattanakiri	Tributary, Srepok River	x	x	x	x	x
CSJ	Downstream of Srepok River junction, Stung Treng	Tributary, Se San River	x	x	x	x	x
CKT	Mekong River, Kampi Pool, Kratie	Mekong River		x	x	x	x
CPT	Preh Kanlong, Kratie	Tributary, Prek Te River			x	x	x
CCK	Tonle Sap Lake, Chong Khnease, Siem Reap	Tonle Sap			x	x	x
CKL	Tonle Sap Lake, Kampong Luong, Pursat	Tonle Sap			x	x	x
CSN	Kampong Thom	Tributary, Stung Sen River			x	x	x
CSK	Battambang	Tributary, Stoeng Sangke River		x	x	x	x
CTU	Prek Kdam Ferry, Kandal	Tributary, Tonle Sap River			x	x	x
CPP	Phnom Penh Port	Tributary, Tonle Sap River			x	x	x
CPS	Damnak Ampil, Pursat	Tributary, Pursat River			x	x	x
CNL	Mekong River, Neak Loeung, Prey Veng	Mekong River			x	x	x
CKK	Khos Khel, Kandal	Tributary, Bassac River		x	x	x	x

CMR (Mekong River, Ramsar Site, Stung Treng)

This site on the upper Mekong River is in a Ramsar site and located at Ouchheatheal Village in Stung Treng Province. The sampling point is on the right bank, approximately 300 m downstream from the Ouchheatheal dolphin deep pool. The right bank is a steep slope covered by flooded forest and farmland, and the left bank has a tourist boat landing, fishing boats and a market. Human disturbance in this area is small. The river is characterised by strong currents and the presence of algae. The substrata are grasses, sand, pebbles, and boulders.

CKM (Tributary, Se Kong River, Kbal Koh, Stung Treng)

This site is at Phdao Village on the tributary of Se Kong River in Stung Treng Province. The sampling point is located on the left bank with a short distance to the village. Human disturbance is minimal. The left bank is covered by forest, bamboo and farmland, while the right bank is predominantly made up of sand, riverine shrubs, trees and bamboo. The river flows slowly, and the substrata are sand and pebbles.

CUS (Tributary, Se San River, Dey It, Rattanakiri)

This site is located on the left bank of the tributary of Se San River in Rattanakiri Province, 500 m from Phumpi Village and 200 m from Phumbinh Village. Approximately 50 m upstream a ferry dock can be found and 1-1.5 km further downstream the Se San hydropower dam is located. Trees grow on the left bank and a cassava farm is located about 50 m from the river bank. On the right bank, there is a 100 m long sand bar, trees and farmland. The site is slightly disturbed by the ferry and the dam. The substrata are boulders, cobbles and sand. In the middle of the river there are boulders. The river water is clear despite the strong currents.

CSS (Tributary, Se San River, Veunsai, Rattanakiri)

This site on the tributary of Se San River is downstream of Banhang Village, in Rattanakiri Province. The sampling point is on the left bank, about 1 km from the upper ferry dock and houses. The left bank slopes and at a distance of 30 metres there is a house and trail with planted trees and a woodland. The right bank is woodland mixed with bamboo. Disturbance from the ferry and houses is low. The water is clear and shallow with strong currents. The substrata are pebbles and sand, and in the middle of the river there are pebbles interbedded in sand.

CSP (Tributary, Srepok River, Phik, Rattanakiri)

This site on the tributary of Srepok River is located in Phik Village, Lomphat District, Rattanakiri Province. The sampling point is on the right bank, 200 m above the ferry dock and at a 300 m distance from some houses; human disturbance is low. Both banks slope steeply and are covered with bamboo and forest. The substrata are made up of sand and boulders.

CSJ (Tributary, Se San River, downstream from junction with the Srepok River, Stung Treng)

The sampling site is located on the tributary of Se San River (lower part of the Srepok River) in Kompun Village, Stung Treng Province. The sampling point is on the left bank between Kompun and Chardoeum Villages, downstream of the Se San Hydropower Dam. Both banks are comprised of forest and farmland with additional bamboo only on the right bank. The site is moderately disturbed by farms and the dam. The water is clear despite the strong currents. Substrata consist of sand, pebbles, boulders and flooded forest. The upper part of the site is made up of islands with farmland and two channels, which merge into one channel in the lower part.

CKT (Mekong River, Kampi Pool, Kratie)

The sampling site is on the upper Mekong River in Kbalchour Village, Kratie Province. The sampling point is on the right bank, 200 m from the Kampi dolphin conservation area where no fishing activities are allowed. The right bank slopes slightly and is covered with flooded forest, boulders and sand. This bank also has a few houses, trees, bamboo, rice fields and farmland. The left bank also contains a tourist-boat pier, the national road, houses, crops, vegetables and rice fields. Human disturbance is low since the sample site is in a protected area. The substrata are sand, boulders and cobbles. Islands with flooded forest also occur in this part of the river, with sand on the lower islands. The water is clear despite the strong currents.

CPT (Tributary, Prek Te River, Preh Kanlong, Kratie)

This site is on the tributary of Prek Te River, in Preh Kanlong Village, Kratie Province. The sampling point is on the right bank, about 200 m from houses, where the river is 12 m wide. The site has been highly disturbed by fishing activity, such as gillnets. The slightly sloping bank is covered with grasses, riparian shrubs, a corn farm and a rice field. The left bank features grasses, riparian shrubs (dominated by Homonoia riparia), trees, bamboo, crops, and houses.

CCK (Tonle Sap Lake, Chong Khnease, Siem Reap)

The sampling site is on the Tonle Sap Lake near Chong Knease Village in Siem Reap Province. The sampling point is about 1 km from the shore and about 500 m from the boat waterway. Disturbing activities are frequent due to numerous fishing and tourist boats. The lake shore is covered with flooded forests and is dominated by Barringtonia asiatica trees. The substrata are muddy soil and dead shells with some solid waste in between. The water is turbid and algal blooms are present.

CKL (Tonle Sap Lake, Kampong Luong, Pursat)

The sampling site is on the left bank of Tonle Sap Lake in Kampong Luong Village. The sampling point is about 800 m from some residential houses, 500 m from the boat waterway and 1 km from the fishing lot margin. Between the rice fields and the lake is a flooded forest area made up of Barringtonia asiatica, grasses and aquatic plants. The site is moderately disturbed by floating houses and fishing activities. The substratum is mud, the water is turbid and algal blooms are present. The waterway is used as a passage from the upper land (houses) to the lake shore.

CSN (Tributary, Stung Sen River, Kampong Thom)

The sampling site is located on the tributary of Stung Sen River, close to Somrong Village in Kampong Thom Province. The sampling site is on the right bank with houses at a distance of 300 m. About 700 m further downstream, the river is highly disturbed by sand exploitation activities; upstream of the site it remains undisturbed. Slopes on the right bank are covered with agricultural crops, tree plantations, rice fields, riparian grasses and shrubs. On the left bank, there are some stretches of eroded areas, shrubs and rice fields. The substrata are mud and sand. The water is turbid with slow currents.

CSK (Tributary, Stoeng Sangke River, Battambang)

The sampling site is on the tributary of Stoeng Sangke River, in Muthbangkang Village, Battambang Province. The sampling point is located on the right bank, about 800–900 m from the village and about 1–2 km upstream from Tonle Sap Lake. This site is moderately disturbed by fishing boats and trading boats traveling between Siem Reap and Battambang Province. Both banks are sloping and covered with water hyacinth (Eichhornia crassipes), riparian grasses (Cyperus elatus), riparian shrubs and flooded forest. The turbid water of the river flows into Tonle Sap Lake. The substrata of the area are muddy soil, bricks, wooden twigs and debris.

CTU (Tributary, Tole Sap River, Prek Kdam Ferry, Kandal)

The sampling site is on the tributary of Tonle Sap River, in Koeu Chhin, Kandal Province. The sampling point is on the right bank, 2 km from the Cambodia-China Bridge and at a distance of 300 m from the village. About 20 m from the slightly sloping left bank, water hyacinth, riparian grasses, shrubs and rice fields can be found. Residential houses and the National Road No. 5 are located on the right bank. Human disturbance from housing is minimal. The turbid water flows from Tonle Sap Lake. The substrata are muddy soil and clay.

CPP (Tonle Sap River, Phnom Penh Port)

The sampling site is located in Chroy Changwa Village, Phnom Penh. The sampling point is on the right bank about 350 m from Chroy Changwa Bridge. Disturbance is low, from a few boats that navigate this stretch of the river and an additional two or three fishing boats. The right bank is made up of water hyacinth, riparian shrubs, some large trees The National Road and houses can be found on this side. On the left bank the Phnom Penh Ferry Port and the National Road can be found. The substrata are pebbles and muddy soil. The turbid water flows slowly here.

CPS (Tributary, Tole Sap River, Damnak Ampil, Pursat)

This site is on the tributary of the tributary of Pursat River, in Damnak Ampil Village, Pursat Province. The sampling point is Koh Thas, about 2-3 km from Damnak Ampil II Inlet. The right bank is a sandy slope with a community space, boulders, riparian grasses, and there are houses about 300 m from the river. A marsh/small lake with lotus (*Nelumbo nucifera*) grows at a distance of about 100 m from the river. Furthermore, the left bank consists of some eroded stretches, riparian grasses and trees. About 100 m from the river are houses, agricultural crops and rice fields. The substrata are sand, mud, boulders and cobbles. The water is clear with slow currents and is slightly disturbed by gillnet fishing activities.

CNL (Mekong River, Neak Loeung, Prey Veng)

The sampling site is located on the lower eastern Mekong River in Prek Svay Village, Prey Veng Province. The sampling point is on the left bank, 500 metres upstream from a sand pumping site and about 1 km from Neak Loeung Ferry Port. The site has been greatly disturbed by sand dredging and fishing. Riparian grasses and shrubs grow on the sloping left bank. Water hyacinth, rice fields and a small lake are also found there, while riparian grasses, shrubs and farmland are found on the right bank.

CKK (Tributary, Bassac River, Khos Khel, Kandal)

The site is located in Khpouk Village, Kandal Province on the tributary of Bassac River. The sampling point was on the left bank, 300 m upstream of the Khos Khel ferry dock. The left bank slopes steeply and is covered with riparian grasses and shrubs, water hyacinth, maize, a vegetable plantation, and a rice field. The right bank has riparian grasses and shrubs. The site is moderately disturbed by houses, the national road, and some farmland.

Sites in Viet Nam

The sampling sites in Viet Nam are on the Mekong and Bassac Rivers. Four sites are on the Bassac River near Can Tho City, Long Xuyen City, and Khanh Binh, An Giang Province. Four sites are on the Mekong River. The substrata of these sites consist of fine sand, alluvia, and hard clay. Six sites are affected by tides. All sites are moderately to heavily impacted by human activities. Sample collection was carried out at the end of March 2015.

Table 4. Sites sampled in 2015 and earlier biomonitoring surveys in Viet Nam

Site	Location	Mekong River/ Tributary	2007	2008	2011	2013	2015	Date of collection
VTP	Thuong Phuoc, Dong Thap	Mekong River		x	x	x	x	21 March 2015
VTT	Thuong Thoi, Dong Thap	Mekong River		x	x	x	x	22 March 2015
VKB	Khanh Binh, An Giang	Tributary, Bassac River		x	x	x	x	24 March 2015
VDP	Da Phuoc, An Giang	Tributary, Bassac River		x	x	x	x	23 March 2015
VCL	Mekong River, Cao Lanh, Dong Thap,	Mekong River		x	x	x	x	19 March 2015
VLX	Long Xuyen, An Giang,	Tributary, Bassac River		x	x	x	x	26 March 2015
VVL	Mekong River, My Thuan, Vinh Long,	Mekong River		x	x	x	x	28 March 2015
VCT	Phu An, Can Tho	Tributary, Bassac River		x	x	x	x	27 March 2015

VTP (Mekong River, Thuong Phuoc, Dong Thap)

The site is located in Thuong Phuoc Commune, Dong Thap Province. Houses, grasslands and fruit orchards are found at this site. The river bank has been littered with solid waste from domestic households. Both banks consist of substrata made up of sandy clay and additional sand in the middle of the river. The main activities having an impact at the site are navigation and sand pumping. Dumping of construction materials, fish farming and fishing also have an impact. This site is highly disturbed due to bank erosion and pollution from domestic waste.

VTT (Mekong River, Thuong Thoi, Dong Thap)

The site, located in Thuong Thoi Commune, Dong Thap Province, consists of crops including legumes, chili peppers and maize, fruit orchards, grassland and housing. The right bank has a substratum made up of sandy clay and detritus, while the middle and left bank of the river comprise of sand and a mudflat. The main human activities are agriculture, navigation activities, cattle ranching, washing and capture fisheries. This site is moderately disturbed with potential impacts being overfishing, river transportation, bank erosion, and pollution from agriculture and domestic waste.

VKB (Tributary, Bassac River, Khanh Binh, An Giang)

This site at Khanh Binh Commune, An Giang Province on the tributary of Bassac River, consists of maize and legume plantations, grasslands and housing. Water hyacinth grows in the river and there is evidence of bank erosion. There are mud and sandflats, detritus, sediment, litter and domestic solid waste. The substrata on both banks are made up of silty mud, detritus with solid waste, while the middle of the river is made up of sandy detritus. The site is highly disturbed from pollution from markets, industrial and commercial areas, grain storage and milling, cattle ranching, navigation, sand pumping, capture fisheries and fish farms, and sewage.

VDP (Tributary, Bassac River, Da Phuoc, An Giang)

This site at Da Phuoc Commune, An Giang Province, is surrounded by farmland and housing.

Bank erosion is present and the river contains water hyacinth, inundated bushes and trees. The substratum on the right bank is clay and sandy detritus. The middle of the river is sandy silt and the left bank is clay with solid waste. Disturbance is very high, from navigation, sand exploitation, fish farming and capture fisheries, as well as a grain processing factory. The site is highly polluted from domestic waste, sewage and further bank erosion.

VCL (Mekong River, Cao Lanh, Dong Thap)

The site, located at Cao Lanh City, Dong Thap Province, is dominated by farmland and residential housing, with scattered grasslands and water hyacinth growing in the river. Domestic solid waste and dead trees are found on the riverbed. The main activities are grain cultivation, fruit orchards and fishing. The right bank and the middle of the river are lined with sandy clay and detritus, while the left bank is made up of a mudflat and sandy detritus. This site is highly disturbed by boat transportation, fishing, pollution from organic and solid waste, including domestic sewage and sand exploitation.

VLX (Tributary, Bassac River, Long Xuyen, An Giang)

This site at Long Xuyen City, An Giang Province, is covered largely by houses and farmland, with some grassland in between. Navigation activities on the river are numerous. Domestic solid waste and dead trees are found on the riverbed. The main activities are fish farming and small industry. The right bank has a substratum of sand and detritus. The middle is sandy silt and the left bank is made up of muddy detritus. This site is highly disturbed by sand exploitation, intense river transportation, overfishing, pollution from domestic sewage, and solid waste in addition to bank erosion.

VVL (Mekong River, My Thuan, Vinh Long)

The site is at My Thuan Commune, Vinh Long Province, and covered largely by houses, hotels, orchards and cattle grazing. The main activity is a warehouse for construction material. Activities on the river are fish farming and capture fisheries. The riverbed is littered with domestic and agricultural solid waste. The substratum of the right and the left banks is silty mud prograding to sand in the middle of the river. The site is moderately disturbed from pollution, solid waste including farm and domestic sewage, and construction of embankments.

VCT (Tributary, Bassac River, Phu An, Can Tho)

The site is at Phu An Commune, Can Tho City and consists of houses, small factories and farmland including fruit orchards. The river has water hyacinth and is also polluted with domestic solid waste. Main activities include water transportation, landing and storage of goods, and fishery capture. A small factory is close by. The right bank is comprised of muddy silt while the middle of the river and the left bank are both made up of silty mud and sand as substrata. This site is highly disturbed by pollution from domestic and factory sewage and solid waste and is influenced by the construction of a river embankment.

2.2 FIELD SAMPLING AND LABORATORY AND STATISTICAL ANALYSIS

Data collection and identification of biota (benthic diatoms, zooplankton, littoral and benthic macroinvertebrates) follow the methodology described by MRC (MRC, 2010a) for field, laboratory, and analytical methods for environmental variables and the four biological indicator groups (zooplankton, littoral macroinvertebrates, benthic macroinvertebrates and diatoms).

Environmental variables and status identification

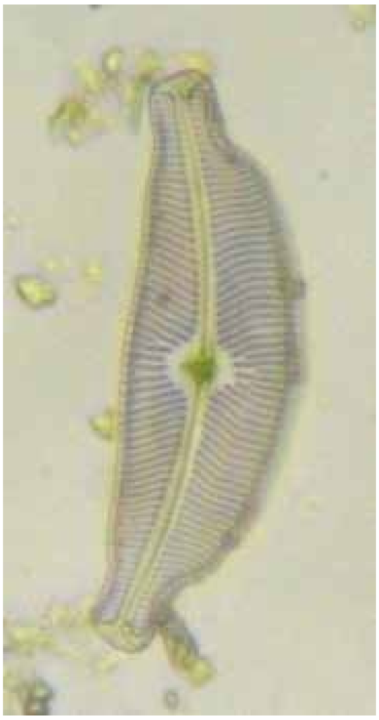
The objective of studying the physical and chemical factors is to describe selected characteristics of the sampling sites in the Lower Mekong River by collecting data on altitude, river width, depth, Secchi depth (water transparency), water temperature, dissolved oxygen (DO), pH, and electrical conductivity (EC). A field data sheet for environmental variables was provided for recording the following site information:

1. The map coordinates and altitudes of the sampling sites are determined using a Garmin GPS 12XL.
2. The stream or river width is measured with a Newcon Optik LRB 7x50 laser rangefinder by its wetted width at the time of sampling. Some sites are measured by Google Earth maps or GPS measurements at both banks.
3. At each site, environmental measurements in the water are made in three sections of the river: (i) near the left bank; (ii) near the right bank; and (iii) in the centre, making sure that the three sampling sections are within that Member Country's border, except at some mainstream border sites (Thailand-Lao PDR) and in the Tonle Sap Grand Lake.
   - Transparency is determined by measurement of Secchi disk depth.
   - Temperature, DO, EC, and pH are measured with an electronic meter. Three readings are taken at each location at a depth of approximately 0.5 m.
   - Water depth is determined by dropping a weighted rope directly to the river bottom and is reported in metres.
4. In some situations, for determination of physical variables such as DO, pH and Conductivity (EC), water samples can be collected 0.5 m below the water's surface and examined later. Details of the method can be found in 'Standard Methods for the Examination of Water and Wastewater' (APHA, 1998).
5. All measured environmental variables are reported as average values. DO is reported as mg/L (ppm); electrical conductivity as mS/m and temperature in degrees Celsius. Water transparency, depth, elevation, and river width are measured in metres.

Benthic diatoms

The objective of studying benthic diatoms is to quantitatively describe the characteristics of the diatom community, including the abundance and the diversity of individual species, as diatoms provide a rapid response to environmental changes.

Figure 2: Diatom 2015 - Cymbella tumida



Field methods

A field data sheet for benthic diatoms was provided to record the following site information:

1. The sampling of benthic diatoms within a site is performed close to the river bank, where the water is less than 1m deep and suitable substrata extend over a distance of 100 m. At sites where the river bed is predominately muddy or sandy and lacks suitably sized stones, samples can be taken from branch litters or other hard substrates, and artificial materials.
2. At each site, ten samples are collected, one at a time, at about 10 m intervals. Where there are no suitable stones, the nearest hard substratum can be sampled.
3. To sample the diatoms, a plastic sheet with a 10 cm2 cut-out is placed on the upper surface of the substratum (Field methods diatoms, (MRC, 2010a)), the surface is then brushed, and the dislodged surface material is then washed into to a plastic container. Samples are preserved with Lugol's Solution.
4. The name of the site, the location code, the date of sampling, the sample-replicate number, the collector's name and substratum type are also noted in the field notebook, as is any information about the site that could be influencing the presence or abundance of different types of diatoms.

Figure 3 Field Methods: Diatoms

Laboratory methods

In the laboratory, the samples are cleaned by digestion in concentrated acid. The raw samples are centrifuged at 3,500 rpm for 15 minutes. The diatom cells (which are the brown layer between the supernatant and solid particles) are pipetted off into an 18 cm core tube.

1. Each sample is cleaned with strong acid (H2SO4, HCl, or HNO3) and rinsed. Distilled water is then added into 1 ml sample volume.
2. A drop of each sample (0.02 ml) is placed on a microscope slide and dried to make a permanent slide for diatom identification and counting.
3. Identifications are made under a compound microscope and are based on the frustule type, size, special characteristics, and structure, as described and illustrated in various textbooks, monographs and other publications on tropical and temperate diatoms (see the list of identification aids).

The following references were used to identify benthic diatoms: Patrick (1939), Foged (1971, 1975, 1976), Krammer & Lange-Bertalot (1986, 1988,1991a, 1991b), Pfisher (1992), Peerapornpisal, et al. (2000), and Handbook on diatoms of the Lower Mekong Basin (Kunpradit et al. 2014).

Analytical methods

1. The richness, abundance, and ATSPT value are determined for each sample collected at a site. An average value is then calculated for each site.

2. Average richness is the number of taxa per 10 cm2 sampled from each 1 ml sample. Calculated as the average of samples from the same site.

3. The total count of cells on the slide (0.02 ml) is used to estimate the total number of individuals per sample, which is the abundance. The number of cells counted when multiplied by 5 gives the number per cm2.

4. The ATSPT for that site is calculated.

5. Richness, abundance and ATSPT scores are always reported per sample (which is 1 cm2)

Zooplankton

Zooplankton was studied in order to quantitatively describe the characteristics of the zooplankton community including the abundance and species diversity. Zooplankton reflects the condition of the environment and water quality of the water column.

Figure 4. Zooplankton 2015 - Arcella vulgaris

Field methods

1. Three samples are collected at each site. One sample is taken near the left bank of the river, at a distance of about 4-5 m from the water's edge. A second sample is taken in the middle of the river and a third sample from the right bank. If a site is on a national border, the three samples should be taken within the surveying Member Country's border.

2. Samples are taken at least 1 m from potential contaminants such as debris and aquatic plants, and at least 2 m away from vertical banks.

3. The 10 L samples of river water are slowly filled through a plankton net (with a mesh size of 20 µm) to avoid any overflow from the net. The plankton is then transferred to a 250 ml sampling jar (Fieldwork: Zooplankton collection, (MRC, 2010a)).

4. The sample is immediately fixed in the field by adding ~ 75 ml of 10% formalin to achieve a final concentration of 4-5% formalin in the sample jar. The sample jars are labeled with the site name, the site code, the sampling position and date. The site name, the site code, the sampling position (left bank, middle, right bank), the sampling date, the sample number and the collector's name are also noted in the field notebook, as is any information about the site that could be influencing the presence or abundance of different types of zooplankton.

Figure 5. Field work for zooplankton collection

Laboratory methods

1. In the laboratory, each sample is filtered through a net with a mesh size of 10 µm, rinsed with distilled water, and then allowed to settle to the bottom of a graduated

cylinder and left for 1 hour.

2. All individuals collected are counted and identified to the lowest taxonomic level possible, generally that of species. After analysis, samples are returned to the bottles and preserved as reference materials.

The following references were used to identify zooplankton: Kudo (1963), Dang *et al*. (1980) and Eiji (1993), as well as the Handbook on the identification of zooplankton for the Lower Mekong (Dang *et al*. 2015).

Analytical methods

The average richness, abundance and ATSPT values are determined and reported for each sample (which is 10 L) and averaged for the site.

Littoral macroinvertebrates

Littoral macroinvertebrates are monitored as they are good indicators for human disturbance and for the status of riparian zones as littoral macroinvertebrates are typically found near the shoreline. Hence, the abundance and richness of the invertebrates are a good indicator for the quality of the riparian zone.

Figure 6. Littoral Macroinvertebtrate 2015 – Baetis Sp.

Field methods

Littoral macroinvertebrate samples are usually taken on only one side of the river at each site. In most instances this is done on the depositional, rather than the erosional side. The depositional side tends to support more habitats for invertebrates. Because the study area is usually large, a wide range of littoral habitat types are typically sampled. As far as possible, similar habitats were selected at each site to facilitate comparisons between sites.

The sampling method follows these steps:

1. At each site, sweep sampling methods are used. A D-frame net with a 30 cm x 20 cm opening and mesh size of 475 µm is used. Sweep samples are taken along the shore at about 20 m intervals – see detailed methods in the MRC identification handbook (MRC 2010a).

2. Ten samples are taken per site, and 10 sweeps make up a sample. Therefore, 100 sweeps are made when taking 10 individual samples at each site.

3. The 10 cleaned invertebrate samples of each site are preserved in 70-90% ethanol for identification in the laboratory and marked with a label indicating the site name, the site code, the date, and the sample replicate number.

4. Information about the collector's name, substrate types sampled as well as any information or characteristics about the site is recorded on the field data sheet.

5. In the laboratory, the samples are identified under a stereo dissection microscope with a 2x – 4x objective lens and a 10x eyepiece. Identification is done to the lowest taxonomic level that could be applied accurately, which is usually to genus.

6. Identified specimens from each site are grouped into Phylum and then Orders, before being kept in separate jars for each taxon along with 70% ethanol and labeled by site.

The following references were used to identify littoral macro-invertebrates: Dudgeon (1999), Morse *et al*. (1994), Merritt & Cummins (1996) and Merritt, Cummins, & Berg (2008), and specifically for the Lower Mekong macro-invertebrate fauna (Sangpradub & Boonsoong, 2006).

Analytical methods

Richness, abundance and ATSPT scores are calculated per sample area (which is 10 sweeps or approximately 3 m^2 of substrate surface area), and the average result is then calculated for each site.

Benthic macroinvertebrates

Benthic macroinvertebrates were monitored in order to describe and quantify the macroinvertebrates that occur in the bottom substratum in deeper waters away from the littoral zone of the river. Benthic macroinvertebrates provide a good indication of the status and quality of the bottom substratum of the river as they are commonly found in deeper areas away from the shoreline. *Figure 7. Benthic macroinvertebrate 2015 - Corbicula sp.*

Field methods

1. Sampling sites at each site are selected in the right, middle, and left parts of the river. If a site is on a national border, the three sections to be sampled should be within the surveying Member Country's border.

2. Samples are taken at a minimum of three to a maximum of five plots at each location. More samples are required at sites with higher inter-sample variability (assessed on the basis of monitoring results from previous years), than in sites with lower variability.

3. At each sampling plot, four sub-samples are taken with a Petersen grab sampler and composited into a single sample, covering a total area of 0.1 m^2

4. Each sample is washed through a sieve (0.3 mm mesh) with care taken to ensure that macroinvertebrates do not escape over the sides of the sieve (Sample Collection of Benthic macroinvertebrates, (MRC, 2010a)).

5. The content of the sieve is then placed in a white sorting tray and the material (including the benthic macroinvertebrates) is dispersed in water. All the animals are fixed with 10% formalin to a final concentration of 5%. Alternatively, 95% ethanol can be used. It is crucial that the final alcohol concentration after specimens are added never falls below 70%.

6. The collector's name, the sampling site name, the location code and the replicated sample number are recorded in a field datasheet. Information about substrate types sampled as well as any information or characteristics about the site that could be influencing the presence or abundance of different types of benthic macro-invertebrates are included.

Figure 8. Sample Collection of Benthic Macroinvertebrates

Laboratory methods

All individuals collected are identified and counted under a compound microscope (with a magnification of 40–1,200x) or dissecting microscope (16-56x). Oligochaeta worms, mollusc, and crustacea are generally identified to species level. Insects are usually identified only to generic level.

The following references were used to identify benthic macro-invertebrates: Resh & Jackson (1993), Morse *et al.* (1994), Thorne & Williams (1997), Dudgeon (1999), Pinder (1999), Merritt *et al*. (2008), Sangpradub and Boonsoong (2006), and Yule & Sen (2004).

Analytical methods

Richness, abundance and ATSPT scores are always calculated and reported per sample (which is 0.1 m^2) and the average of each site and the individual scores are taken.

2.3 CALCULATION OF BIOMETRIC INDICATORS

This section reviews the calculation and analysis of the different biological metrics: (1) average abundance; (2) average richness; and (3) ATSPT of the four taxa: (1) benthic diatoms; (2) zooplanktons; (3) Littoral macroinvertebrates; and (4) benthic macroinvertebrates as follows:

Calculation of abundance:

Abundance is a measure of the number of individual plants or animals belonging to a particular biological indicator group counted in a sample. Low abundance is sometimes a sign that the ecosystem has been harmed. Abundance can be measured as the number of individuals per unit of area, volume or sample. In this report the average abundance is referred to as the average number of all individuals per sample taken at one site. The final average is used for comparison.

Calculation of average richness:

Average richness refers to the average number of taxa (types) of plants or animals belonging to a particular indicator group (e.g. diatoms, zooplankton) counted in samples from the same site.

Calculation of ATSPT

A tolerance value was calculated for each taxon collected during the baseline studies conducted in 2004, 2005, 2006 and 2007 (MRC, 2005b; MRC, 2006; MRC, 2008, and MRC, 2010a). Tolerance values for new taxa collected in 2008 onward were determined from the average Site Disturbance Scores (SDS) at the sites where these new taxa were found. Tolerance values are derived by assessing the relationship between the presence and absence of species in samples from each study site and the value of an independently measured SDS for each site. A visual method for determining the SDS is described in MRC (2010a).

The tolerance of each species (or higher taxon where identification to species is not possible) is calculated as the average SDS for all sites at which that species occurs weighted by the number of samples per site in which the species is recorded. The tolerance values are then re-scaled so that they range from 0 to 100, where 0 represents low tolerance and 100 represents high tolerance to human-generated stress.

The ATSPT is then calculated for each sample collected. ATSPT is the average tolerance of all taxa recorded in a sample, calculated without regard to their abundance. A working example on the calculations is given in MRC (2010a).

2.4 USING BIOLOGICAL METRICS TO EVALUATE SITES

Three types of metrics of the health of the aquatic ecosystem are calculated for each of the four indicator groups included in the biomonitoring programme (benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates). These metrics are abundance (average number of individual organisms per sample), average richness (average number of taxa per sample) and tolerance ATSPT. Signs of a disturbed ecosystem are low abundance (few individual organisms present), low average richness (low biodiversity), or a high ATSPT (signifying a scarcity of disturbance-sensitive species and a predominance of species that are able to withstand outside disturbance), relative to the conditions found at the reference sites.

Each metric is calculated for the individual samples of each group of organisms that are collected at a site. The collection of multiple samples per site enables the assessment of within-site variability of the indicators and also statistical testing of the significance of differences between sites and within the same site over multiple years. For the overall assessment of a site, the values of each indicator from individual samples are averaged.

Guidelines for site-average values of each indicator are set according to the range of site-average values obtained at the reference sites. For indicators where low values indicate harm to the ecosystem (abundance and average richness) the guideline is set at the 10^{th} percentile of reference site values (the value that is lower than 90% of all reference values). For the indicator where a high value indicates harm to the ecosystem (tolerance) the guideline is set at the 90^{th} percentile of reference site values (the value that is higher than 90% of all reference values). These percentiles are commonly used in biomonitoring programmes in other parts of the world. Interim guidelines are listed in Table 5. The sites are classed and grouped according to the number of the 12 indicators that meet the guidelines, based on biological conditions (MRC, 2010a). It is important to remember that while each of the rating criteria has a scientific basis, the classification and guideline system is subjective, and being a political decision, can be changed.

2.5 DESIGNATION OF REFERENCE SITES

Reference sites are used in both physical-chemical monitoring (e.g. to set water quality criteria) and biological monitoring programmes worldwide. In biomonitoring, the sites chosen as reference sites are usually selected on the basis of good water quality and habitat, and minimal disturbance from human activities. They are commonly those sites that are in a most natural, or pristine, state but at other times they are the sites with the best attainable condition. Reference sites for the Mekong provide benchmark data against which all sites in the system can be compared (MRC 2010a, Figure 2).

Characteristics of reference sites

Reference sites were selected from those sampled in the biomonitoring programme by the application of water quality criteria that are based on those applied by the MRC Environment Programme's Water Quality Index (MRC 2008). Site disturbance is scored by the national and international experts present on each sampling occasion, with regards to 13 site-scale activities which for instance include bank erosion, human activities, agriculture expansion, removal of natural vegetation, infrastructure development, and hydrological changes (MRC, 2010a).

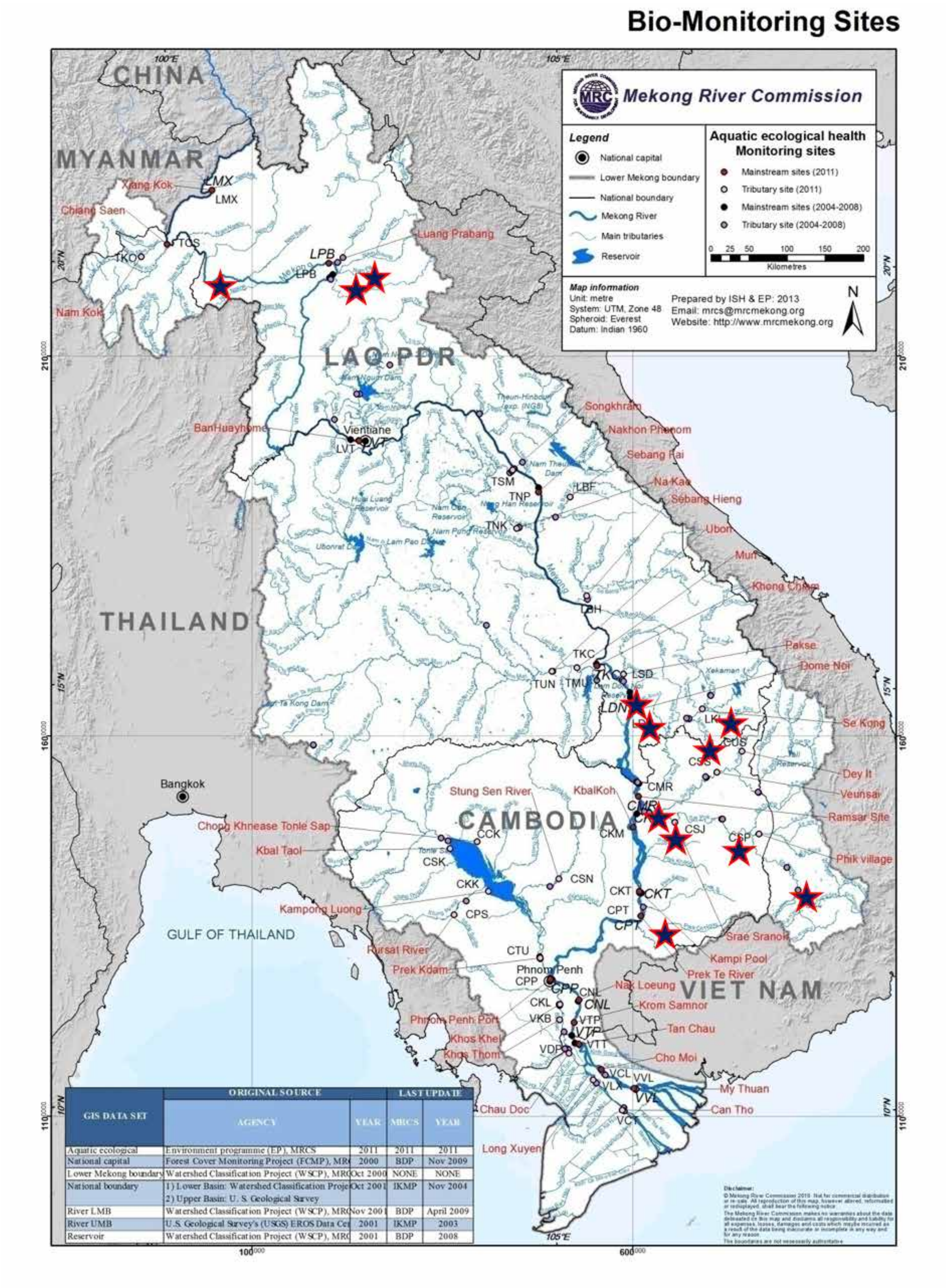
The SDS (Site Disturbances Score) scores can range from 1 (little or none of any of these types of disturbance) to 3 (substantial disturbance of one or more types). Visual assessment is used because it is not possible to make quantitative measurements of all of these types of disturbance.

Visual scoring systems are widely used in stream assessments for features that are not amenable to quantitative measurement. Averaging of the scores determined by several observers even out the influence of individual perceptions.

To be selected as a reference site, a site has to meet *all* of the following requirements:

1. The pH of the site at the time of biological sampling is between 6.5 and 8.5.
2. The electrical conductivity at the time of biological sampling is less than 70 mS/m, but due to the brackish water conditions in the Delta, this criterion might be exempted.
3. The dissolved oxygen concentration at the time of biological sampling is higher than 5mg/L.
4. The average SDS is between 1 and 1.67 on a scale of 1 to 3; that is, in the lowest one third of possible scores. A typical site with a score between 1 and 1.67 might have low-level rural development, such as low-density village activities, but not major urbanization, intensive agriculture or waste disposal.
5. No major dam or city within 20 km upstream of the site and flow at the site is not affected by inter-basin water transfer. Downstream development is also considered where a site has upstream flow because of tidal influence.

Figure 9. Reference sites (stars) agreed in 2004-2008 biomonitoring activities



GIS DATA SET	ORIGINAL SOURCE		LAST UPDATE	
	AGENCY	YEAR	MRCS	YEAR
Aquatic ecological	Environment programme (EP), MRCS	2011	2011	2011
National capital	Forest Cover Monitoring Project (FCMP), MR(	2000	BDP	Nov 2009
Lower Mekong boundary	Watershed Classification Project (WSCP), MR(	Oct 2000	NONE	NONE
National boundary	1) Lower Basin: Watershed Classification Proje 2) Upper Basin: U. S. Geological Survey	Oct 2001	IKMP	Nov 2004
River LMB	Watershed Classification Project (WSCP), MR(	Nov 2001	BDP	April 2009
River UMB	U.S. Geological Survey's (USGS) EROS Data Cer	2001	IKMP	2003
Reservoir	Watershed Classification Project (WSCP), MR(	2001	BDP	2008

2.6 CLASSIFICATION AND SCORING SYSTEM FOR SAMPLING SITES

For each biological group, three metrics were used to assess the site – average abundance, average richness, and ATSPT. The final impact of human activities was assessed by comparing how similar the three metrics for the four biological groups compare to the values at the 12 MRC reference sites (MRC, 2008, 2010a).

Four biological groups: benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates were selected for the study and the three metrics measured for each, giving a total of 12 biological results for the evaluated sites. The sites were graded into one of the four following groups:

- **Class A (Excellent):** 10–12 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity to support fish and other freshwater functions are similar to those at the reference sites defined in the 2004–2007 surveys. These reference sites provide a 'baseline' against which other sites can be measured.
- **Class B (Good):** 7–9 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are slightly less than that at the reference sites. Human activities may have caused some disturbance.
- **Class C (Moderate):** 4–6 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are markedly less than that at the reference sites. Disturbance resulting from human activities is present.
- **Class D (Poor):** 0–3 of the 12 indicators meet the guidelines. The biodiversity and ecological capacity are significantly less than that at the reference sites. Various disturbances from human activities are likely to be present.

Table 5. Guidelines for biological indicators of ecosystem health based on the 2004–2007 baseline studies

Metrics	Biological indicator groups								Guidelines of healthy ecosystem
	Diatoms		Zooplankton		Littoral macroinvertebrates		Benthic macroinvertebrates		
	Reference site value								
	10th percentile	90th percentile	10th percentile	90th percentile	10th percentile	90th percentile	10th percentile	90th percentile	
Abundance (mean number of individual organisms per standard samples)	136.22	376.34	22.33	174.07	46.68	328.56	5.37	56.34	Greater than 10th percentile
Average richness (mean number of taxa per standard samples)	6.54	11.78	9.8	20.2	5.37	18.48	1.84	7.85	Greater than 10th percentile
Average Tolerance Score per taxon (ATSPT)	30.85	38.38	35.54	41.8	27.8	33.58	31.57	37.74	Less than 90th percentile

3. RESULTS

3. RESULT

3.1 PHYSICAL ENVIRONMENTAL VARIABLES

The physical environmental variables measured at each site include site altitude, depth and width of the river, transparency, water temperature and general chemical parameters; Dissolved Oxygen (DO), pH and Conductivity (EC) (Table 6). The variables showed a broad range of values across the study sites. The Site Disturbance Score (SDS) is determined by the physical condition of the site; the method used for calculated SDS was presented comprehensively in the Biomonitoring Handbook (MRC, 2010a). Hereafter, the results of the physical environment is presented in mainstream order: Lao PDR, Thailand, Cambodia and Viet Nam.

Lao PDR

The environmental variables showed a large range of values across the eight widely dispersed study sites (Table 6). For example, altitude varied from 72 m above sea level (ASL) at site LKL to 410 m at site LMX. The channel width varied from being as narrow as 105 m at LBF to as wide as 1,200 m at LDN. Water transparency (Secchi depth) ranged from 1.0 – 2.5 m (Table 6). The average transparency of all sites was 1.67 m (± 0.51 m).

The lowest value of water temperature (21.2 °C) was measured at site LMX, and the highest value (33.6 °C) was measured at site LBH. A broad range of temperatures were obtained with an average of 28.2 °C (± 4.4 °C). Dissolved oxygen (DO) concentrations were generally high compared to those typically reported for tropical waters, with an average of 7.6 mg/L (± 0.78 mg/L). Water pH was neutral at most of the sites, with the pH varying between 6.94 and 7.00 with an average pf 6.97 (± 0.02). Electrical Conductivity (EC) varied from 60.9 to 320 µS/cm with an average of 214.6 µS/cm (± 96.79). The highest conductivity was measured at the sites LMX and LPB, respectively, while the lowest value was found at site LBF. Regarding the Site Disturbance Score (SDS), one out of eight sites (LMX) showed a value of 2.25 corresponding to medium stress, while the other six sites were close to being medium stress ranging from 1.81 to 1.96. Finally, only LPB was evaluated to lie between light and medium stress with a value of 1.65.

Thailand

A large variation of the river's environmental condition in Thailand was observed across all the sites. The site located at the lowest altitude is TMU with 85 m. TKO is the highest site at 395 m ASL. The widest part of the river channel was measured at TKC (1,250 m) followed by TSM (1,100 m), while the narrowest channel width was measured at TNK (38 m). The river depth varied between the sites. The shallowest river depth was at TKO with 0.61 m, while the deepest was at TKC with a depth of 6.29 m. Like other variables, water transparency differed from site to site with the lowest at TNP (0.30 m) and the highest at TMU (2.08 m).

Concerning the water temperature, the average of the eight sites was 28.43 °C (±3.51 °C). The lowest temperature was recorded at TCS (21.32 °C) and the highest at TUN (32.08 °C). DO concentration was slightly different among the eight sites. The average was 7.30 mg/L (±0.50 mg/L) with the lowest being 6.50 mg/L measured for site TMU and the highest 8.19 mg/L at TUN. The river pH of all sites varied from neutral to slightly alkaline with an average of 7.84 (±0.32). Three sites showed a pH of more than 8 (TKC, TUN and TSM). EC values ranged from 87.71 µS/cm at TMU to 420.99 µS/cm at TUN with an average of 251.08 µS/cm (±104.52 µS/cm). For SDS, TKC and TCS were assessed and given a medium stress (2.06 and 2.34, respectively), while TNK and TMU were evaluated as being under slight stress (1.48 and 1.60, respectively). The remaining sites were close to medium stress.

Cambodia

Like other countries, Cambodia measured the same environmental variables within its 17 sampling sites. The altitude of the river ranged between 5 m and 134 m. For the river width, the narrowest (40 m) was at CPT and the largest was measured (1,500 m) at CNL. The river depth varied within the different sites. The shallowest was measured at CCK with a depth of 0.6 m, and the deepest at CNL with a depth of 24.00 m. Water transparency varied from site to site with the lowest value (0.04 m) at CCK and the highest value (2.50 m) at CUS.

Water temperature was at an average of 29.66 °C (±1.14) in all 17 sites. The lowest temperature was measured in CUS with a value of 26.00 °C, while the highest of 30.90 °C was measured for CCK. For DO, it was observed that the DO at CSN and CKL were very low with a value of only 4.28 mg/L and 5.61 mg/L, respectively. The rest was within an acceptable range. Like DO, pH was in a suitable range with an average of 7.50 (±0.34). Regarding EC, an average of 131.64 µS/cm (±74.49 µS/cm) was obtained with the lowest value (51.60 µS/cm) at CSJ and the highest (251.00 µS/cm) at CMR. SDS differed between the sites; ten sites were assessed as having medium stress. The rest were under light stress (Table 6).

Viet Nam

Based on the results in Table 6, the environmental conditions between the eight sites varied. Unlike the other three countries, however, the river altitudes are relatively low. The lowest altitude is at VDP with 5 m (ASL) and the highest at VCT with only 10 m. The river width of all sites was generally large. It ranged from 190 m at VKB to 1,720 m at VTP. For the river depth, the shallowest (1.3 m) was found at VTT and the deepest (10.7 m) at VLX. Water transparency was found with only a slight difference between sites (0.50 at VDP to 0.85 at VKB).

The recorded water temperature was quite similar for all sites. Six sites showed a temperature of approximately 30°C, while VKP and VCT were measured at 29.7 °C. DO concentration was relatively low for all sites, ranging from 3.66 mg/L to 5.81 mg/L with an average of 4.83 mg/L (±0.78). It was found that DO concentration of VCL, VVL, VDP and VCT was lower than that of the reference site (>5 mg/L). pH values of all sites were in an acceptable condition ranging from 6.32 at VDP to 7.29 mg/L at VTT. Also, the average of all sites was 6.65 (±0.30) mg/L. The measured electrical conductivity varied between 161 µS/cm at VKB and 211 µS/cm at VCT having a total average of 196.25 µS/cm (±15.62). Concerning SDS, all sites were assigned to be under medium stress ranging from 1.7 to 2.2 and at an average of 1.90 (± 0.19).

Table 6. Physical and chemical conditions and Site Disturbance Scores (SDS)

Site	Altitude (m)	Width (m)	Average depth (m)	Secchi depth (m)	Tem (oC)	DO (mg/L)	pH	EC (µS/cm)	SDS
LMX	410	125	19.17	2.5	21.2	8.36	7	320	2.25
LPB	407	250	2.33	1	23.07	7.06	7	320	1.65
LVT	178	810	4.5	1.5	27.5	6.25	7	282	1.86
LBF	134	105	8	2.2	27.5	8.36	7	60.9	1.86
LBH	111	160	1.83	1.2	33.6	6.92	6.9	216.7	1.81
LSD	101	300	7	2	33	8	7	116	1.81
LKL	72	220	2.33	1.5	30.6	7.74	7	150.2	1.86
LDN	82	1,200	2.5	1.5	29.7	8.24	6.9	251	1.96
TCS	360	750	1.97	0.8	21.32	8	7.9	306.49	2.34
TKO	395	90	0.61	0.6	26.71	7.2	7.7	126.92	1.71
TSM	135	1,100	0.9	0.36	27.91	7.33	8.1	264.6	1.97
TNP	135	950	2.47	0.3	27.79	7.09	7.7	261.13	1.94
TNK	140	38	1.12	1.1	31.77	7	7.4	296.83	1.48
TUN	109	135	3.55	1.28	32.08	8.19	8	420.99	1.79
TMU	85	350	3.67	2.08	31.19	6.5	7.5	87.71	1.6
TKC	90	1,250	6.29	0.76	28.63	7.08	8.4	243.95	2.06
CMR	58	200	7.1	0.99	29.3	8.3	8	251	1.65
CKM	48	250	2.5	1.1	30.2	7.33	7.7	73.3	1.6
CUS	134	70	4.2	2.5	26	7.88	7.2	54.2	1.54
CSS	126	270	2.3	0.88	30.5	7.33	7.2	52.2	1.48
CSP	100	180	4.2	0.95	30.1	7.2	7.5	66.4	1.57
CSJ	50	470	1.2	1.15	29.2	7.78	7.7	51.6	1.55
CKT	12	900	3.1	1.3	30.1	7.8	8	235	1.74
CPT	39	40	1.9	0.3	30.5	6.65	7.7	109.1	2.04
CCK	5		0.6	0.04	30.9	6.23	7.1	94.5	1.86
CKL	5		0.7	0.06	28.2	5.61	7.1	90.1	1.94
CSN	16	125	2.1	0.25	30.1	4.28	7.1	215	1.98
CSK	5	180	2.4	0.18	30.4	6.55	7.2	59	2
CTU	16	490	5.2	0.69	29.5	7.15	7.6	94.4	2.06
CPP	8	700	9.2	0.78	30.1	6.42	7.9	184.8	2.25
CPS	23	265	4.5	0.48	29.3	6.35	7.1	165.3	1.55
CNL	6	1,500	24	1.3	29.7	7.69	7.8	234.1	1.98
CKK	5	285	7.5	2.1	30.2	7.81	7.8	207.8	2.15
VTP	7	1,720	3.3	0.63	30	5.21	6.8	199	1.8
VTT	6	1562	1.3	0.65	30	5.37	7.3	203	1.8
VKB	6	190	2.7	0.85	29.7	5.81	6.6	161	2
VDP	5	325	3.3	0.5	30	4.45	6.3	190	1.9
VCL	7	1,090	4.7	0.72	30	3.66	6.5	200	1.7
VLX	7	798	10.7	0.58	30.3	5.61	6.5	198	2.2
VVL	8	1,015	5.7	0.8	30	4	6.6	208	2.1
VCT	10	1,612	2.3	0.6	29.7	4.55	6.7	211	1.7

3.2 DIATOMS

Lao PDR

In total, 30,511 diatoms were collected, and 59 species were identified from 80 samples at eight sites in 2015. It was found that two species, namely *Neidium gracille* and *Gomphonema* sp.1, were present at all sites and hence distributed widely in Lao PDR.

Abundance

The average abundance of diatoms per sample (10 cm^2) ranged from 50 to 2,278 individuals (Table 7 and Figure 10). It was found that the average abundance of diatoms increased in five sites, compared to 2013 apart from LDN, LMX, LBH and LBF. It is likely that more diatoms were found due to the accessible permanent substratum (bedrock and stones) when collecting the samples rather than a change in the environment. In LBF, the abundance may have decreased since the site is located at the drainage of the Nam Theun 2 Hydropower Dam. Thus, the water level at that site was high and the permanent substrata were deep, making sample collection more difficult and unreliable. Although the abundance increased at most of the sites, it was found that three sites (LMX, LBF and LDN) were below the threshold value of a healthy ecosystem according to the guidelines.

Average richness

The average richness per sample ranged from 1 to 18 species (Table 7 and Figure 10). The lowest average richness was found at LBF and the highest at LPB. The average richness at LMX, LBF and LBH slightly decreased, while that at LKL remained the same compared to the results from 2013. Among the eight sites, the survey team found that the condition of three sites – LMX, LBF and LKL – was lower than the threshold value of a healthy ecosystem according to the guidelines.

ATSPT

The Average Tolerance Score Per Taxon (ATSPT) of diatom samples taken from 2015 ranged from 22 at LBF to 43 at LMX (Table 7 and Figure 10). The results showed that ATSPT was slightly lower or similar in 2015 compared to the last survey in 2013. Particularly, LBF shows a lower ATSPT value during this monitoring period. Regardless, only two sites met the guidelines, which is one more compared to 2013. It is noted that due to missing data the ATSPT measurements were recalculated for this report.

Thailand

The eight sites sampled in 2015 yielded a total of 108 species with 127,493 cells from 80 samples. The most common species were found in the Naviculales order which was the same in 2013. *Surirella* sp.1, *Cymbella turgidula, Navicula cincta*, *Nitzschia levidensis* var *salinarum* were the most abundant and observed in all sites.

Abundance

The average abundance of diatoms collected at all sites ranged from 404 to 3,830 cells (Table 7 and Figure 11). The team found that the average abundance at TUN, TMU and TKC had significantly dropped compared to the obtained values from 2013, while the rest showed higher values. Regardless, the obtained average abundance values at all sites were above the threshold value of the healthy ecosystem guidelines.

Average richness

Species richness per site ranged from 9.5 to 19.6 (Table 7 and Figure 11). The highest richness was found at TCS, while the lowest richness was observed at TKO. The study found that the average richness decreased at sites TKO and TMU compared to the results of the studies in 2011 and 2013, while the rest showed an increase in average richness. According to the healthy ecosystem guidelines, all sites lay within the required range.

ATSPT

The team found that the ATSPT slightly varied between sites; it ranged from 35 to 45 with the lowest score at TNK and the highest at TNP. The result showed that ATSPT scores of all sites had slightly increased since the previous survey in 2013 but only TNK and TMU did not meet the requirements of the guidelines of a healthy ecosystem.

Cambodia

A total of 170 sub-samples were collected in the Cambodian part of the Mekong Basin. In total, 194,405 cells of benthic diatoms were counted, with 172 species/taxon. This was higher than the study in 2013. The number of diatoms per sampling site ranged from 20 to 2,995 individuals.

Abundance

The average abundance of benthic diatoms among the 17 sites was between 129 and 392. The results revealed that CSS had the lowest average abundance, while CPS had the highest. All sites showed an increasing trend compared to the results in 2013. However, when comparing the obtained results with the values from 2011, the abundance of benthic diatoms at those sites was relatively low (Table 6 and Figure 11). Due to missing data from 2011, they are not present in this report. All sites, except CSS, met the requirements of the guidelines of a healthy ecosystem.

Average richness

The number of species per sampling site varied among the 17 sites, ranging from 7 species at CSS to 34 species at CPS (Table 7 and Figure 12). The study also found that the number of species at CMR, CUS, CSS, CSP, CPT, CTU and CNL remained the same as in the previous study in 2013. Finally, all sites met the guidelines of a healthy ecosystem.

ATSPT

The study found an adverse change of ATSPT in 2015 (Table 7 and Figure 12). The score of ATSPT at all sites rose, ranging from 35 at CMR to 45 at CPP, All sites were below the threshold value according to the guidelines of a healthy ecosystem. However, the latter mentioned sites are on the threshold value for indicating an unealthy environment. The distinct rise in ATSPT of all sites could indicate the interference of more and more tolerable species for the sampled sites.

Viet Nam

The survey conducted 80 sub-samples in Viet Nam in 2015 and found 117 species more than in 2013. The identified species ranged from 44 at VVL to 70 at VKB. The sites with an increased number of taxa compared to 2013 were VCT, VLX, VDP, VKB, and VVL. Besides new species found in 2011, four additional species were also discovered during monitoring in 2015. They are *Nitzschia sigmoidea, Eunotia robusta, Navicula granulata and Stauroneis* sp*,* belonging to the Bacillariophyceae class. This class also showed the highest number of orders and families (8 orders, 15 families and 18 genus), with the number of individual taxa reaching 103. The most dominant was the Naviculales order with 45 species.

Abundance

The average abundance of the benthic diatoms ranged from 388.4 to 1,372 cells per sample (Table 7 and Figure 13). The values of abundance in 2015 were very high compared to those in 2011 and 2013. The greatest abundance was found at VVL and the lowest at VDP. The values of all sites were higher than the reference values of the guidelines of a healthy ecosystem.

Average richness

The average richness of benthic diatoms at the eight sites varied between 14 and 22; the lowest average richness was at VVL and the highest at VKB and VDP (Table 7 and Figure 13). The study found that values of the average richness of almost all sites were higher than those in 2013, except VVL. VCT showed a drastic drop from 20 in 2011 to 13 in 2013. However, in 2015 the average richness was evaluated at 18. Overall, all sites were in a healthy condition since their values were higher than the reference values in the guidelines.

ATSPT

The ATSPT in 2015 fluctuated between 44.08 and 45.64. In general, the values in 2015 had a similar range as 2013; however, compared to 2008 and 2011, a downward trend can be observed (Table 7 and Figure 13). Regardless, no sites could meet the required standard for the ATSPT values according to the guidelines. Hence, more tolerant species towards environmental stress than sensitive species were present, suggesting a modified and more stressed environment compared to further upstream.

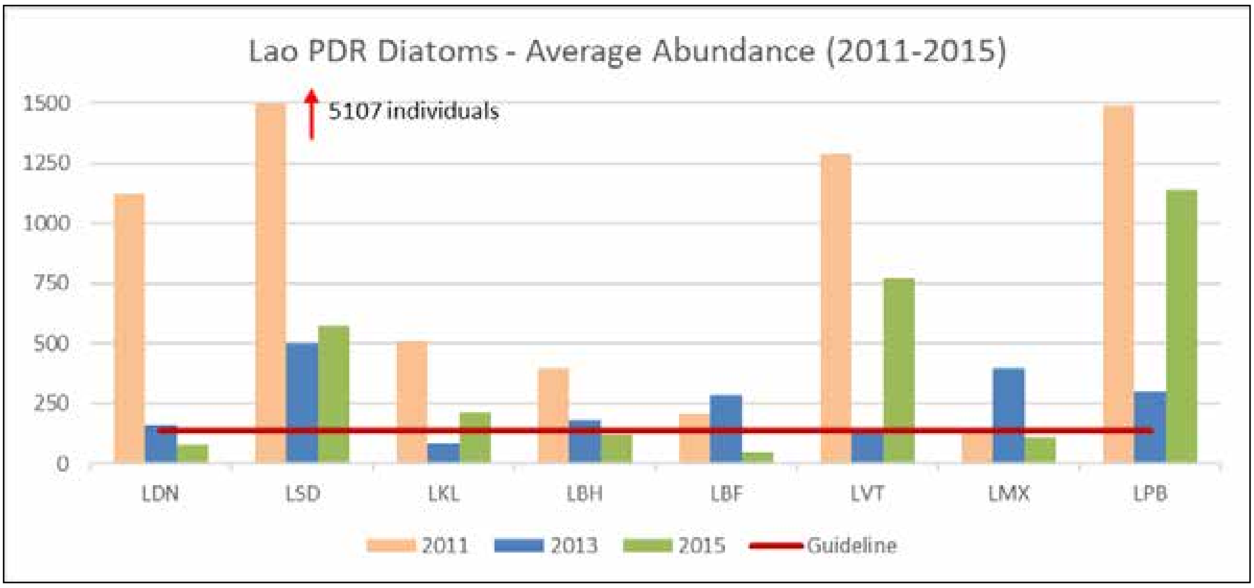
Table 7. Value of average abundance, richness, and ATSPT for benthic diatoms (2007-2015)

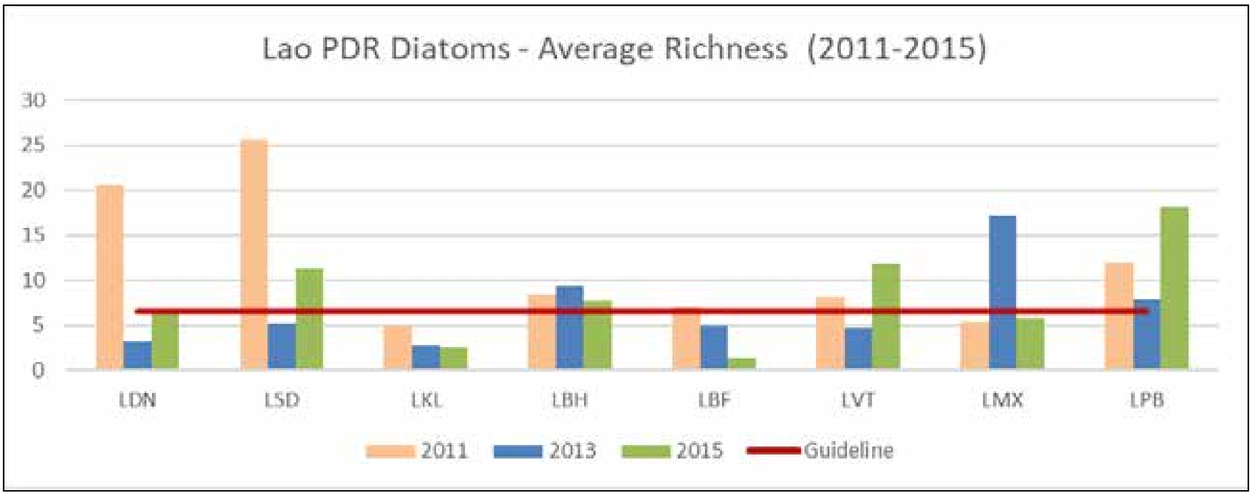
Site Code	Abundance					Average richness					ATSPT				
	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015
LMX		82	26	80	112		3	5	17	6		45	21	44	43
LPB		568	299	60	2,278		5	12	8	18		41	20	42	41
LVT	1,338	373	258	25	768	8	6	8	5	12	39	40	29	39	42
LBF	46	75	42	57	50	6	2	7	5	1	36	36	21	43	22
LBH	257	197	79	36	118	8	6	8	9	8	36	39	16	43	42
LSD	108	58	1,021	101	575	8	2	26	5	11	38	40	40	43	42
LKL	63	305	26	17	213	7	5	5	3	3	40	38	12	18	26
LDN	266	213	224	32	78	9	3	21	3	7	34	35	34	41	38
TCS		366	2,911	888	1,913		12	16	14	19.6		37	44	42	43
TKO		318	1,275	2,098	3,830		8	20	16	9.5		37	41	36	41
TSM	128	252	1,028	869	1,909	5	11	10	9	16	39	36	40	40	43
TNP		219	777	192	1,518		6	12	7	14.2		38	41	39	45
TNK	101	300	103	411	1,047	7	8	9	9	19	48	39	38	34	35
TUN		45	434	4,743	897		7	10	10	13.3		37	40	34	40
TMU		272	1,471	4,581	404		6	13	18	11.7		39	40	35	38
TKC		279	1,069	2,981	1,325		12	10	10	18.3		38	38	39	42
CKM	71	820	292	160	295	7	10	27	15	16	34	34		35	39
CMR				124	218				12	12				32	35
CUS	287	412	44	181	326	5	8	24	19	19	38	37		36	38
CSS			162	74	129			11	7	7				36	40
CSP	532	219	1,105	87	147	8	6	14	8	8				36	41
CSJ	655	916	46	118	205	6	9	18	12	13	35	36		33	39
CKT		307	272	136	233		6	21	21	22	34	33		34	40
CPT			489	118	198			14	13	13		36		38	44
CCK			513	169	298			17	22	23				37	42
CKL			274	146	194			16	23	9				37	44
CSN			357	85	171			11	12	16		41		39	44
CSK		469	323	114	216		5	14	17	20				38	44
CTU			1,188	109	194			12	8	8				36	42
CPP			186	148	279			14	18	21		34		39	45
CPS			107	225	392			33	33	34				34	39
CNL			358	78	140			11	8	8				37	43

CKK		64	503	111	261		3	12	9	23				35	42
VTP	553.6	100.4	354.4	523.2	455.6	13	14	14	15	15	46	45	47	49	44
VTT	944.8	158	172.4	286.4	661.8	16	16	17	16	16	47	51	45	46	44
VKB	204	91.6	168.8	900.4	604.9	12	12	12	13	22	48	51	45	47	45
VDP	1,974	84.8	177.2	623.6	388.4	14	14	11	14	22	47	50	45	45	45
VCL	241.2	324.4	232.4	747.6	1,024	13	3	18	16	19	48	51	45	47	46
VLX	85.2	250	162	376	1,048	12	12	14	15	18	47	50	46	46	45
VVL	5,970	209.6	216.8	1,515	1,372	15	15	19	15	14	48	52	46	46	45
VCT	144.8	299.6	268.8	577.6	1,332	11	11	20	13	18	47	50	47	49	45

Figure 10. Average abundance, richness, and ATSPT for diatoms in Lao PDR (2011-2015)

Note: the arrow at site LSD indicates the actual number of individuals found at that site. Due to better visualization and comparison, the y-axis was adjusted.





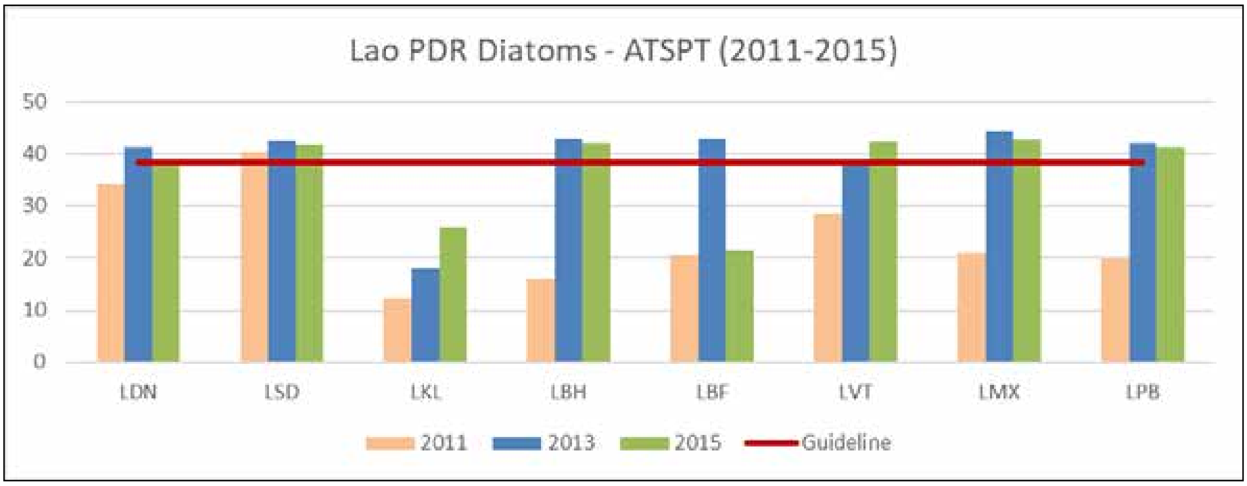
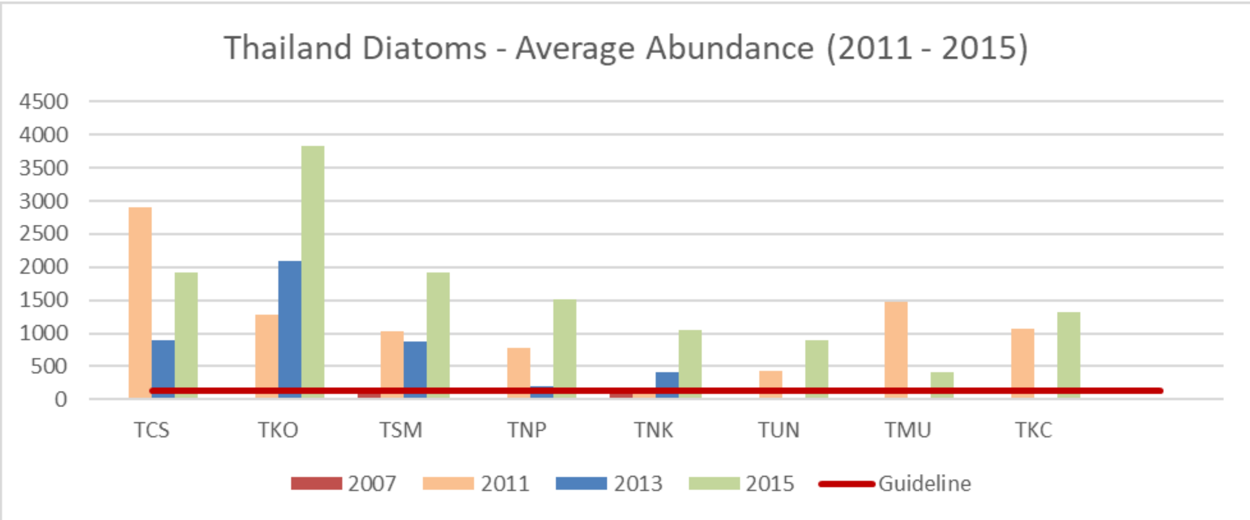
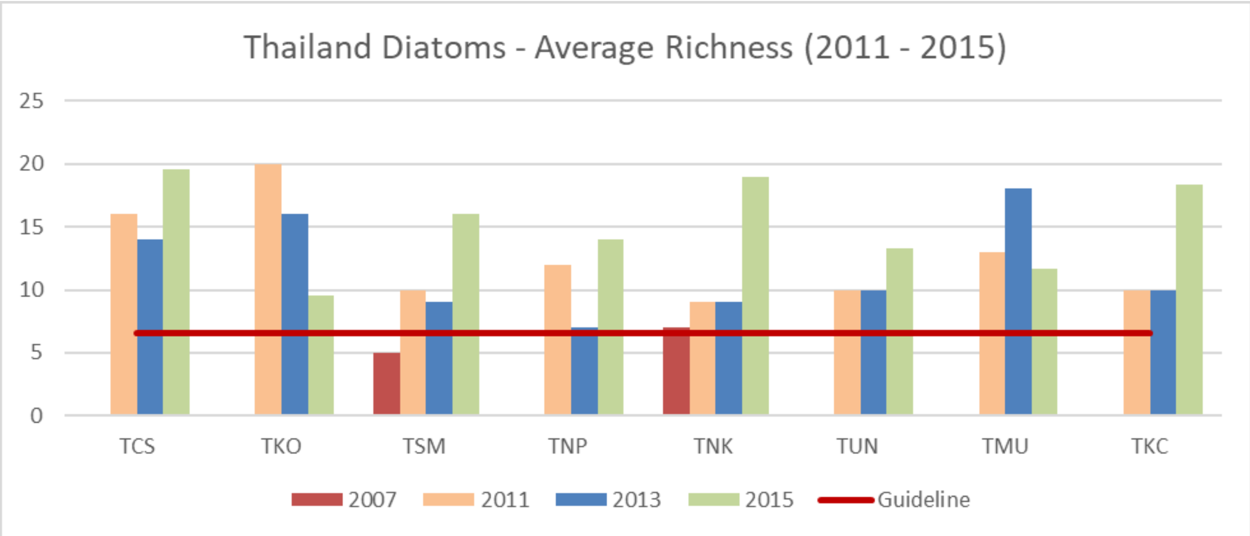


Figure 11. Average abundance, richness, and ATSPT for diatoms in Thailand (2007-2015)





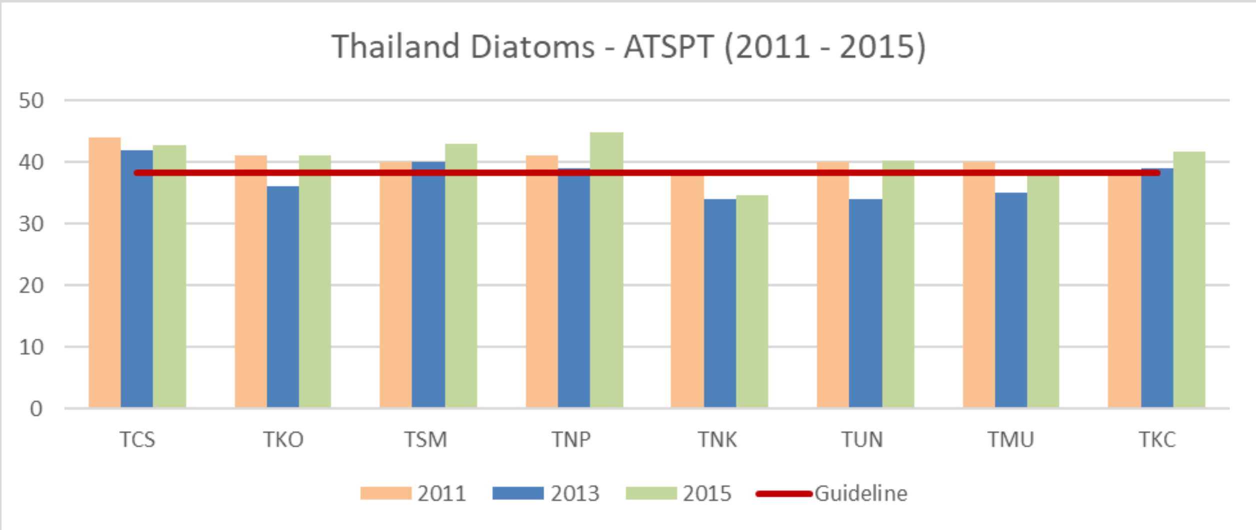
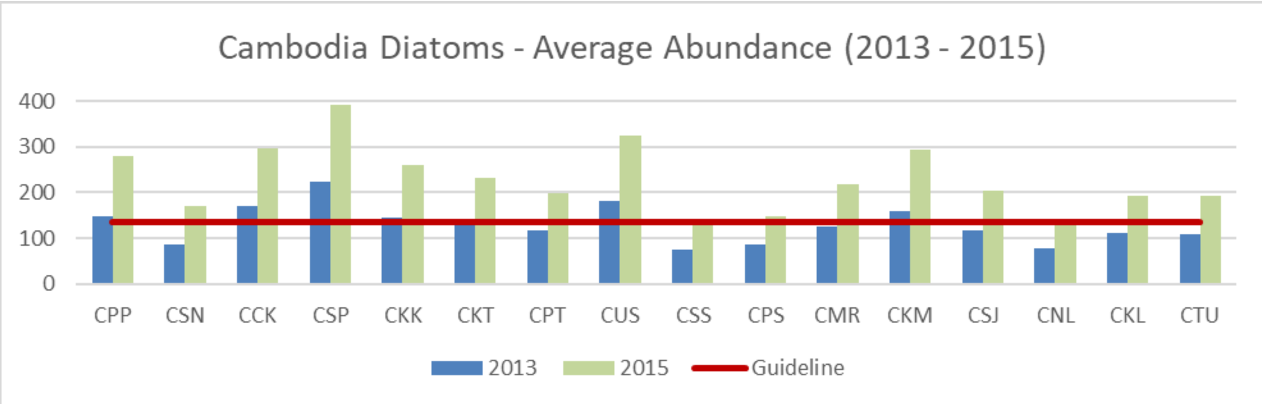
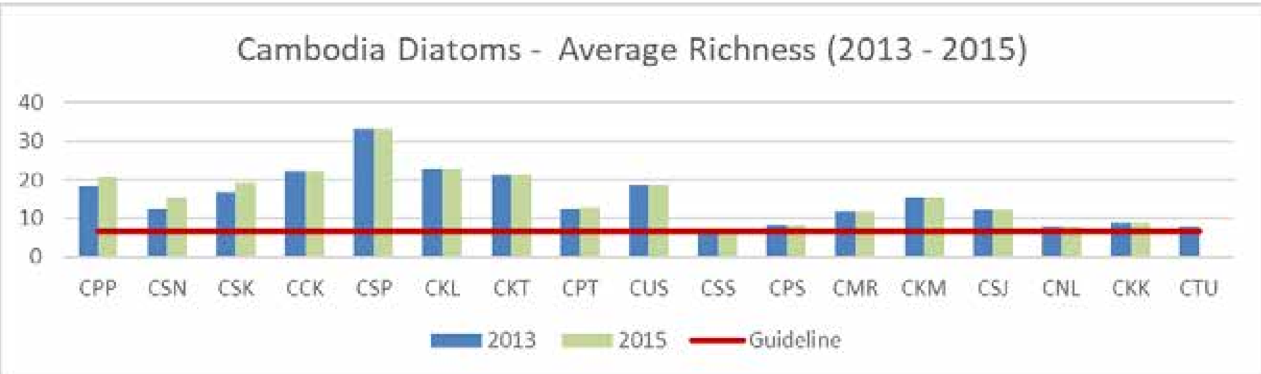


Figure 12. Average abundance, richness, and ATSPT for diatoms in Cambodia (2013-2015)





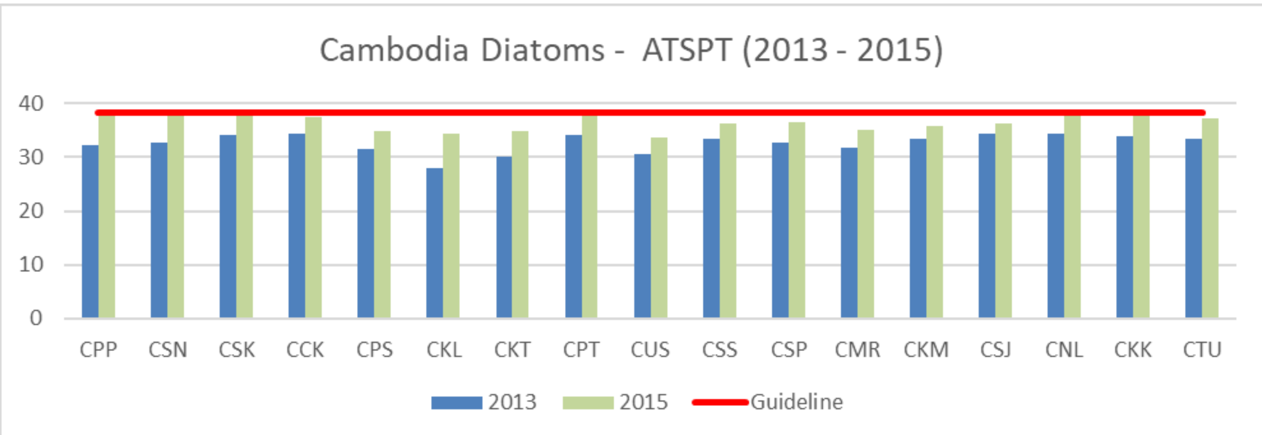
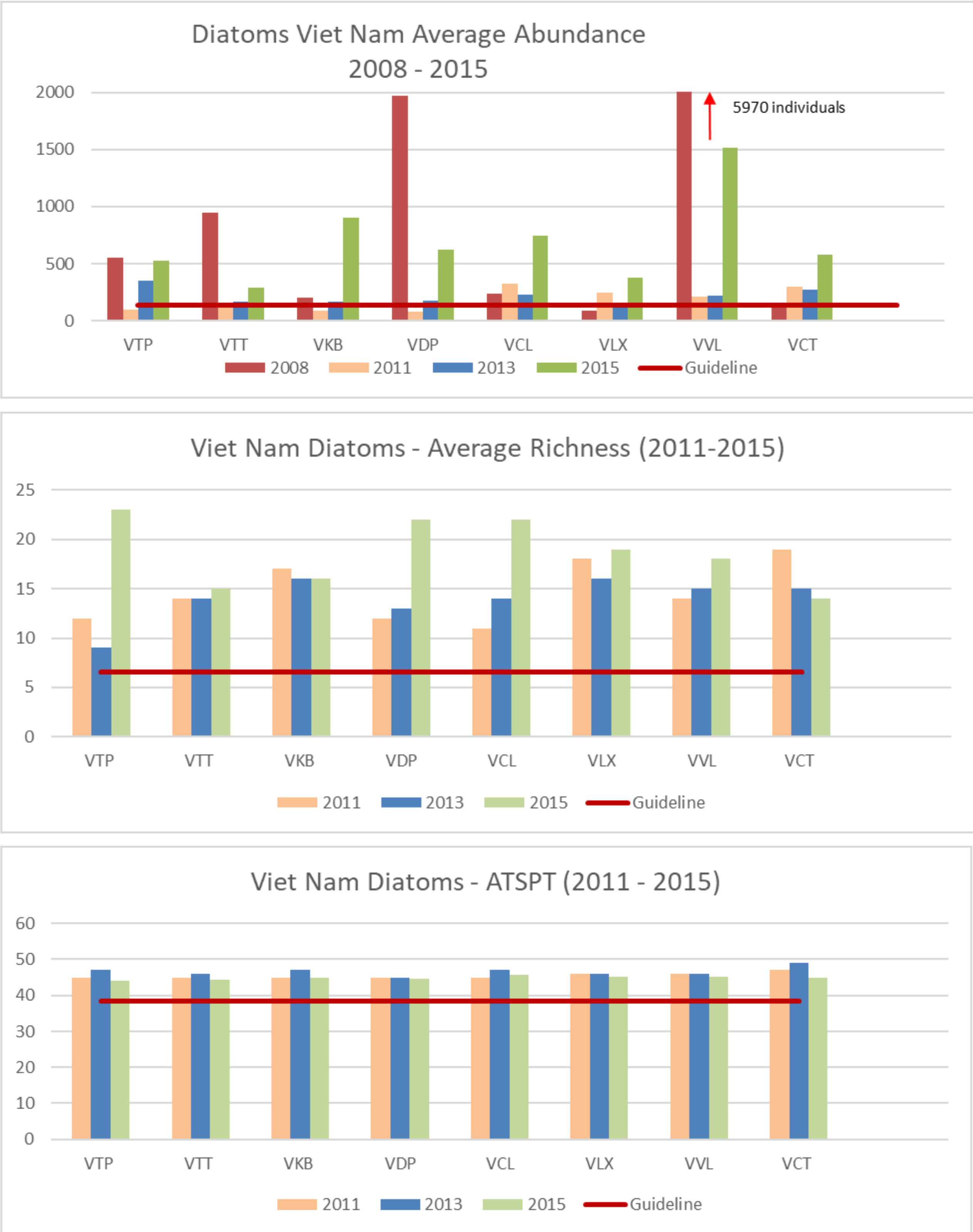


Figure 13. Average abundance, richness, and ATSPT for diatoms in Viet Nam (2008-2015)

Note: the arrow at site VCT indicates the actual number of individuals found at that site. Due to better visualization and comparison, the y-axis was adjusted.



3.3 ZOOPLANKTON

Lao PDR

A total of 3,087 individual specimens of zooplankton and larvae were found in the eight sites surveyed in Lao PDR. These were comprised of 105 taxa within 25 families and 3 forms of larvae. The zooplankton included 4 main groups: Crustacea, Eurotatorea, Lobosea, Phytomastigophora and larvae form.

Abundance

The variability of average abundance across the 8 sites was observed with a range varying between 58 and 22 individuals per sample (Table 8 and Figure 14). The highest abundance was found at LDN, while the lowest abundance was found at LMX. The abundance of all sites in 2015 showed a 7- to 10-fold increase compared to 2013 because the water current was not as strong as in the previous study (2013); thus, the survey team could access and sample at the monitoring site more easily. Moreover, the abundance values of all sites met the requirements of the guidelines of a healthy ecosystem.

Average richness

The average richness per site ranged from 19 to 40 taxa (Table 8 and Figure 14). The lowest average richness was at LMX and the highest at LKL. The average richness of most samples in 2015 showed a great increase compared to the values obtained in 2013. All sites' values lay above the threshold value of the healthy ecosystem guidelines suggesting a safe environment.

ATSPT

The ATSPT for zooplankton ranged from 42 to 47 (Table 8 and Figure 14). The lowest occurred at LKL and the highest at LMX. Only a small variation of ATSPT between the sites was observed compared to the previous years with a tendency to increase. Only one site, LPB was below the threshold value of the guidelines.

Thailand

In 2015, the eight sampling sites yielded a total of 1,126 individuals and 30 species. The number and richness of zooplankton significantly decreased compared to the studies undertaken in 2011 and 2013. The *Copepoda* (nauplius and copepodate) and *Keratella cochlearis* were the highest number of individuals from the 8 sample sites, with the most common species being *Copepoda* (copepodate).

Abundance

The average abundance of zooplankton ranged from 3 to 171 individuals in the eight sites (Table 8 and Figure 15). It was observed that the abundance in all sites decreased compared to 2013. Almost all sites showed a major reduction except TCS. For the 2015 study, the highest abundance occurred at TUN, while the lowest abundance was observed at TSM and TKC. Among the eight sites, only TUN and TMU could meet the healthy ecosystem guidelines.

Average richness

The species average richness varied from 1.3 to 14.7 between sites (Table 8 and Figure 15). The highest richness occurred at TUN, while the lowest was found at TSM. Unsuitable environmental conditions, such as high turbidity in the Mekong River channel, may have had an impact on the found distribution of zooplankton, especially at sites TNP, TSM, TKC and TCS. The richness of zooplankton significantly decreased compared to 2013. Only TUN and TMU met the standard of the healthy ecosystem guidelines.

ATSPT

Variability of the ATSPT was calculated for the eight sites. It ranged from 36.5 at TNK to 44.9 at TKO (Table 8 and Figure 15). If compared to the study from 2013, the ATSPT of almost all sites increased, except for ATSPT of TMU. As a result of that increase, three sites (TCS, TKO and TSM) could no longer meet the guidelines of healthy ecosystems.

Cambodia

Abundance

The average abundance of zooplankton at each site ranged from 7 to 1,289 (Table 8 and Figure 16). It was observed that the highest average abundance of zooplankton was at CPP and the lowest at CSS. Among the 17 sites, only CSS and CKT did not reach the required standard of the healthy ecosystem guidelines.

Average richness

The average richness of the species per site ranged from 2 at CPT to 27 at CSK and CPP (Table 8 and Figure 16). It was found that the highest number for richness significantly decreased from 52 to 27 compared to 2013. Predominately, most sites showed a stable or an increase in average richness and only four sites showed a decrease. Two sites showed the same number of species as in 2013. Five sites (CCK, CKT, CSS, CMR and CPT) were unable to meet the healthy ecosystem guidelines. Hence, compared to the previous study in 2013, a slight overall increase was observed since 2013, when only 3 sites were able to meet the required standards of the guidelines.

ATSPT

The variability of ATSPT for zooplankton was in a range of 14 and 45 (Table 8 and Figure 16). It was recorded that CKL and CPT had the lowest scores of 14, while CPP and CNL had the highest scores. Comparing the 2015 values with the results from 2013, it was found that the scores of all sites had increased except for two sites, CSS and CMR. All sites are still within the guidelines.

Viet Nam

In 2015, eight monitoring sites yielded 9,096 zooplankton specimens under seven phyla, eight classes, 13 orders, and 27 families. Among seven phyla, Rotifera was the most dominant phylum with 36 taxa in total, followed by the Arthropoda phylum with 13 taxa. For other phyla, the number of taxa were only one or two of each, except Protozoa phylum, which recorded seven taxa. It was recorded that seven taxa – *Copepoda* sp, *Polyarthra vulgaris, Pseudodiaptomus* sp, *Bivalvia* sp, *Brachionus calyciflorus f anuraeiformis, Hexarthra mira,* and *Polyarthra vulgaris* – were most commonly found in the eight sites.

Abundance

The average abundance of zooplankton fluctuated between the sites with the lowest abundance (112) at VCT and the highest (862) at VTT. It was observed that the abundance of zooplankton in three sites had declined while five sites showed a 2-fold increase compared to the study of 2013 (Table 8 and Figure 17). Although a decrease in abundance was observed for a small number of sites, all sites fulfilled the requirements of the healthy ecosystem guidelines.

Average richness

As shown in Table 8, a fluctuation of average richness of zooplankton between 12 and 25 can be observed. It was found that VCL and VCT had the lowest average richness, while VTT and VDP had the highest. Compared with the results from 2013, the average richness of almost all sites had increased, except VKB which remained the same. Finally, the average richness of all sites lies above the threshold value of the guidelines of a healthy ecosystem.

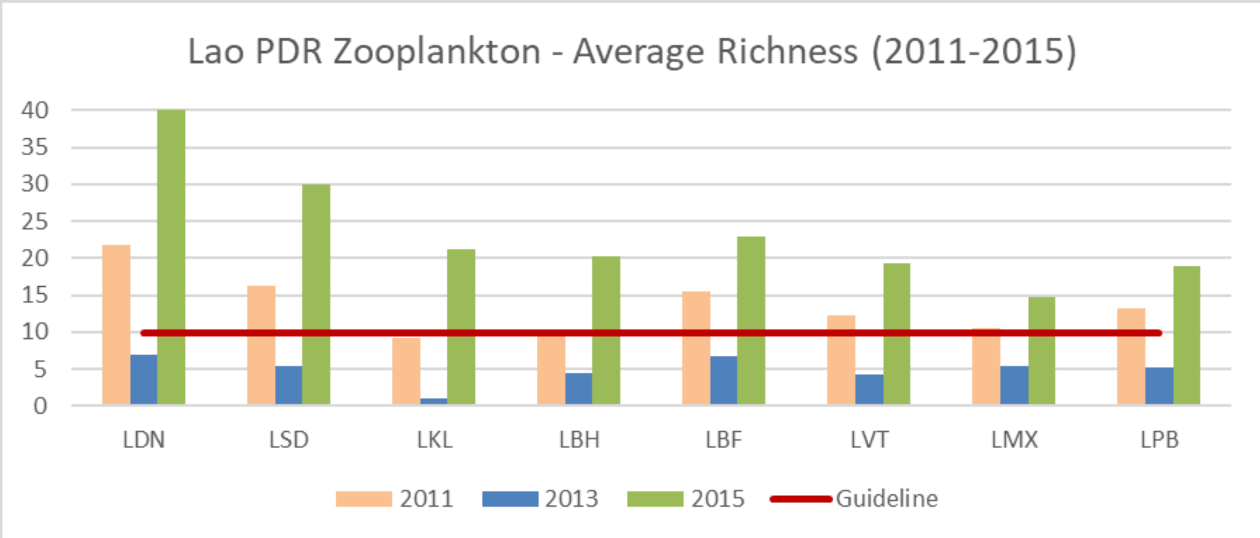
ATSPT

There was a slight change in the overall values of ATSPT between the studies in 2013 and 2015 (Table 8 and Figure 17). An increased value of ATSPT was recorded at VTP and VCT. On the other hand, the ATSPT values at VDP, VLX and VVL have declined. It was observed that the value of ATSPT at VTT, VKB and VCL was identical. Table 8 shows that all sites have failed to meet the required standards of the healthy ecosystem's guidelines since 2008.

Table 8. Values for average abundance, richness, and ATSPT for zooplankton (2007-2015)

	Abundance					Average Richness					ATSPT				
Site code	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015
LMX		47	31	11.7	58		7	13	7	20		29	47	45	47
LPB		231	42	9	90		9	16	7	25		38	39	40	43
LVT	160	17	29	8	151	10	7	14	5	26	40	41	42	42	43
LBF	222	508	56	10	178	17	20	21	9	31	39	41	43	42	43
LBH	473	19	27	17	82	16	6	12	6	27	41	42	41	42	43
LSD	1,408	278	102	30	161	26	16	22	7	40	44	40	41	44	43
LKL	17	219	40	5	86	10	8	12	1	28	39	40	41	41	42
LDN	194	1,707	145	14	229	21	40	28	9	53	40	41	38	42	44
TCS		15	0	5	4		3	0	3	3.3		40	-	39	42.2
TKO		27	3	53	6		3	2	8	2		38	32	39	44.9
TSM	2,586	328	1	53	3	19	8	1	13	1.3	43	40	43	38	43
TNP		60	1	110	9		7	1	18	3		40	50	38	40.5
TNK	473	200	0	516	18	25	6	0	35	6	43	40	-	37	36.5
TUN		300	116	1,357	171		7	6	23	14.7		40	48	38	39.9
TMU		77	10	803	166		11	5	26	13		39	54	38	38
TKC		115	1	116	3		7	1	16	2.3		39	33	38	41.8
CMR	35		56	14	27	12		3	8	8	38			33	40
CKM	35		100	7	269	14		5	2	19	39			20	40
CUS	113		55	35	25	28		3	12	11	39			35	39
CSS			41	12	7			3	6	4				37	33
CSP	62		57	11	67	15		4	8	16	42			38	39
CSJ	52		66	20	26	17		3	9	10	38			39	39
CKT			58	63	20			4	7	10				38	40
CPT			4,362	4	49			8	1	2				42	44
CCK			312	29	56			8	3	15				12	42
CKL			1,586	26	339			7	5	11				34	14
CSN			554	39	212			15	7	17				35	42
CSK			156	729	171			7	52	27				39	42
CTU			83	286	372			3	11	11				37	41
CPP			201	21	1,289			4	5	27				49	45
CPS			252	24	558			9	7	25				41	43
CNL			3,216	357	151			18	12	23				47	45
CKK			1,473	273	317			6	3	15				56	44
VTP		16	72	19	613		6	10	8	20		49	44	44.2	46.1
VTT		35	329	13	862		5	15	7	25		47	45	45	45.1
VKB		1,115	56	490	439		13	11	21	21		50	46	45	45.9
VDP		32	18	61	471		5	11	9	25		47	46	46	45
VCL		11	33	40	126		5	6	9	12		49	47	45	45.4
VLX		39	8	47	282		9	5	12	20		51	46	49	46.4
VVL		7	6	215	127		5	2	11	14		54	45	48	46.6
VCT		47	129	250	112		7	10	11	12		52	47	46	47.4

Figure 14. Average abundance, richness, and ATSPT for zooplankton in Lao PDR (2011-2015)



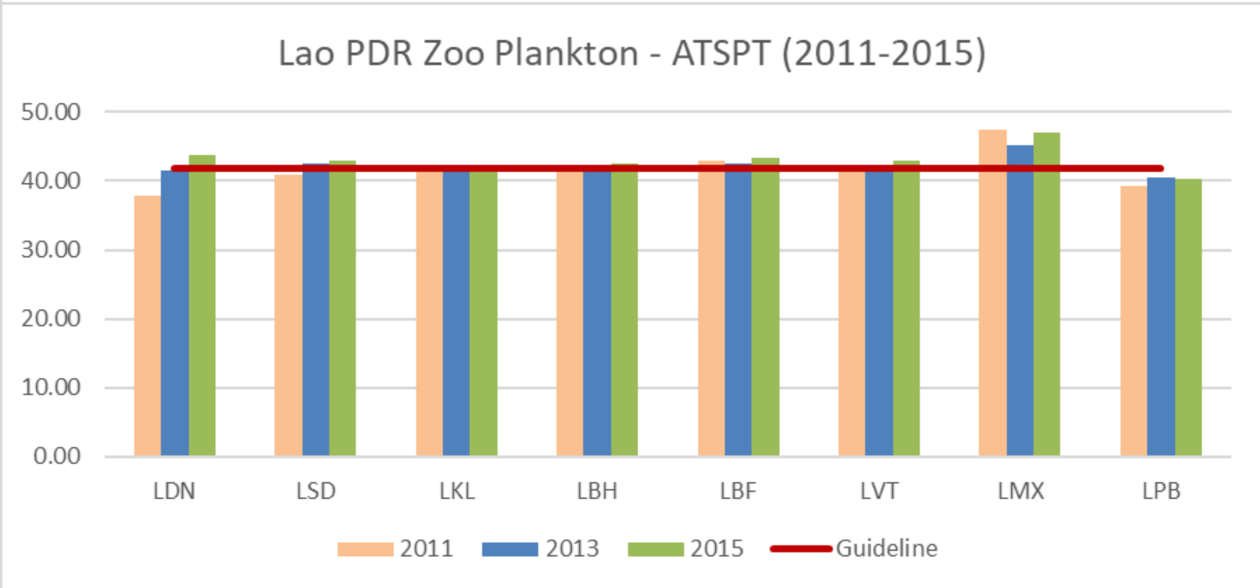
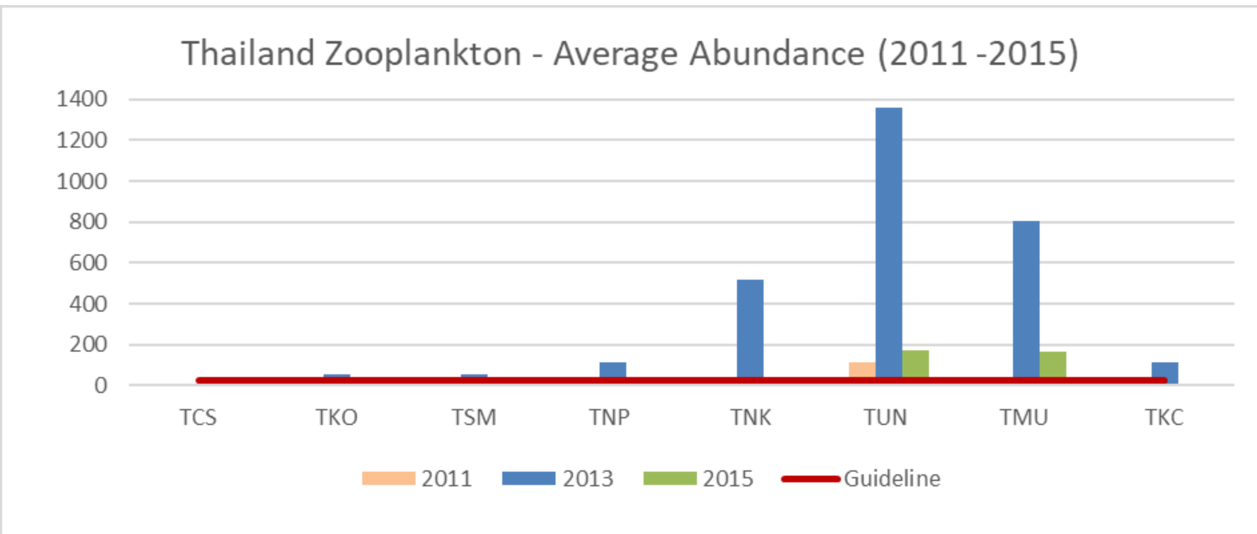
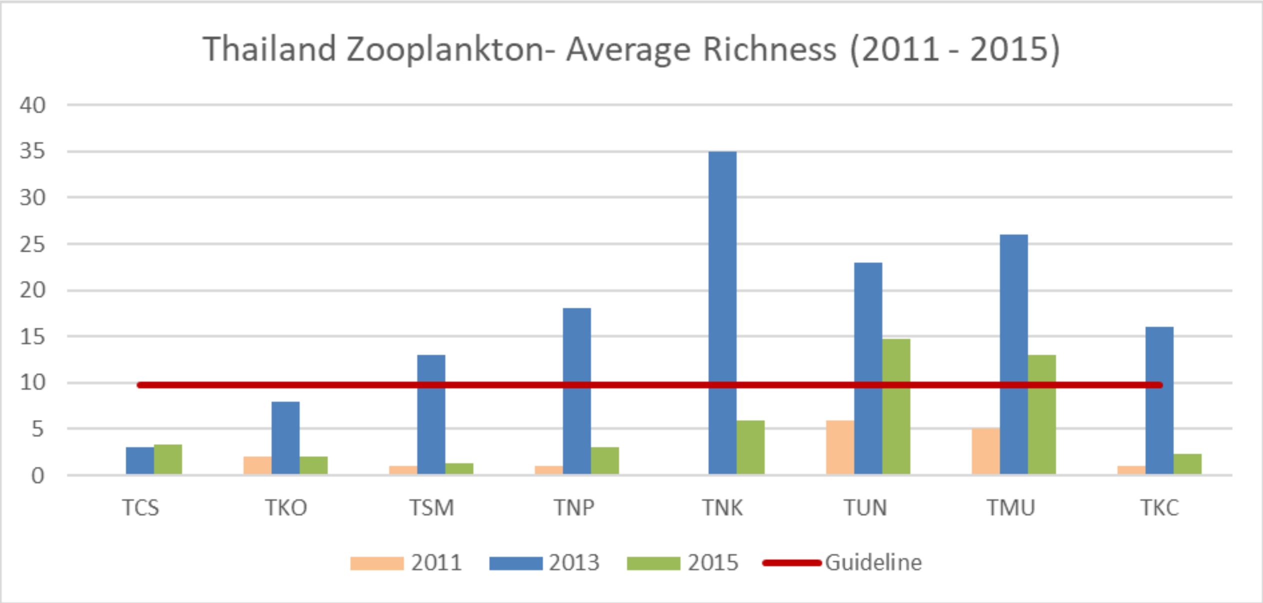


Figure 15. Average abundance, richness, and ATSPT for zooplankton in Thailand (2011-2015)





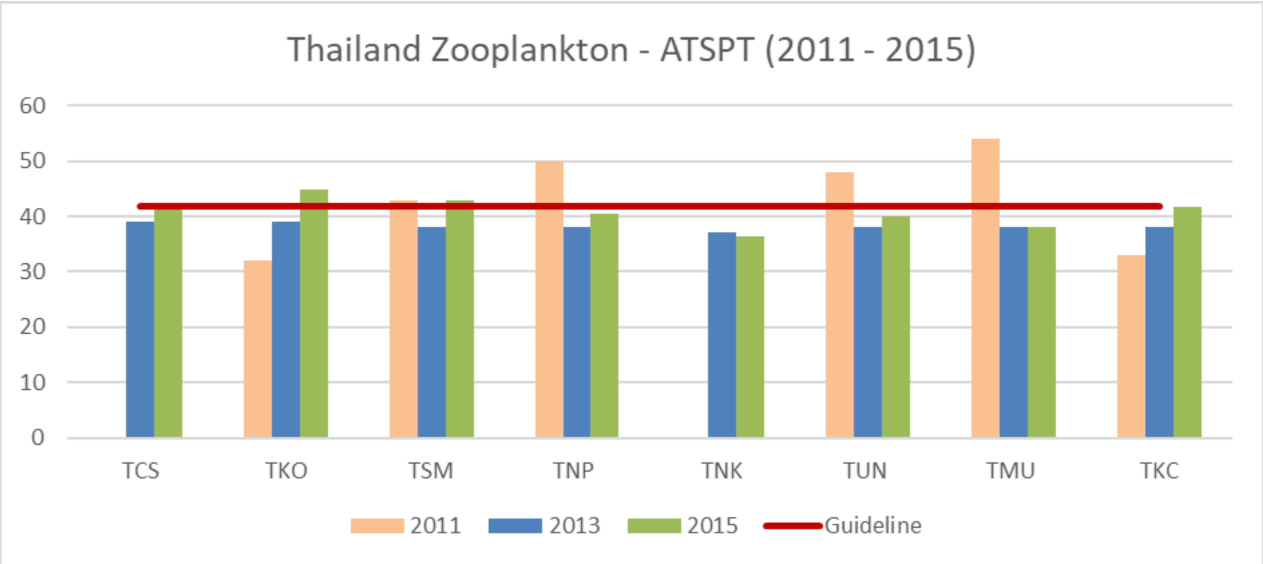
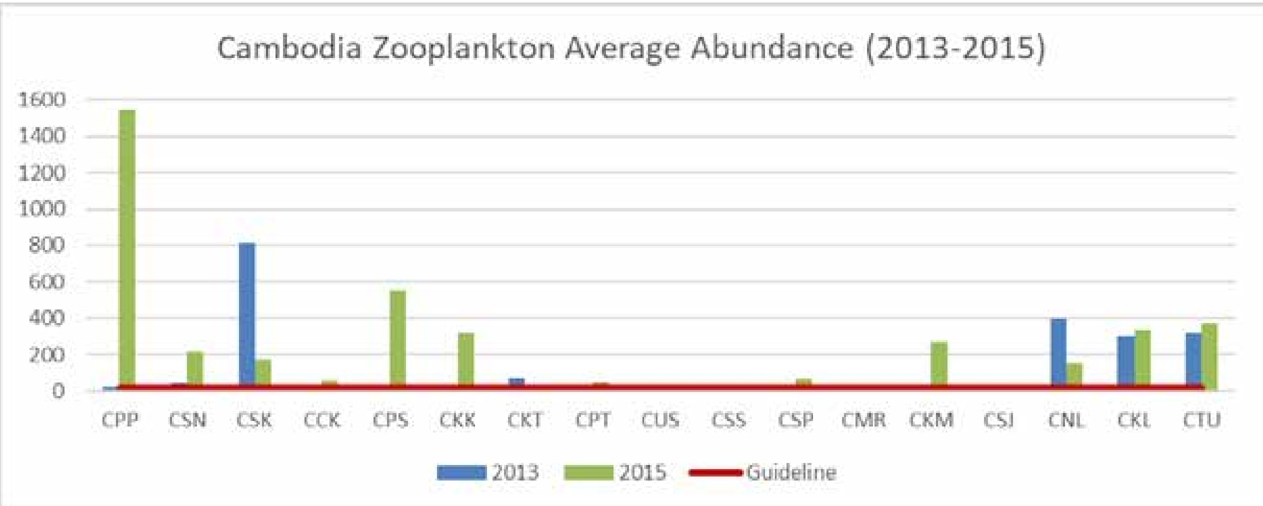
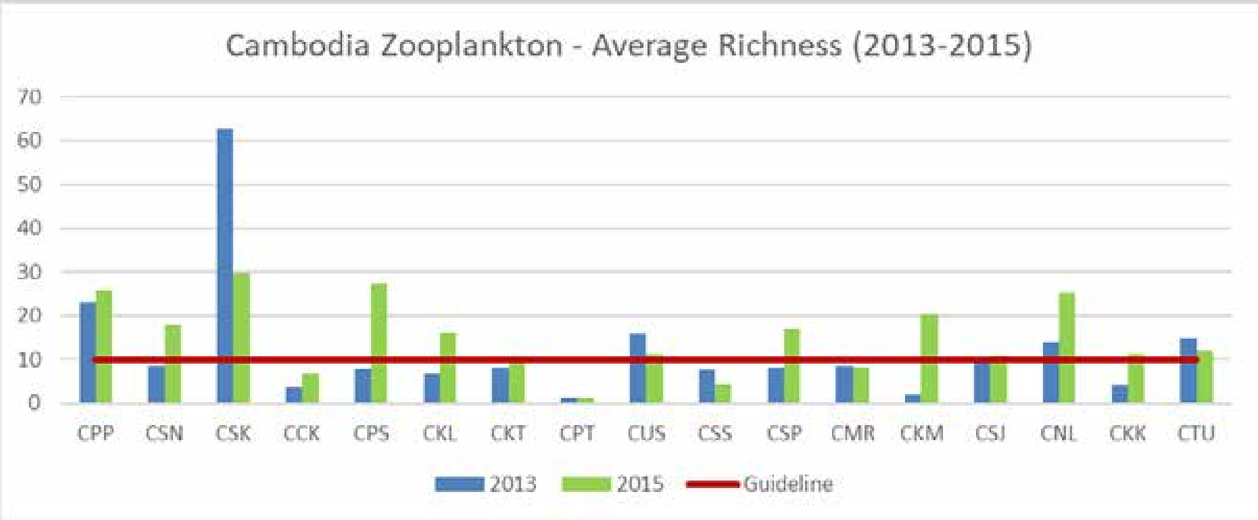


Figure 16. Average abundance, richness, and ATSPT for Zooplankton in Cambodia (2013-2015)





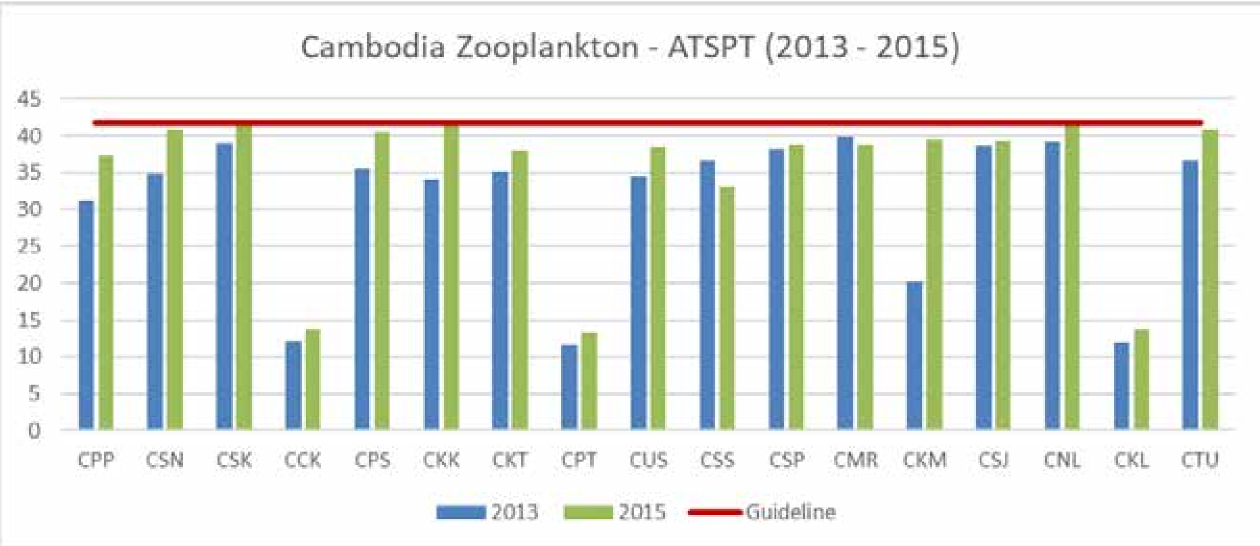
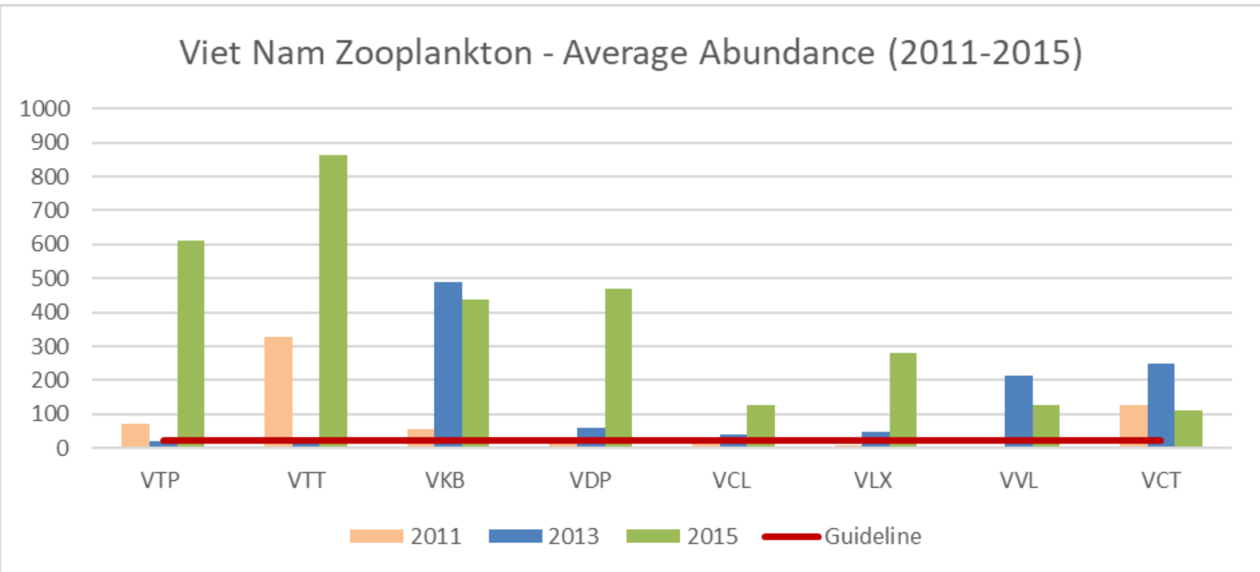
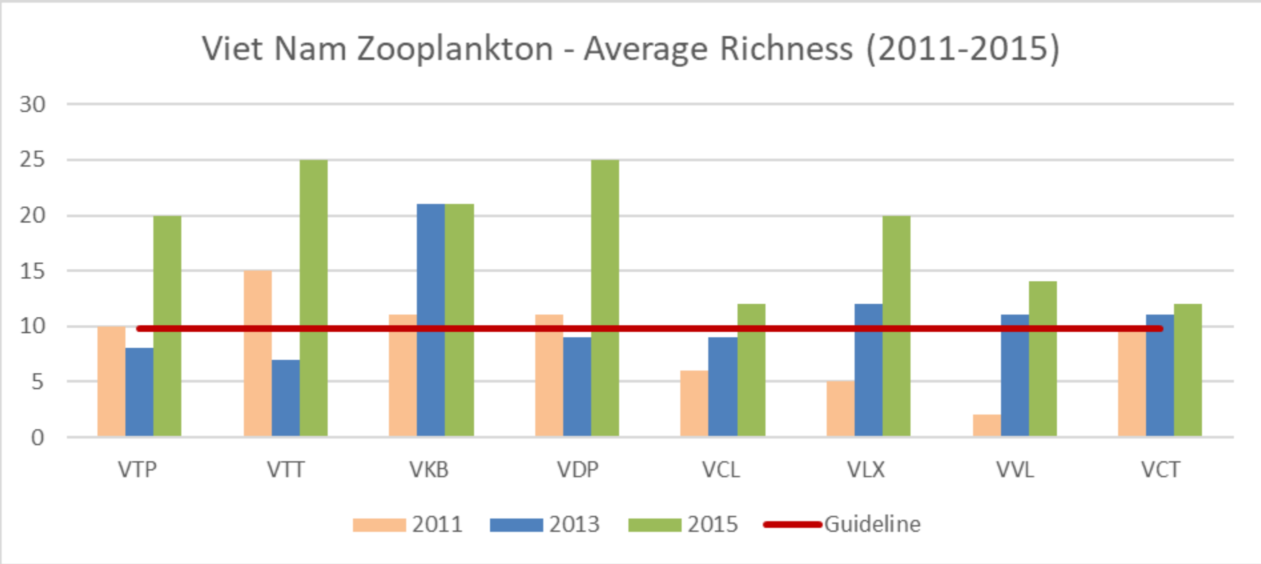
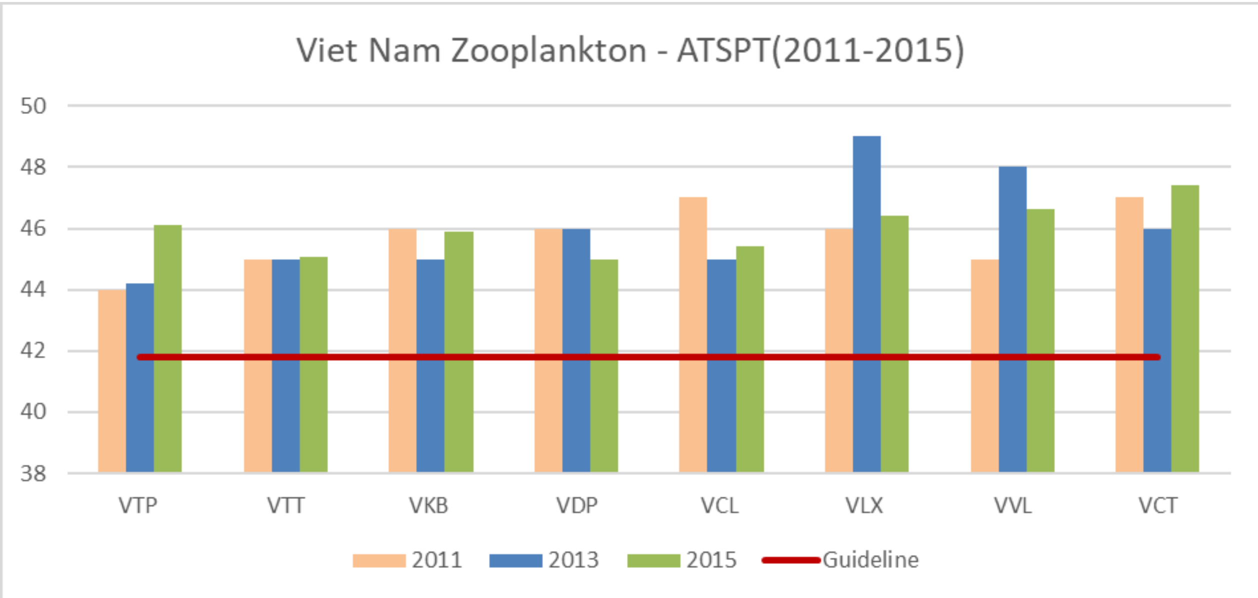


Figure 17. Average abundance, richness, and ATSPT for Zooplankton in Viet Nam (2011 -2015)




Viet Nam Zooplankton - Average Richness (2011-2015)
30
25
20
15
10
5
0
VTP
VTT
VKB
VDP
VCL
VLX
VVL
VCT
2011
2013
2015
Guideline


Viet Nam Zooplankton - ATSPT(2011-2015)
50
48
46
44
42
40
38
VTP
VTT
VKB
VDP
VCL
VLX
VVL
VCT
2011
2013
2015
Guideline

3.4 LITTORAL MACROINVERTEBRATES

Lao PDR

The 2,890 individual specimens collected at the eight sites in Lao PDR contained 111 taxa of littoral macroinvertebrates. In terms of biodiversity, the highest number of taxa were of the insect orders Ephemeroptera, Hemiptera and Diptera. The *Baetis* sp (Ehemeroptera) was the dominant species and found in abundance at almost all sites.

Abundance

Similar to the study in 2013, the most dominant species present at the sites was a swimming mayfly (*Baetis* sp) with 373 individuals, followed by *Kiefferulus* sp and *Caridina* sp with 288 and 243 individuals, respectively. For the average abundance of littoral macroinvertebrates, it ranged from 11 to 60 individuals (Table 9 and Figure 18). The lowest value was found at LBF and the highest at LKL. It was observed that the average abundance at all sites had increased compared to 2013 with the only exception being LMX, which showed a slight decrease of 2. For the sites showing an upward trend, it was found that the abundance for sites LPB, LKL and LDN had doubled since 2013. Regardless of the observed increase, only two sites (LKL and LDN) were able to meet the requirements given by the healthy ecosystem guidelines.

Average richness

A large variability in average richness was observed between the sites. The highest richness occurred at LDN and the lowest was found at LBH (Table 9 and Figure 18). Noticeably, the average richness of all sites had increased in comparison with the 2013 study and all sites were higher than the threshold value outlined in the healthy ecosystem's guidelines.

ATSPT

The ATSPT for littoral macroinvertebrates ranged from 38 at LBF to 50 at LMX (Table 9 and Figure 18). In comparison to the 2013 study, the ATSPT increased gradually at 5 out of eight sites while 3 (LPB, LSD and LBF) showed a slight decrease. Regardless, it was found that no site met the healthy ecosystem guidelines' standard as the evaluated scores were higher than the threshold value of 33.58.

Thailand

In 2015, the team collected a total of 173 species with an estimate of 15,041 individuals of littoral macroinvertebrates from the eight sites. It was noticed that the *Caridina sp.* had the highest occurrence (3,396 individuals) followed by *Melanoides* sp. (2,232 individuals) and *Stenothyra* sp. (1,949 individuals). Other species such as *Caenodes* sp., *Micronecta* sp, and *Polypedilum* sp were found at all sites.

Abundance

The average abundance ranged from 7 to 662 individuals (Table 9 and Figure 19). The highest abundance was measured at site TUN, while the lowest abundance was found on the Mekong River at Chiang San (TCS). At site TCS, the observed abundance of littoral macroinvertebrates was even lower than in 2013. This may have been due to the high water velocity and turbidity while sampling. However, the overall abundance in the 2015 study slightly increased compared to the previous study. Only TCS failed to meet the required standard of the healthy ecosystem guidelines.

Average richness

Species average richness ranged from 4 to 23 within the 2015 sampling sites (Table 9 and Figure 19). The highest richness occurred at site TNK, while the lowest value was obtained for TCS. However, the status of TCS remained stable compared to the 2013 study. It was observed that the average richness of all other sites increased compared to 2013. During the 2015 monitoring, only TCS failed to fulfill requirements set by the healthy ecosystem guidelines.

ATSPT

From the 2015 study, the ATSPT ranged from 31.7 to 43.2 (Table 9 and Figure 19). The highest ATSPT score was calculated for TCS at 43.2 and the lowest for TUN at 31.7. Comparing the results with the 2013 study it was found that only two sites showed an improving trend (lower ATSPT in 2015), suggesting a continuously declining ecological health status. Among the eight sites, only three met the standards of the healthy ecosystem guidelines.

Cambodia

The result of the study in 2015 showed that 58,317 individuals of the littoral macroinvertebrates were collected from the 17 sites. These consisted of 644 species, which was twice the observed amount during the study in 2013. The most common species observed was *Macrobrachium lanchesteri*.

Abundance

A wide range of average abundance values was calculated for littoral macroinvertebrates in Cambodia, and it was observed that for most sites the obtained values were significantly higher compared to the values from the previous studies in 2013 and 2011. The highest value was found at CCK (2,359) and the lowest at CPP (9). Ten sites showed an increase in average abundance compared to the study in 2013. As can be seen in Table 9, a 20-fold increase was observed at sites CCK and CKK compared to previous periods. It needs to be noted that at CCK a large number of *Micronecta* sp. were present at this site, which has biased the result. Although the calculated average abundance of many sites increased, only 10 sites complied with the healthy ecosystem guidelines.

Average richness

The average richness of littoral macroinvertebrates ranged from 4 to 20 species per site (Table 9 and Figure 20). The highest number of species was found at CCK and the lowest species richness was found at both CSJ and CPP. Comparing these values with the values from the previous study in 2013, it was found that the richness of seven sites has decreased, while nine sites showed an increase. One site (CUS) showed the same average richness as in 2013. On the other hand, among the 17 sites, four sites lay below the threshold value of the guidelines during this monitoring period .

ATSPT

The ATSPT for littoral macroinvertebrates of the 17 sites varied between 10 and 45 (Table 9 and Figure 20). The result showed that ATSPT of 12 sites increased compared to 2013. The lowest value was obtained at CPS and the highest at CTU. Overall, the ATSPT values for the sites located at the upper part of the Mekong (Cambodia only) were significantly smaller than those at the sites located in the lower part of the river. It was found that no sites complied with the healthy ecosystem guidelines, with the exception of CPS.

Viet Nam

In 2015, the survey at eight sites yielded 76 taxa and 18,507 individuals of littoral macroinvertebrates, which was higher than that in 2013 (3,967 individuals). The team discovered 16 new taxa including: (i) *Limnodrilus grandisettosus* belonging to the Annelida phylum; **(**ii**)** *Corallanidae larva, Cyathura truncata,* Dolichopodidae larva, Ephydridae larva, *Ictinogomphus* sp, *Kamaka* sp, *Pseudagrion* sp, *Siamthelphusa beauvoisi,* and *Tanaididae larva* belonging to the Arthropoda phylum; and (iii) *Corbicula blandiana, Hyriopsis **(**Limnoscapha**)** desowitzi, Gyraulus* sp, *Rehderiella parva, Stenothyra koratensis* belonging to the Mollusca phylum. Of the 76 taxa, *Chironomus* sp, *Clea helena, Corbicula baudoni,* and *Corbicula* sp were the most predominant species at all sites from the upper to the lower parts of the river.

Abundance

The average abundance fluctuated across the sites ranging from 12 to 811 individuals (Table 9). Overall, it was observed that the abundance of all sites was significantly higher than in 2013. VTT was found to have the highest average abundance, while VTP had the lowest. As can be seen from Table 9, for seven sites the abundance increased compared to the previous study in 2013. Particularly, sites VTT and VKB showed a significant increase in abundance. Despite the upward trend of almost all sites, only half could meet the threshold value of the healthy ecosystem guidelines (Figure 21).

Average richness

Table 9 shows the values for the average richness of littoral macroinvertebrates at the eight sites. The highest richness was observed at VKB (13 species) and the lowest at VTP (2 species). In comparison with the study in 2013, the richness increased at five sites and only one site, VTP, could not meet the healthy ecosystem guidelines.

ATSPT

Unlike the study in 2013, ATSPT scores showed a narrow range from 42 to 49 with the lowest scores at VTP and VTT, and the highest at VLX and VVL. It was found that four sites showed a decreased ATSPT score compared to the values obtained from the monitoring period in 2013. Nevertheless, the overall status was poor as no site met the required standards set by the guidelines.

Table 9. Values of average abundance, richness, and ATSPT for littoral macroinvertebrates (2007–2015)

Site code	Abundance					Average richness					ATSPT				
	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015
LMX		24	8	48	46		5	4	4	5		40	46	44	50
LPB		23	48	20	45		8	7	6	7		35	40	40	39
LVT	122	34	103	13	22	8	8	11	3	5	34	35	42	42	42
LBF	254	795	90	12	11	16	15	6	3	5	35	37	42	45	38
LBH	73	35	532	8	13	8	7	19	4	4	36	35	41	45	43
LSD	50	83	225	27	38	11	10	10	5	9	37	39	44	43	42
LKL	35	11	202	25	60	13	5	14	6	9	33	34	41	41	42
LDN	340	369	402	32	55	14	12	13	3	11	33	35	44	38	43
TCS		21	93	2	7		5	9	1	4		29	35	32	43.2
TKO		54	63	16	83		13	13	4	18		29	35	35	35.1
TSM	24	52	111	23	57	6	6	13	7	7	38	32	29	37	41.9
TNP		8	209	134	96		5	16	10	12		34	32	37	40.3
TNK	23	24	74	1,024	430	6	7	14	16	23	38	34	29	36	34.4
TUN		107	371	360	662		7	14	18	22		33	32	35	31.7
TMU		21	213	11,523	91		6	16	11	10		33	35	36	40.6
TKC		22	522	28	78		6	16	4	9		33	34	38	40.2
CMR	311	587	309	373	65	8	4	9	5	14	34	27		40	36
CKM	33	56	107	12	40	9	5	15	6	9	34	29		30	36
CUS	10	83	24	25	52	3	4	7	9	10	34	32		30	39
CSS			68	13	62			21	5	18				38	40
CSP	136	22	36	38	212	17	3	12	10	19	31	13		35	43
CSJ	88	128	22	10	62	14	6	9	6	5	32	37		39	34
CKT		105	133	26	59		6	10	5	10		27		30	39
CPT			43	17	47			11	3	12				34	34
CCK			15	107	2,359			7	9	20				34	32
CKL			24	85	28			8	17	6				30	44
CSN			28	77	22			10	12	8				28	40
CSK			26	40	17			4	12	5				35	37
CTU			57	52	34			11	14	8				41	45
CPP			20	56	9			6	13	4				31	37
CPS			17	39	24			7	7	5				22	10
CNL		299	9	2	627		5	3	2	18		31		22	39
CKK		17	111	124	2,114		3	20	16	14		38		32	38
VTP		7	7	48	12		3	2	8.4	2		50	33	46	42
VTT		546	243	192	811		5	7	17.8	8		52	46	46	42
VKB		37	117	30	769		8	11	7.2	13		52	39	45	46
VDP		15	106	11	33		7	13	4	8		53	42	46	46
VCL		49	961	93	110		13	9.4	8.3	7		58	45	46	44
VLX		51	19	5	40		14	5.1	3.5	12		54	43	49	49
VVL		173	83	12	22		12	11	4.3	6		56	45	49	49
VCT		95	37	6	54		11	7.6	3	9		55	42	51	45

Figure 18. Average abundance, richness, and ATSPT for littoral macroinvertebrates in Lao PDR (2011-2015)

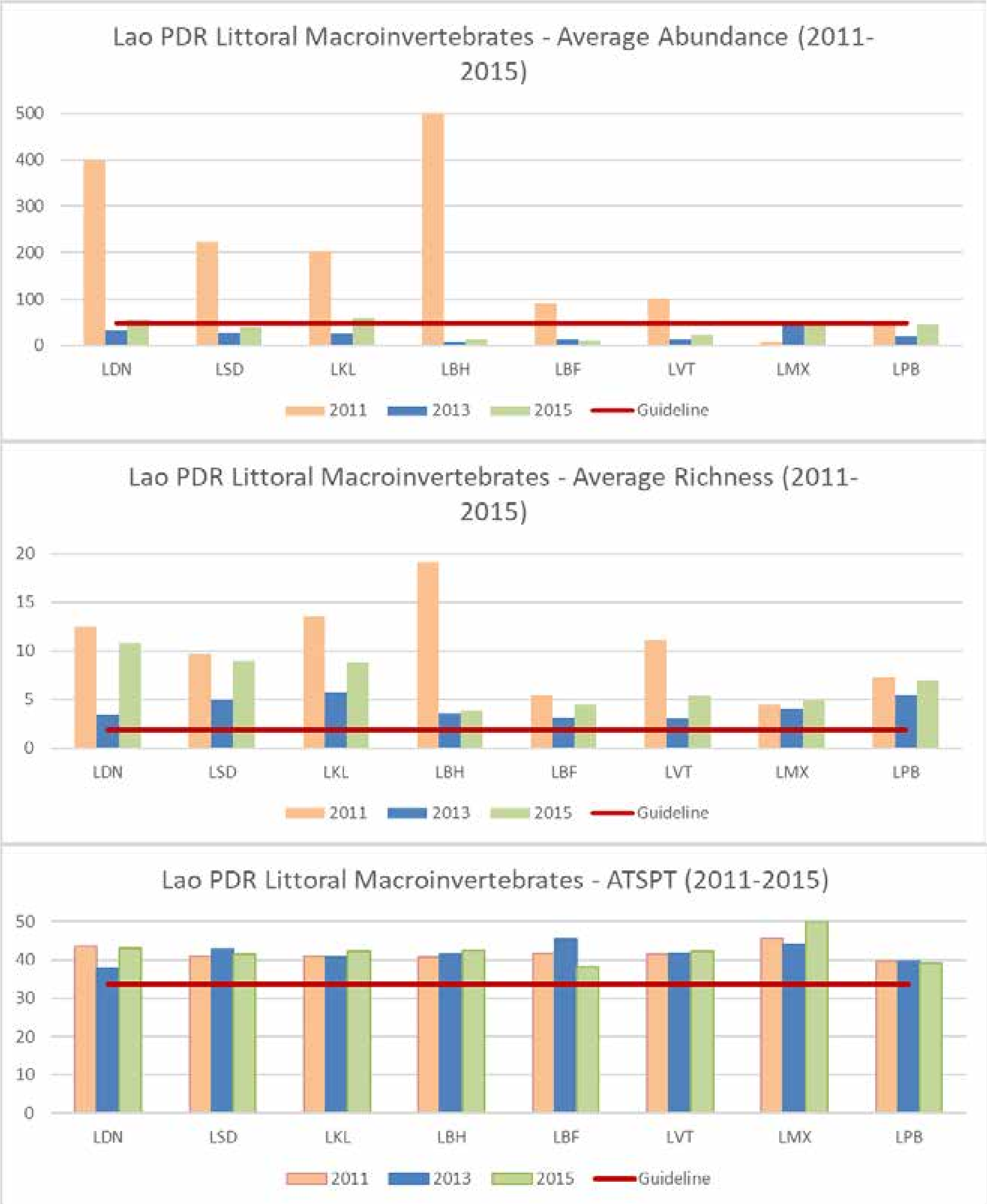


Figure 19. Average abundance, richness, and ATSPT for littoral macroinvertebrates in Thailand (2011–2015)

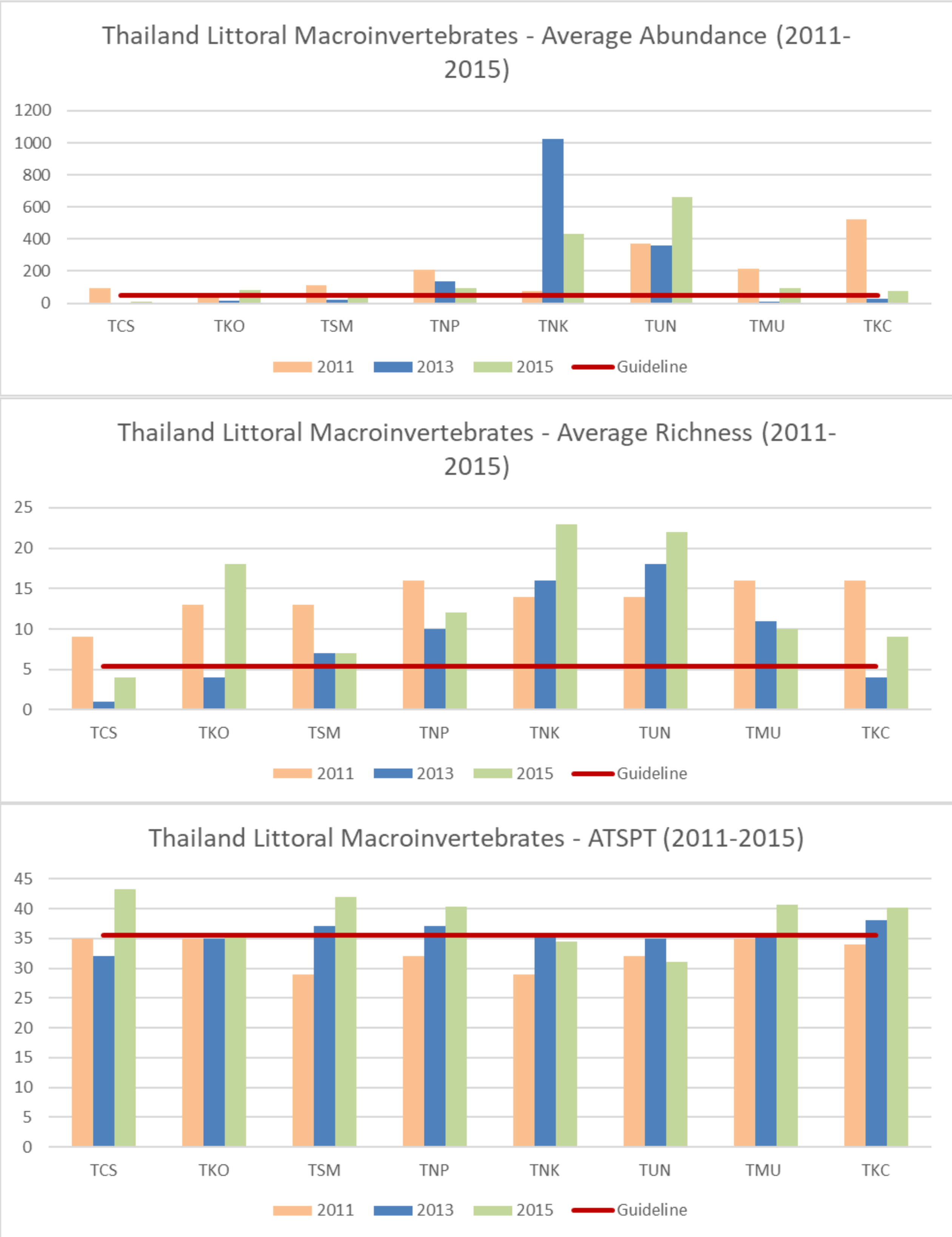


Figure 20. Average abundance, average richness, and ATSPT for littoral macroinvertebrates in Cambodia (2013-2015)

Note: the arrow at sites CCK and CKT indicate the actual number of individuals found at that site. Due to better visualization and comparison, the y-axis was adjusted.

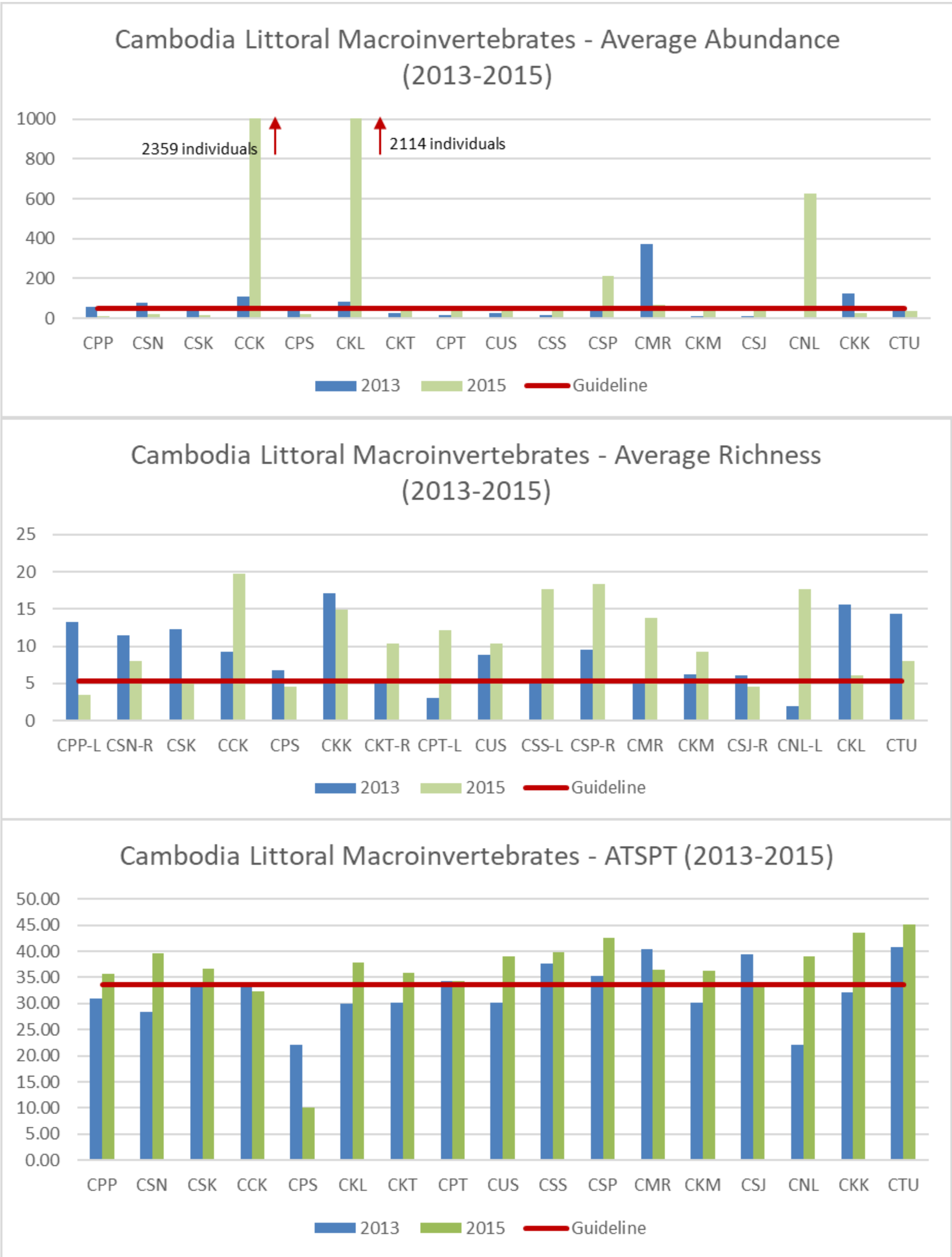
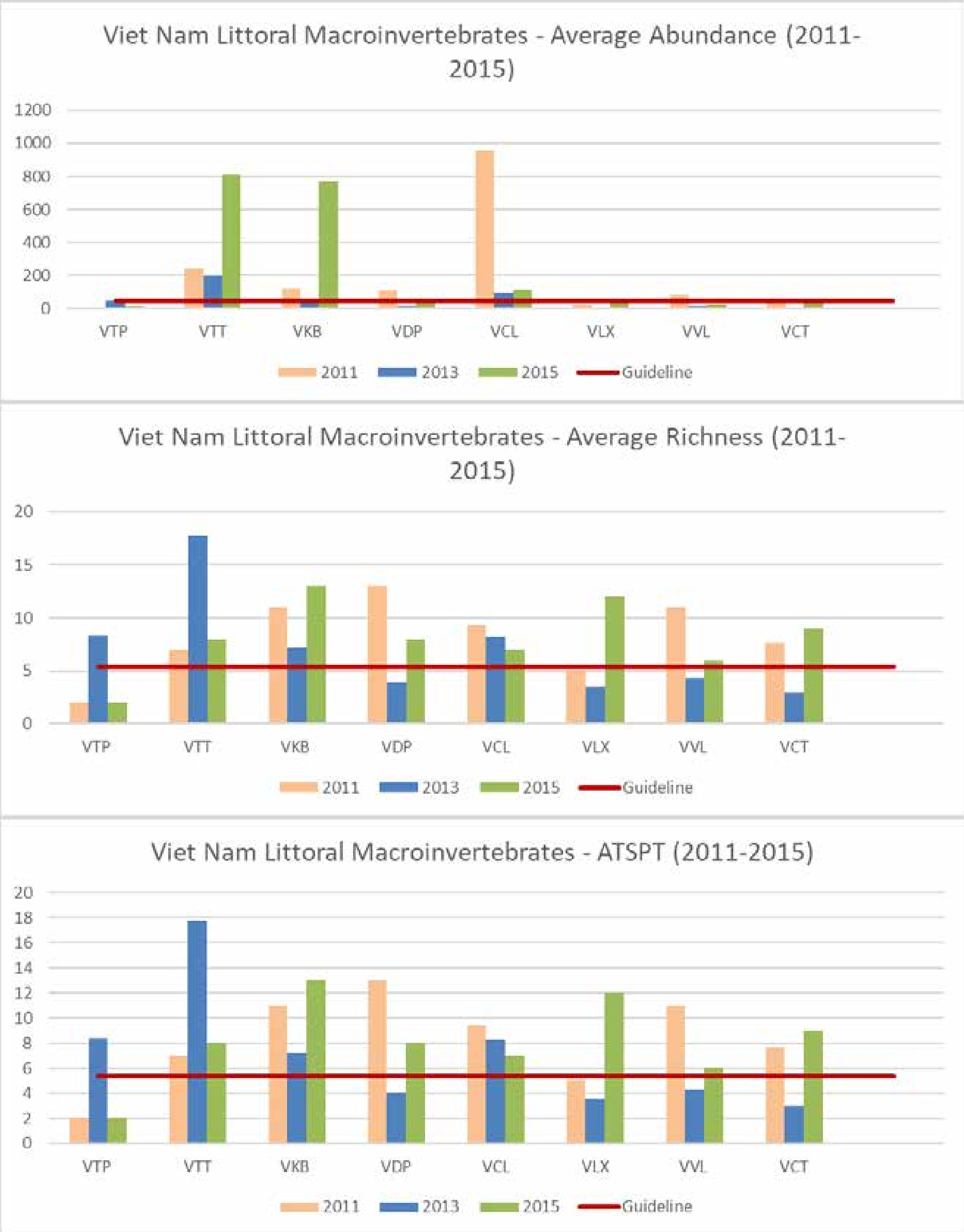


Figure 21. Average abundance, average richness, and ATSPT for littoral macroinvertebrates in Viet Nam (2011-2015)



3.5 BENTHIC MACROINVERTEBRATES

Lao PDR

In 2015, a total of 1,025 individual specimens of benthic macroinvertebrates belonging to 96 taxa were collected from eight sites. The insect order of Diptera and Oligochaeta were most predominant, with particular families being present at all sites, such as Ceratopogonidae and Chironomidae.

Abundance

The number of individuals per site was highly variable, ranging from 92 individuals at LMX to 151 individuals at LDN. The average abundance of benthic macroinvertebrates ranges from 8 to 14 individuals per sample (a square metre). The highest abundance occurred at LKL and the lowest at LMX (Table 10 and Figure 22). In 2015, the number of individuals increased at 6 out of 8 sites in comparison with the study conducted in 2013, which could be related to the fact that field sampling was done in the dry season. Finally, all sites lay above the threshold value set by the guidelines of a healthy ecosystem.

Average richness

The average richness among the eight sites ranged from 3 to 5 taxa per sample (Table 10 and Figure 22). The highest average richness was found at LSD, while the lowest were calculated for sites LMX and LBH. If comparing those with the values obtained from the study in 2013, it can be noticed that only one site (LMX) showed a decrease in average richness while all others showed an increase. Similar to the values for the average abundance, all sites' average richness complied with the healthy ecosystem guidelines.

ATSPT

The ATSPT for benthic macroinvertebrates ranged from 39 to 44 with the highest found for LDN and the lowest for LPB. Four sites showed a decreased value compared to the study in 2013 but were still above the guidelines of a healthy ecosystem (Table 10 and Figure 22).

Thailand

The eight sites sampled in 2015 yielded a total of 109 species of benthic macroinvertebrates out of the 6,368 individuals collected. *Anagenisia* sp. were the most abundant with 1,151 individuals. *Melanoides* sp., *Stenothyra* sp., *Polypedilum* sp., and *Corbicula* sp. were commonly present at all sites.

Abundance

The study on benthic macroinvertebrates of 2015 revealed an average abundance ranging from 65 to 545 individuals (Table 10 and Figure 23). The highest abundance occurred at site TNP (545 individuals). An explanation for that abundance could be the soft substrate comprised of mud, sand and gravel, which is suitable for this organism. On the other hand, the high turbidity of the water during sample collection could be responsible for the low abundance at site TCS. Compared to the previous monitoring period, the overall abundance of benthic macroinvertebrates significantly increased and was able to meet the healthy ecosystem guidelines.

Average richness

The study revealed that the average species richness per site ranged from 10 to 25 (Table 10 and Figure 23), which is high above the exosystem's threshold value indicating a good and healthy ecosystem. The highest average richness was evaluated at the site TKO, while the lowest was at TCS, which regardless of being the lowest was higher than the previous monitoring period. This might be because the site's substratum is made up of sand and mud and is dominated by a fast-flowing current.

ATSPT

The team found that the value of ATSPT increased for all sites compared to the study in 2013. It was observed that the highest ATSPT was at TCS (43) and the lowest at TKO (37). Unlike the average richness, only one site (TKO) could fulfil the requirements of the healthy ecosystem guidelines.

Cambodia

A total of 124 individuals of benthic macroinvertebrates were found at the 17 sites. The result showed that Chironomidae (Cricotopus) and Tubificid worms were the most common species present.

Abundance

The average abundance of the benthic macroinvertebrates in each sampling site varied between 1 and 117. Table 10 shows that the highest abundance was found in the lower part of the country. For instance, the highest abundance was found at Phnom Penh Port (CPP), while the lowest was at CKM, CUS and CSS, which are all found in the upper part of the river in Cambodia. It is noted that the average abundance of CPP was so high in 2015 predominantly due to the abundance of one species, horsehair worms. 738 individuals were found on this site. Five out of 17 sites could not comply with the healthy ecosystem guidelines. Regardless, compared to the previous study conducted in 2013, the average abundance of individuals has generally increased.

Average richness

Species richness across the 17 sampling sites ranged from 1 to 11, which is higher than was found in the previous study in 2013. It was observed that the highest richness occurred at CKL. The lowest richness was recorded at sites CUS, CKM and CSS, which likewise were the only ones not complying with the healthy ecosystem guidelines (Table 10 and Figure 24).

ATSPT

The ATSPT of benthic macroinvertebrates in 2015 ranged from 4 to 48 (Table 10 and Figure 24). The highest ATSPT was at CPP, while the lowest was at CUS. The result showed that the ATSPT of benthic macroinvertebrates was significantly lower in the upper part of the Mekong in Cambodia, compared to the downstream and Tonle Sap area. Only seven of the 17 sites were above the threshold value indicating more tolerable species within those sites. The majority of the sites, such as CPP CSN, CKK and CSK showing a higher ATSPT, are located around the Tonle Sap and Phnom Penh area. Hence, more attention should be given to those sites in the next monitoring periods.

Viet Nam

A total of 11,253 benthic macroinvertebrates were collected at eight sites falling within 39 families of eight classes and three phyla. The most predominant and most present groups were Corbiculidae (Veneroida, Bivalvia); Mytilidae (Mytiloida, Bivalvia); Chironomidae (Diptera, Insecta); and Tubificidae (Haplotaxida, Oligochaeta).

Abundance

The average abundance of benthic macroinvertebrates at the eight sites ranged from 16 to 260 individuals; the lowest value was calculated for site VCT and the highest for VKB (Table 10 and Figure 25). In comparison with the previous study in 2013, an increase in the average abundance was observed in only five sites. Still, all sites could fulfill the requirements set by the guidelines of healthy ecosystems.

Average richness

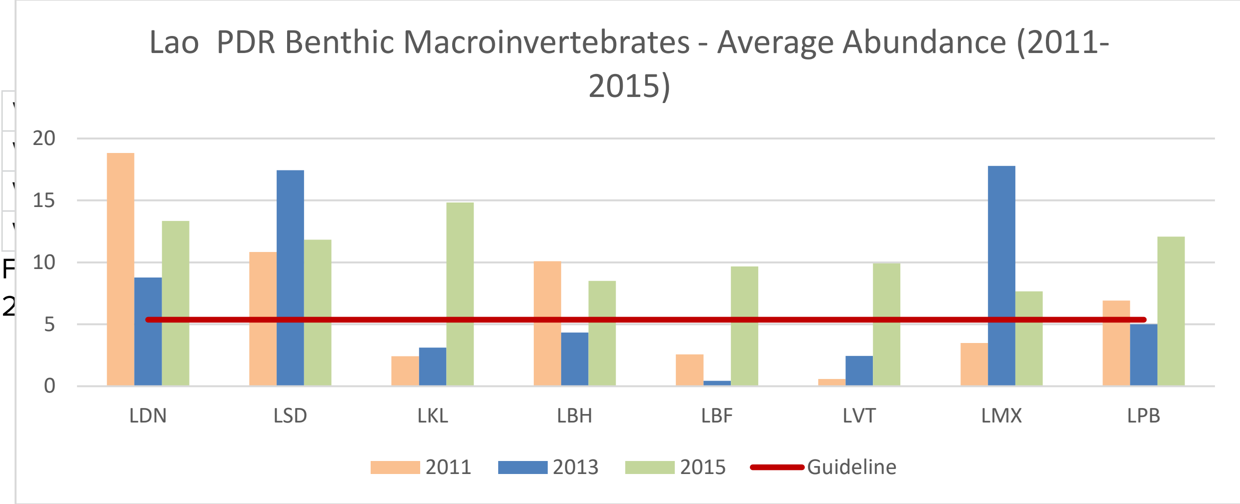
The average richness in 2015 varied between 3 and 13 with the highest average richness at VKB where the substratum was soft mud and sand. The lowest value was recorded for VVL. In comparison with the study in 2013, the richness of five sites (VTP, VTT, VKB, VDP and VCL) has increased, while the rest remained the same. Like the average abundance, all sites complied with the guidelines of the healthy ecosystem.

ATSPT

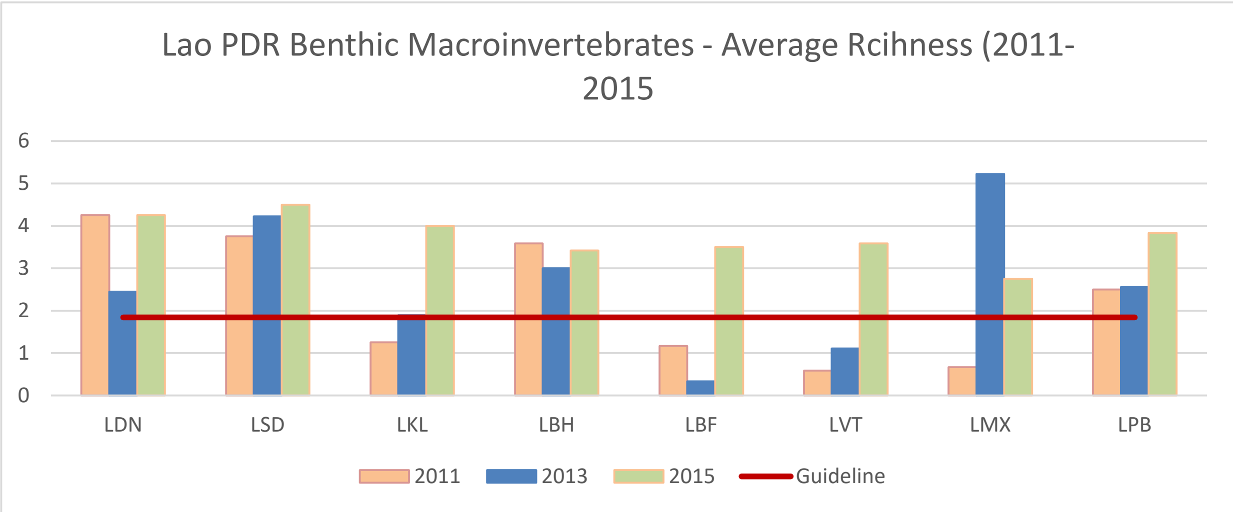
The ATSPT of the eight sites fluctuated between only 47 and 50. The highest ATSPT was found at VKB and VVL while the lowest was calculated for VTP and VTT. The team noticed that the ATSPT score of four sites (VDP, VCL and VLX and VVL) had decreased, while the other three sites (VTP, VTT and VKB) had slightly increased and one site remained the same as in the previous study in 2013. Figure 25 clearly illustrates that no site could meet the threshold value of the healthy ecosystem guidelines.

Table 10. Values for average abundance, richness, and ATSPT for benthic macroinvertebrates (2007-2015)

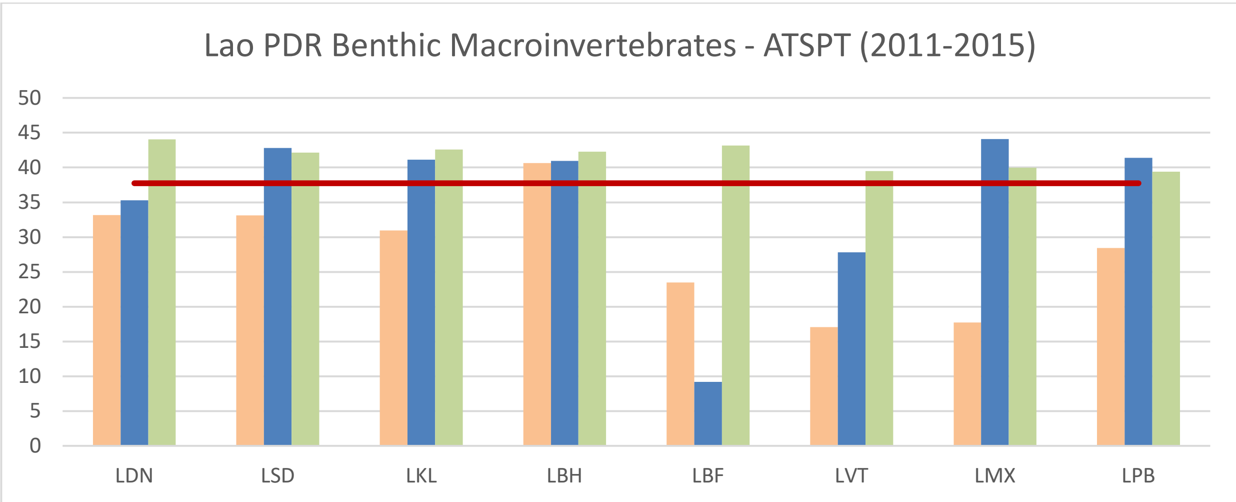
Site code	Abundance					Average richness					ATSPT				
	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015	2007	2008	2011	2013	2015
LMX		10	4	13	8		1	1	4	3		41	18	44	40
LPB		6	7	4	12		2	3	2	4		36	28	41	39
LVT	6	7	1	2	10	3	3	1	1	4	39	40	17	28	40
LBF	38	26	3	0.33	9	6	6	1	0.25	4	38	40	24	9	43
LBH	7	20	10	3	9	3	5	4	2	3	38	38	17	41	42
LSD	13	11	9	13	11	5	4	3	3	5	40	40	33	43	42
LKL	4	2	2	2	15	2	2	1	1	4	37	40	31	41	43
LDN	51	50	18	7	13	8	7	4	2	4	36	37	33	35	44
TCS		14	441	6	65		1	16	4	10		26	25	28	43
TKO		68	302	12	208		3	26	6	25		29	24	22	37
TSM	9	59	0	88	235	3	2	0	7	15	37	32	-	33	42
TNP		79	184	240	545		2	16	12	18		33	26	24	40
TNK	3	12	115	132	471	2	2	21	5	21	42	35	32	26	38
TUN		12	235	281	215		2	27	5	15		36	33	30	38
TMU		7	282	108	269		1	23	8	19	46	32	25	31	40
TKC		51	68	23	115		3	10	4	12		31	27	37	41
CMR	11	10	49	4	17	3	3	7	2	5	37	26		23	31
CKM	4	6	13	2	1	3	2	4	2	1	37	26		24	11
CUS	5	7	4	2	1	3	3	1	2	1	37	34		21	4
CSS			3	1	1			2	1	1				11	13
CSP	7	6	10	3	8	3	2	4	2	4	33	23		22	30
CSJ	5	4	4	3	3	3	2	3	2	3	36	27		31	25
CKT		11	38	7	13		3	3	2	4		31		13	27
CPT			4	1	6			2	1	2				17	15
CCK			40	15	83			5	2	8				10	43
CKL			55	35	77			12	6	11				10	43
CSN			14	2	12			4	1	4				27	41
CSK		20	21	5	11		4	4	2	4		34		31	38
CTU			62	56	21			4	5	5				28	39
CPP			13	34	117			4	6	6				30	48
CPS			7	13	5			3	4	4				29	36
CNL			53	37	26			7	7	6				46	34
CKK		11	10	58	45		3	4	7	8		39		27	43
VTP		18	47	6	127		5	6	1.6	8		50	49	44	47
VTT		47	49	13	124		9	6	4	6		54	49	48	47
VKB		145	205	65	260		8	10	8	13		55	48	47	50
VDP		108	49	25	57		11	9	7	8		56	46	49	49



Lao PDR Benthic Macroinvertebrates - Average Abundance (2011-2015)
20
15
10
5
0
LDN
LSD
LKL
LBH
LBF
LVT
LMX
LPB
2011
2013
2015
Guideline



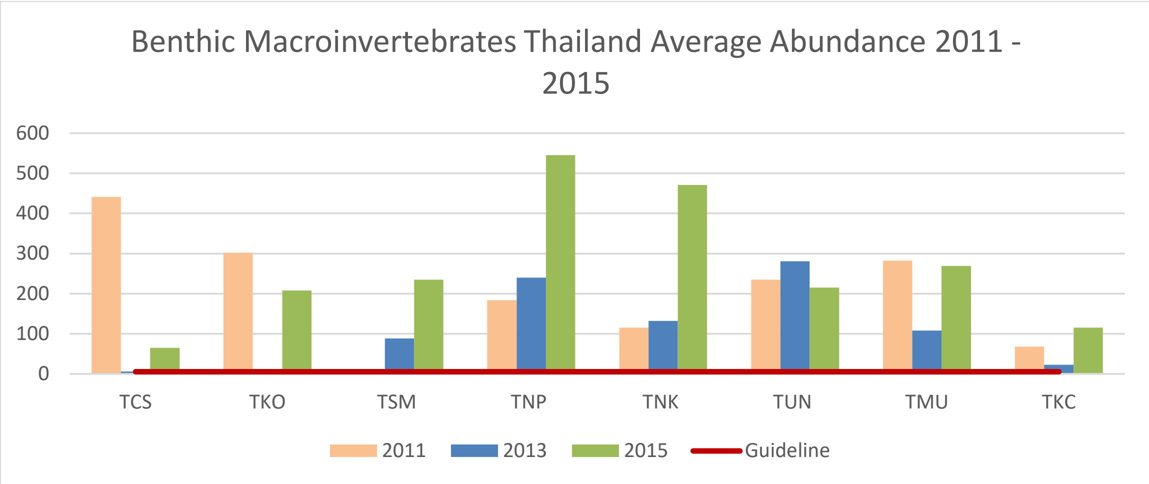
Lao PDR Benthic Macroinvertebrates - Average Rcihness (2011-2015
6
5
4
3
2
1
0
LDN
LSD
LKL
LBH
LBF
LVT
LMX
LPB
2011
2013
2015
Guideline

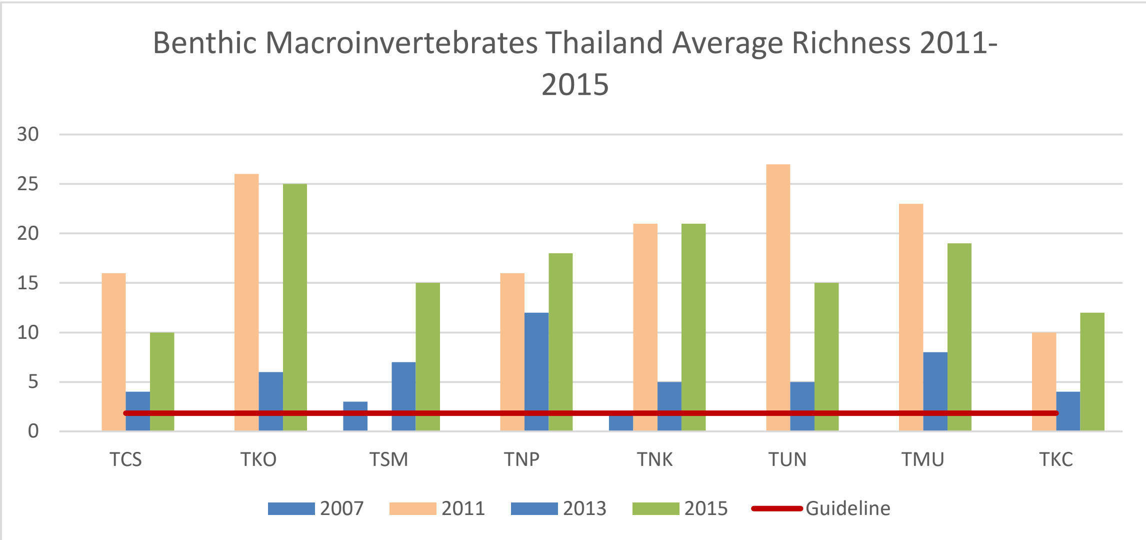


Lao PDR Benthic Macroinvertebrates - ATSPT (2011-2015)
50
45
40
35
30
25
20
15
10
5
0
LDN
LSD
LKL
LBH
LBF
LVT
LMX
LPB

Figure 23. Average abundance, average richness, and ATSPT for benthic macro invertebrates in Thailand (2011-2015)

It needs to be noted that the ATSPT calculations were not possible due to missing data. Hence the ATSPT values from 2008 were used instead





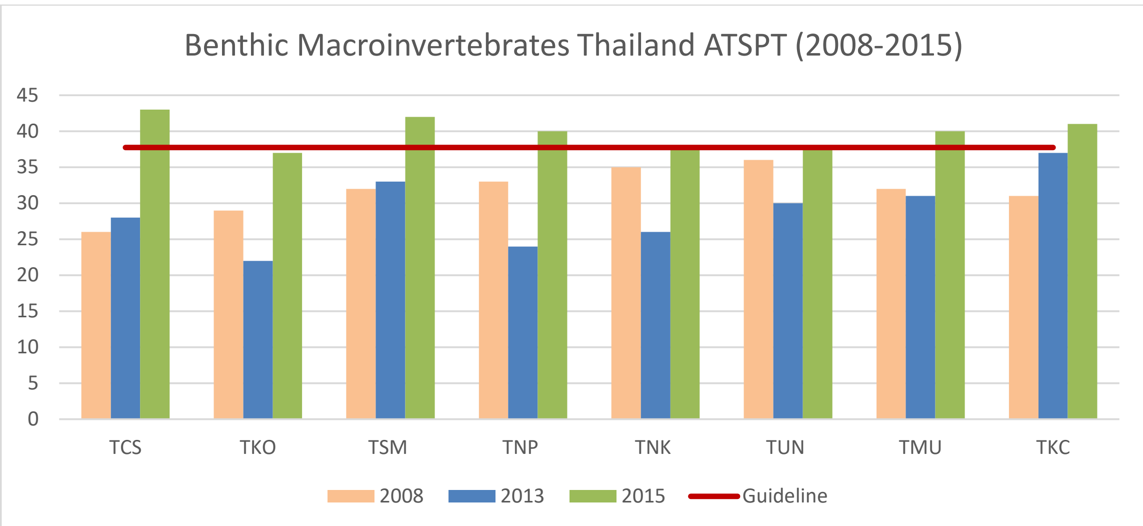


Figure 24. Average abundance, richness, and ATSPT for benthic macroinvertebrates in Cambodia (2013–2015)

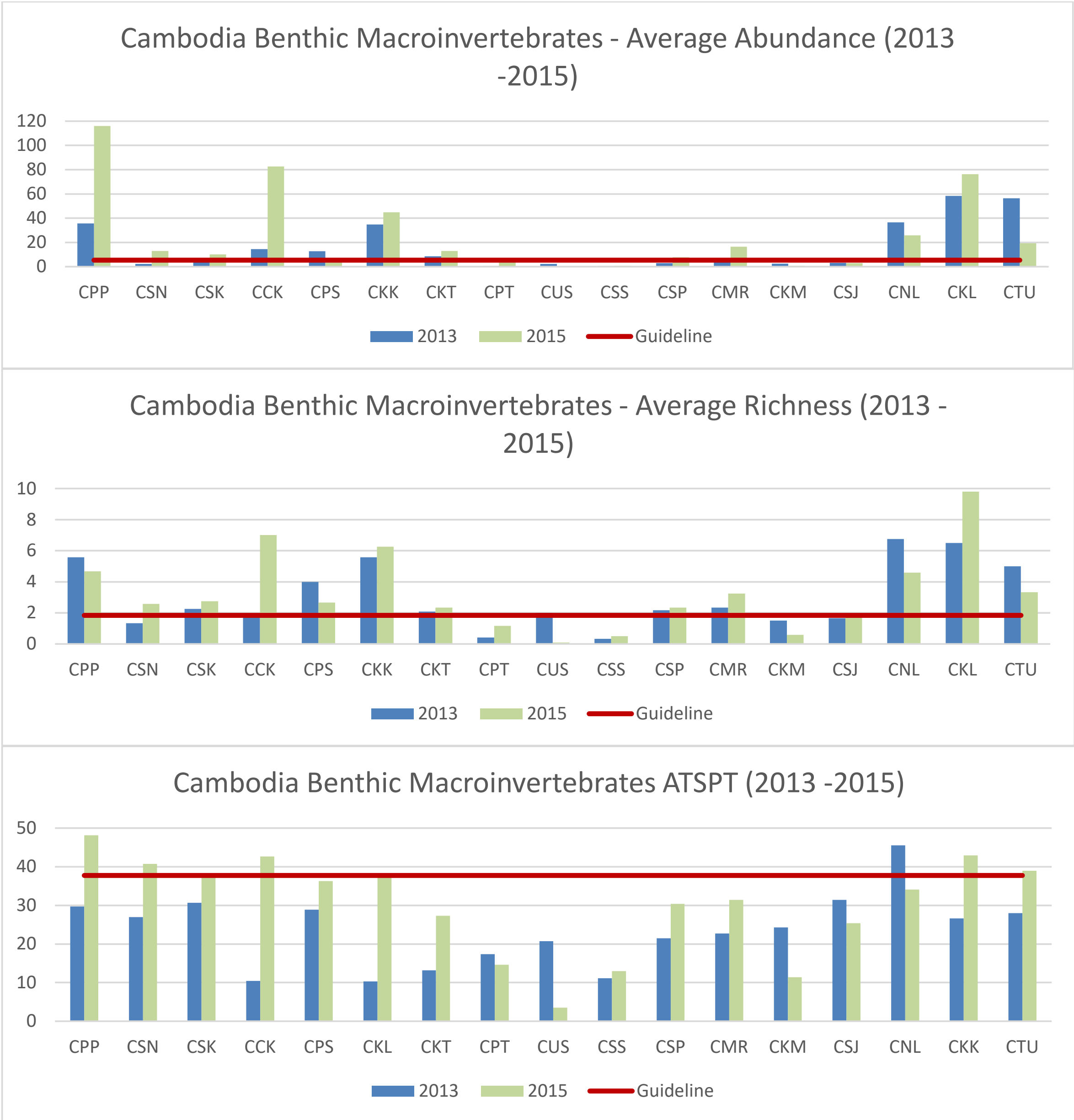
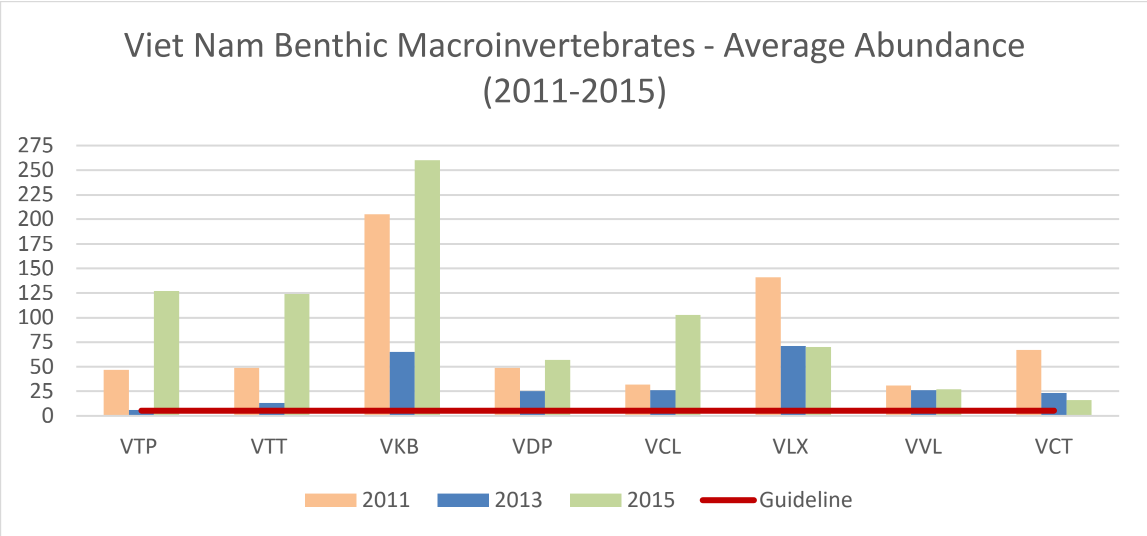
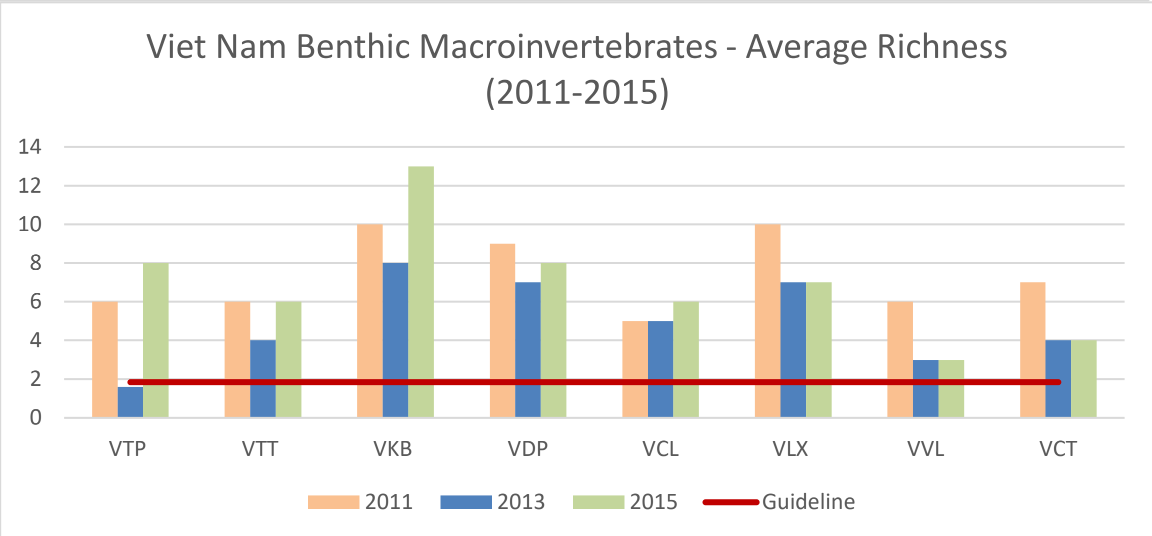
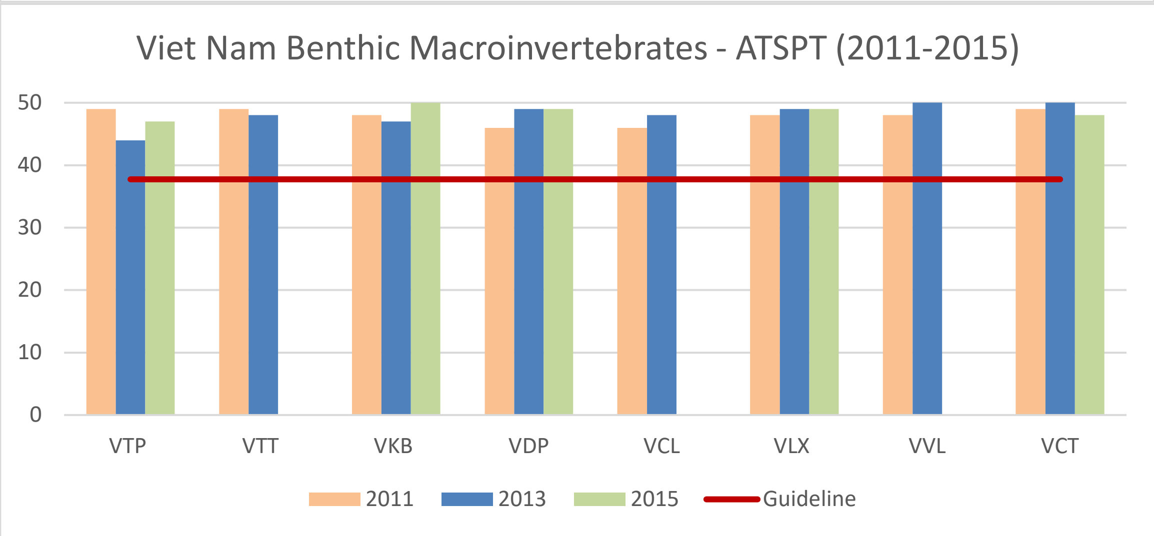


Figure 25. Average abundance, average richness, and ATSPT for benthic macroinvertebrates in Viet Nam (2011-2015)







3.6 EVALUATION OF SITES

Three biological metrics (average abundance, average richness and average tolerance score per taxon) were computed for each of the four biological groups (benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates) in order to assess the status of each site based on the scoring system described in section 2.6. The site assessment and classification for 2015 is summarised in Table 11 and figure 26, and the historical development since 2007 is summarised in Table 12.

Lao PDR

In Lao PDR, four sites were assessed as class C (LBF, LBH, LSD and LKL), and the rest as class B (Table 11 and figure 26). It was observed that four showed an improved condition from poor to good (B) (LMX, LPB, LDN and LVT). The other four sites (LBF, LSD, LKL and LBH) were assessed and showed a slight improvement from a poor to a moderate condition (C).

Thailand

Four of the eight sites were assessed and classified as class A (Excellent): TSM, TKC, TUN and TMU, and the rest as class B (Good). Four sites showed an improved condition while TCS and TKO remained unchanged. The abundance and richness increased for all biological groups except zooplankton. TCS, TKO and TNP had been continuously impacted by construction, river bank development, tourist activities, navigation and fish farming, which could be the reason why their overall condition remained unchanged. Bank erosion was found in site TNK. Also, at the sites where the EH status remained constant (TCS and TKO), there was an increase of individual metrics lying above the reference standard.

Cambodia

Of the 17 sampling sites monitored in 2015, four sites (CSP, CPS, CNL and CKK) at the upstream of Sre Pok River were classified as A (Excellent). The majority of the monitoring sites (12 sites) were classified B, and only one site was classified as class C (CSS). No sampling site was classified as D. In comparison with the study in 2013, three sites improved their condition from good to excellent, and CNL even improved from moderate to excellent. Four sites improved from a moderate to a good condition (CKM, CSJ, CPT, CSN and CPP). The rest remained unchanged.

Viet Nam

In 2015, the condition of five sites improved from class C to B giving a total of seven sites classified as Good – VKB and VCL received the same classification (class B) as in 2013. During this monitoring period, only VTP was classified as C, which is also consistent with the last monitoring period. Since 2008, the overall condition of the Mekong River in Viet Nam has remained constant. Moreover, the results from the 2015 study show a better condition of the assessed sites compared to that of the most recent studies in 2013.

Table 11. Site Assessment for all biological indicators (2015)

Site code	Benthic diatoms			Zooplankton			Littoral macroinvertebrates			Benthic macroinvertebrates			Meeting guidelines	Rating
	Abundance	Richness	ATSPT	Abundance	Richness	ATSPT	Abundance	Richness	ATSPT	Abundance	Richness	ATSPT		
LMX	✔	✔		✔	✔		✔	✔		✔	✔		7	B
LPB	✔	✔	✔	✔	✔	✔		✔		✔	✔		9	B
LVT	✔	✔		✔	✔			✔		✔	✔		7	B
LBF	✔			✔	✔			✔		✔	✔		6	C
LBH				✔	✔			✔		✔	✔		5	C
LSD				✔	✔			✔		✔	✔		5	C
LKL				✔	✔		✔	✔		✔	✔		6	C
LDN	✔		✔	✔	✔		✔	✔		✔	✔		8	B
TCS	✔	✔	✔			✔			✔	✔	✔	✔	8	B
TKO	✔	✔	✔			✔	✔	✔	✔	✔	✔		9	B
TSM	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	10	A
TNP	✔	✔	✔				✔	✔	✔	✔	✔	✔	9	B
TNK	✔	✔					✔	✔	✔	✔	✔	✔	8	B
TUN	✔	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	10	A
TMU	✔	✔		✔	✔		✔	✔	✔	✔	✔	✔	10	A
TKC	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	10	A
CMR	✔	✔		✔		✔	✔	✔		✔		✔	8	B
CKM	✔	✔		✔	✔	✔		✔				✔	7	B
CUS	✔	✔	✔	✔	✔	✔	✔	✔				✔	9	B
CSS		✔	✔			✔	✔	✔				✔	6	C
CSP	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	10	A
CSJ	✔	✔	✔	✔	✔	✔	✔				✔	✔	8	B
CKT	✔	✔	✔			✔	✔	✔		✔	✔	✔	8	B
CPT	✔	✔	✔	✔		✔	✔	✔		✔		✔	7	B
CCK	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔		8	B
CKL	✔	✔	✔	✔	✔	✔		✔		✔	✔		7	B
CSN	✔	✔	✔	✔	✔	✔		✔		✔	✔		7	B
CSK	✔	✔	✔	✔	✔	✔				✔	✔		7	B
CTU	✔	✔	✔	✔	✔	✔		✔		✔			7	B
CPP	✔	✔	✔	✔	✔	✔				✔	✔		7	B
CPS	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔	10	A
CNL	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔		10	A
CKK	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔		10	A
VTP	✔	✔		✔	✔					✔	✔		6	C
VTT	✔	✔		✔	✔		✔	✔		✔	✔		8	B
VKB	✔	✔		✔	✔		✔	✔		✔	✔		8	B
VDP	✔	✔		✔	✔			✔		✔	✔		7	B
VCL	✔	✔		✔	✔		✔	✔		✔	✔		8	B
VLX	✔	✔		✔	✔			✔		✔	✔		7	B
VVL	✔	✔		✔	✔			✔		✔	✔		7	B
VCT	✔	✔		✔	✔		✔	✔		✔	✔		8	B

Figure 26. Ecological Health Status of the Mekong River in 2015

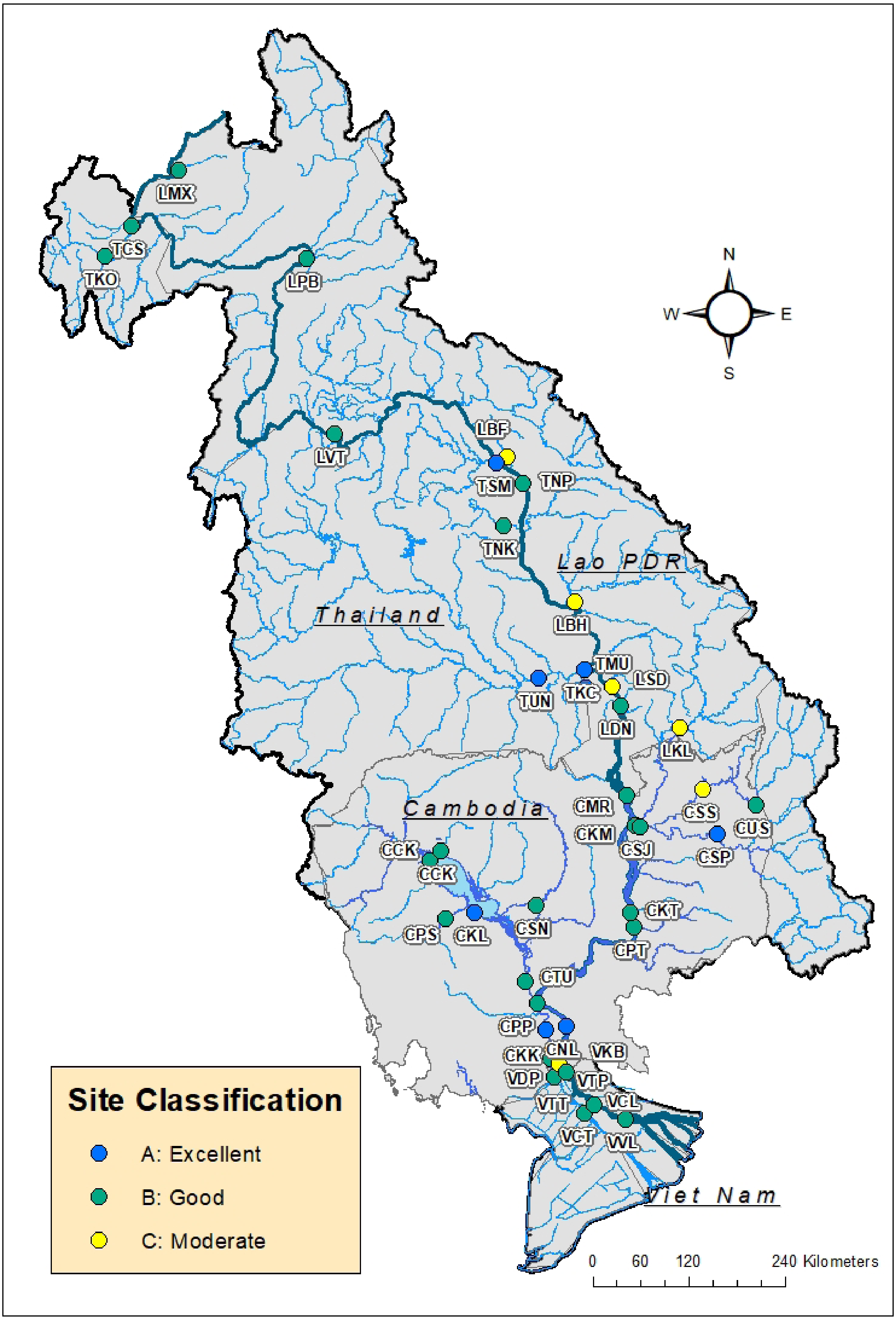


Table 12. Site assessment between 2007 and 2015

Site code	Location	Year				
		2007	2008	2011	2013	2015
Lao PDR						
LMX	Mekong River , Ban Xiengkok, Luangnamtha		D	D	C	B
LPB	Mekong River, Done Chor, Luang Prabang		B	A	Abnormal C	B
LVT	Mekong River, Ban Huayhome, Vientiane	B	C	C	Abnormal D	B
LBF	Se Bang Fai River, Se Bang Fai, Khammouan	B	B	C	Abnormal D	C
LBH	Se Bang Hieng River, Songkhone, Savannakhet	A	C	B	Abnormal D	C
LSD	Sedone River, Ban Hae, Pakse	B	B	B	Abnormal D	C
LKL	Se Kong River, Ban Somsanouk, Attapeu	B	C	C	Abnormal D	C
LDN	Mekong River, Done Ngie , Champasak	A	B	A	Abnormal D	B
Thailand						
TCS	Mekong River, Chiang San		B	B	B	B
TKO	Kok River, Chiang Rai City		A	B	B	B
TSM	Songkram and Mekong River junction, Nakorn Phanom	C	A	C	B	A
TNP	Mekong River, Nakorn Phanom City		C	B	A	B
TNK	Nam Kham River, Na Kae Mukdaharn	C	B	B	A	B
TUN	Mun River, Ubon Rachathani City		A	A	A	A
TMU	Mun River, Kong Chiam Ubon Rachathani		B	C	A	A
TKC	Mun and Mekong River junction, Ubon Rachathani		A	C	B	A
Cambodia						
CMR	Mekong River, Ramsar Site, Stung Treng	B	B	A	B	B
CKM	Se Kong River, Kbal Koh, Stung Treng	B	A	B	C	B
CUS	Se San River, Dey It Rattanakiri	B	A	C	B	B
CSS	Se San River, Veunsai, Rattanakiri			B	C	C
CSP	Srepok River, Phik, Rattanakiri	A	B	A	B	A
CSJ	Se San River, Downstream of Srepok River junction, Stung Treng	A	A	A	C	B
CKT	Mekong River, Kampi Pool, Kratie		A	A	B	B
CPT	Prek Te River, Preh Kanlong, Kratie			C	Abnormal D	B
CCK	Tonle Sap Lake, Chong Khnease, Siem Reap			B	B	B
CSN	Stoeng Sangke River, Battambang			B	C	B
CSK	Stung Sen River, Kampong Thom		B	C	B	B
CTU	Tonle Sap River, Peek Kdam Ferry, Kandal			B	B	B
CPP	Tonle Sap River, P Phnom Penh Port			B	C	B
CPS	Pursat River, Damnak Ampil, Pursat			B	B	B
CKL	Tonle Sap Lake, Kampong Luong, Pursat			B	B	A
CNL	Mekong River, Nak Loeung, Prey Veng			B	C	A
CKK	Bassac River, Koh Khel, Kandal		C	B	B	A
Viet Nam						
VTP	Mekong River, Thuong Phuoc, Dong Thap		C	B	C	C
VTT	Mekong River, Thuong Thoi, Dong Thap		C	B	C	B
VKB	Bassac River, Khanh Binh, An Giang		B	B	B	B
VDP	Bassac River, Da Phuoc, An Giang		C	B	C	B
VCL	Mekong River, Cao Lanh, Dong Thap		C	B	B	B
VLX	Bassac River, Long Xuyen, An Giang		B	C	C	B
VVL	Mekong River, My Thuan, Vinh Long		C	C	C	B
VCT	Bassac River, Phu An, Can Tho		B	B	C	B

4. REGIONAL SUMMARY

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This section gives a broad summary of each biological indicator group for all assessed sites. Its purpose is to assess the overall status of the river and highlight regional trends of the ecological health status of the rivers and Tonle Sap Lake.

The regional summary of the benthic diatom study revealed that the overall abundance of diatoms has slightly increased with the study in 2015 showing 400 more individuals than in the previous study in 2013. Furthermore, the average richness of diatoms of all sites seems to be reasonably stable, fluctuating at approximately 80 over the last three monitoring periods. The same applies for the ATSPT values, which remained stable at about 40. It should, however, be mentioned that in Cambodia all sites assessed met the guidelines' standards for ATSPT. However, there was an increase in ATSPT values, which suggests that the distribution of individuals for the different species may be out of balance compared to the last monitoring period where all sites were well below the threshold value. In Viet Nam, no site's ATSPT value met the required standard. Five sites in Lao PDR and six sites in Thailand were unable to meet the guidelines' standard. Regardless of the increase of individuals, all metrics should show an improvement if the ecological health status increases.

The trend for the zooplankton study is similar to that for the benthic diatoms but with a more upward trend. Both the average abundance and richness seem to have increased, while the ATSPT stayed constant. Particularly, average abundance has increased by almost 25%. Regardless, there was a great variability among the four countries. Almost all sites were able to meet the guideline's standards except for six sites located in Thailand. The six sites were unable to meet the guidelines' threshold value for abundance and richness and 3 sites showing an increased value of ATSPT no longer met the guidelines. Viet Nam and Cambodia show relatively constant values. However, it is noted that despite meeting the guidelines for average richness and abundance, no ATSPT value met the set requirements in Viet Nam, indicating a higher amount of environmental tolerable species present at the sites. The same pattern was observed for Lao PDR. It is suggested that more attention should be paid to the relevant species which occur in abundancy as they seem to be more and more dominant in occurrence.

For the littoral macroinvertebrates, the trend is different since the overall average abundance has decreased compared to the last monitoring period in 2013. Among the 41 assessed sites, only 17 in total were able to meet the healthy ecosystem guidelines. Most of those were located in Thailand (seven out of eight) and Cambodia (seven out of 17). ATSPT and richness stayed reasonably constant with most sites (33 out of 41) meeting the set standard for average richness. It is noted that within the 41 sites only two (one each in Cambodia and Thailand) were able to meet the standard for ATSPT according to the guidelines. Considering that littoral macroinvertebrates are the indicator group, which represents the quality of the riparian zone, it may be likely that the condition of the river zone has become more stressed as most sites host more species that are able to tolerate changing environments.

The benthic macroinvertebrates showed an overall increase in abundance. Comparing the overall average of species abundance of all sites from 2015 with previous studies in 2013, a duplication of present species was observed. This indicates that almost all sites assessed met the required standard for average abundance except for only five sites in Cambodia. Likewise, the average richness doubled compared to 2013 with only four sites in Cambodia not meeting the guidelines' requirements. However, it needs to be noted that only a few sites were able to meet the required threshold value for ATSPT. Unlike for average abundance and richness, most sites (7 out of 17 assessed) were located in Cambodia and Thailand (7 out of 8 met the required guidelines of a healthy ecosystem).

The sites were classified based on the compliance of their 12 indicators (three for each group of organisms) with the guidelines. Predominantly, most sites were classified as good, as can be seen in Table 12. Eight sites were evaluated as in an excellent condition (20 %), four in Thailand and four in Cambodia. Another five sites, however, were classified with a C (16%) of which most were located in Lao PDR, with four sites and one site in each Cambodia and Viet Nam, respectively. The remaining 27 sites, corresponding to 64 %, were classified as good (class B). This suggests that overall, the EH status of the river is in a good condition with some individual fluctuations.

5. CONCLUSION

5. CONCLUSION

In 2015, ecological health monitoring (EHM) has been implemented by the four Member Countries at the same sites as the last monitoring period in 2013. In total, 41 sampling sites have been assessed; eight sites in each of Lao PDR, Thailand, and Viet Nam, and 17 sites in Cambodia. Four biological indicators/organisms including diatoms, zooplankton, littoral and benthic macroinvertebrates were employed and assessed using an agreed standard methodology. Based on the individual site assessments, an evaluation of the ecological health status at each site was reported.

It was found that in 2015 the ecological health status of the Lower Mekong Basin remained predominantly stable in a good condition (class B). The greatest change was observed for Viet Nam, which showed an improved health status for five sites from moderate to good. Three of the four biological indicator groups showed an increase in species abundance at most assessed sites, with littoral macroinvertebrates being the exception. Average richness seemed to be reasonably constant but increasing for two of the biological indicators. However, it needs to be noted that despite most sites meeting the guidelines' standards for the three assessment metrics, the guidelines' threshold for the given ATSPT value often was not met. Hence, more tolerant species of environmental stress than sensitive species were present, suggesting a modified and more stressed environment.

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Appendix 1. List of participants on the sampling field trip in 2015

Lao PDR			
No.	Name	Position	Professional
1	Dr. Niane Sivongxay	Team leader	Zooplankton
2	Ms. Chanthima Polthalith	Member	Benthic Diatoms
3	Dr. Chanda Vongsombath	Member	Benthic macro-invertebrates
4	Ms. Viengkhone Vannachak	Member	Literal macro-invertebrates
5	Mr. Sopha Keoinpeng	Member	Water quality Analysis
6	Mr. Phonesavanh Lorkhamheuang	Member	Biologist
7	Mr. Khonekeo	Member	LNMC
8	Mr. Souliyo Yodyingnouthong	Member	BSc student
9	Ms. Phouangmaly Phomsouvanh	Member	BSc student
10	Mr. Sinvixay Thongmixaysompheng	Member	BSc student
11	Mr. Phone Phommavong	Member	BSc student
Thailand			
1	Mr. Tatporn Kunpradid	EHM National Expert, Team leader, Rajabhat Chiang Mai University	Benthic Diatoms
2	Mr. Songyot Kullasoot	National Expert, Chiang Mai University	Literal macro-invertebrates
3	Mr. Nirut Tengpongsathorn	National Expert, Rajabhat Chiang Mai University	Benthic Diatoms
4	Mr. Atinut Joradol	National Expert, Rajabhat Chiang Mai University	Water quality Analysis
5	Ms. Sujeephon Atibai	National Expert, Khon Kaen University	Zooplankton
6	Ms. Benjamas Suksai	National Expert, Khon Kaen University	Benthic macroinvertebrates
7	Ms. Em-on Sriariyanawath	National Expert, Khon Kaen University	Benthic macroinvertebrates
8	Ms. Thitima Phuavong	EP Coordinator, TNMCS, Dept. of Water Resources	

9	Mr. Rathaphum Nakhamphan	EP Coordinator, TNMCS, Dept. of Water Resources	
Cambodia			
1	Mr. Chheng Phen	EHM / National Expert, Team leader IFReDI/FiA (Inland Fisheries Research for Development Institute)	Littoral macroinveterbrates
2	Mr. Thach Phanara	IFReDI/FiA	Littoral macroinveterbrates
3	Ms. Kim Sopheap	IFReDI/FiA	Zooplankton
4	Mr. Uy Sophorn	IFReDI/FiA	Biology Division
5	Mr. Mao Chheang	IFReDI/FiA	Biology Division
6	Mr. Sar Yuthy	IFReDI/FiA	Biology Division
Viet Nam			
1	Mrs. Do Thi Bich Loc	Team leader	Benthic Diatoms
2	B.Sc. Huynh Duc Khanh	Member	Benthic macroinvertebrates
3	B.Sc. Trinh Khac Cang	Member	Benthic macroinvertebrates
4	B.Sc. Le Tan Nguyen	Member	Zooplankton
5	B.Sc. Ngo Duc Minh	Member	Environmental variables
6	B.Sc. Huynh Duc Khanh	Member	Benthic macroinvertebrates

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