Mekong River Commission
For Sustainable Development

# REPORT ON THE 2017 BIOMONITORING SURVEY OF THE LOWER MEKONG RIVER AND SELECTED TRIBUTARIES

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# Mekong River Commission

# Report on the 2017 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

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 environmental conditions that are long standing.

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 taxa that are related through evolution, macroinvertebrates are a disparate group of unrelated taxa that share the characteristics 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 suitable for particular biological indicator groups. Sites were chosen to provide broad geographical coverage of the basin and to sample a wide range of river settings along the mainstream of the Mekong and its tributaries.

Site Disturbance Score (SDS) – 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.

# Summary

This report describes the biomonitoring survey conducted in the dry season of 2017 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 2017; (ii) use this information to derive biological indicators for the sites examined in 2017; and (iii) use biometric indicators to evaluate these sites.

A total of 41 sites, the same as for the EHM 2015 survey, 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 2017 EHM was conducted based on mainly on an agreed and standardized methodology. Three biological metrics of the aquatic ecological health were calculated for each of the four groups of organisms including benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. The biological metrics were average abundance, the average richness, and the Average Tolerance Score per Taxon (ATSPT). Signs of a healthy ecosystem can be defined through a high abundance, a high average richness, and low ATSPT (signifying scarcity of pollution-sensitive species) of aquatic organisms. 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 guideline.

It was found that 6 sites were in excellent health condition, the majority of them being on the tributaries of Cambodia. Two sites, both situated in Thailand, on the other hand, were classified as D indicating very poor health conditions of those sites. Furthermore, 8 sites were scored with a C, indicating a moderate ecological health. All the other remaining sites were in a good condition and met at least 7 out of 12 biological indicator threshold values in accordance with the MRC guideline. It was found that all biological indicators varied in distribution, abundance and species diversity. Overall, it is observed that more species that are tolerant to 'extreme environments' are present. This is a sign for an unbalanced ecosystem. CUS in Cambodia met all threshold values, indicating an undisturbed environment, while TCS only met 3 criteria suggesting an unhealthy environmental condition.

For the benthic diatoms 10 sites failed to meet the guidelines for average abundance (three sites in Lao PDR, three sites in Thailand and four sites in Cambodia), in addition to 3 sites not meeting the richness guideline respectively (LVT, LSD, LKL). Alarmingly, only 6 sites, which all are located in Cambodia, met the threshold value for the ATSPT scores. All sites in Lao PDR, Thailand, and Viet Nam lay above the lay above the threshold guideline, which indicates either rapid changes in the environment or the dominance of more tolerable species. The total abundance of benthic diatoms across the Lower Mekong Basin has declined by almost 50 %. Compared to a total of 22,555 individuals in 2015 still, only 11,033 were collected in average across all sites in 2017, indicating a rapidly changing environment. Due to their sensitivity towards short-term environmental changes, there is likely to have been unfavorable change for the diatoms.

For zooplankton only six sites failed to meet the threshold value for the average abundance (TCS, TKO, TMS, TNP, TKC and CMR), most of them being in Thailand. In fact, at three sites no zooplankton was found and at two other sites only one individual was found. This can be due to the fact of the unsuitable river conditions during sampling or due to a change in ecology making the sites unsuitable for zooplankton. With only one addition (CKK), the already mentioned sites also failed to meet the richness threshold value. Similar to the benthic diatoms it was observed that only the 14 sites in Cambodia were in compliance with the MRC guidelines. However, since 2013, the overall ATSPT values have risen getting closer to being above the guideline's threshold. Compared to the previous monitoring periods, the overall abundance across all sites shows an extreme increase of 19,045 individuals compared to 8,824 in 2015. However, it needs to be noted that approximately 12,000 individuals correspond to the worm volvocacae, which makes the total only around 6,700 individuals for the remaining sites. Hence, it can be said that overall there is also been a decline in the abundance of zooplankton.

Overall, there are fewer littoral macroinvertebrates present than in 2015. Only 8,994 individuals were sampled on average during 2017, while in 2015 it was 9,474 individuals. Of the 41 sites, 8 sites failed to meet MRC's guidelines, while 7 showed low species diversity. The ATSPT scores of all sites, with the exception of CUS in Cambodia and TUN in Thailand, were above the guideline's value, which is consistent with the other biological indicators.

As for the littoral macroinvertebrates, also the benthic macroinvertebrates showed a 25 % decline, compared to the previous monitoring period. In 2017, only 2,253 individuals were found in average. Only two sites (TCS, CPT) and one (TCS) site, respectively failed to meet the guideline of average abundance and richness. Regardless, only 5 sites lay below the ATSPT threshold value.

During the monitoring period in 2017, the summarised evaluation of the sites revealed that 25 out of the 41 sites were found to have good ecological health (class B). From 41 sites, six were rated class A, corresponding to an excellent condition. All of those were located in the tributaries of Cambodia (CSP CKM, CSJ, CSP, CKT and CPP). TCS and TKC were the only sites that were found to have poor ecological quality according to the MRC guidelines (class D). Finally, the eight remaining sites were classified as having a moderate ecological health status (Class C) (LBF, LBH, LSD, LKL, LDN, TKO, TSM, TNP, TSM and VTP). When summarizing the above, it is found that in total out of 164 ATSPT scores (the sum of all biological indicators) only 27 were below the corresponding threshold value. The majority of those lay in Cambodia. This indicates that the ecological health of the river is declining and becoming more stressed. A few sites in particular, including CSK, CCK in the northern part of the Tonle Sap, TCS in northern Thailand, and site VDP in the Mekong have shown an increase in ATSPT values, which coincides with their SDS values, respectively. Detailed monitoring is required to provide the necessary datasets for conservation activities in the future.

# 1. Introduction

The Mekong River is recognized as one of the largest rivers in the world, and also one of the richest areas of biodiversity since it is home to more than 800 fish species (So, *et al*., 2016). In addition to fish, it provides supporting services to an abundant number of crabs, snails, frogs, snakes, algae and higher plants. These are one of the main sources contributing to the livelihoods and food supply for about 70 million people who live in the Lower Mekong Basin (So, *et al*., 2016). Due to the development goals of the four Member Countries (MCs), the revenue from other development projects such as hydropower, irrigation, navigation and tourism has been used for poverty alleviation and enhancing standard of living of their peoples; however, these development projects may be a major risk to the river ecosystem and impact on people's livelihoods and food security. Hence, since 2003 the governments and their line/implementing agencies have tried with serious effort 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 (MRC, 2009) of the river. The results of each site were compared and analysed on their biological variability the year after. The analysis confirmed that within-site variability is comparatively low, and that the sampling effort used in the pilot studies was sufficient enough 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 became available.

In 2007, the study focused on three biological metrics (abundance, richness and Average Tolerance Score Per Taxon (ATSPT)). Regression analyses were used to examine relationships between biological metrics and environmental variables. The results of the development of the biomonitoring survey are 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 own countries.

To date, EHM is done in a biennial basis, and three indicator metrics of the health of the Mekong aquatic ecosystem were calculated for each of the four groups of the organisms: benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. The metrics are average abundance, average richness and 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 previous results from 2008 up to 2017 indicate that the river is in a reasonably good condition. However, a trend has been observed indicating that due to fast environmental changes occurring in the water column of the rivers, less individuals of the biological indicator groups, in addition to that more tolerable species start to dominate the sites due to their ability to adapt easily to a changing environment.

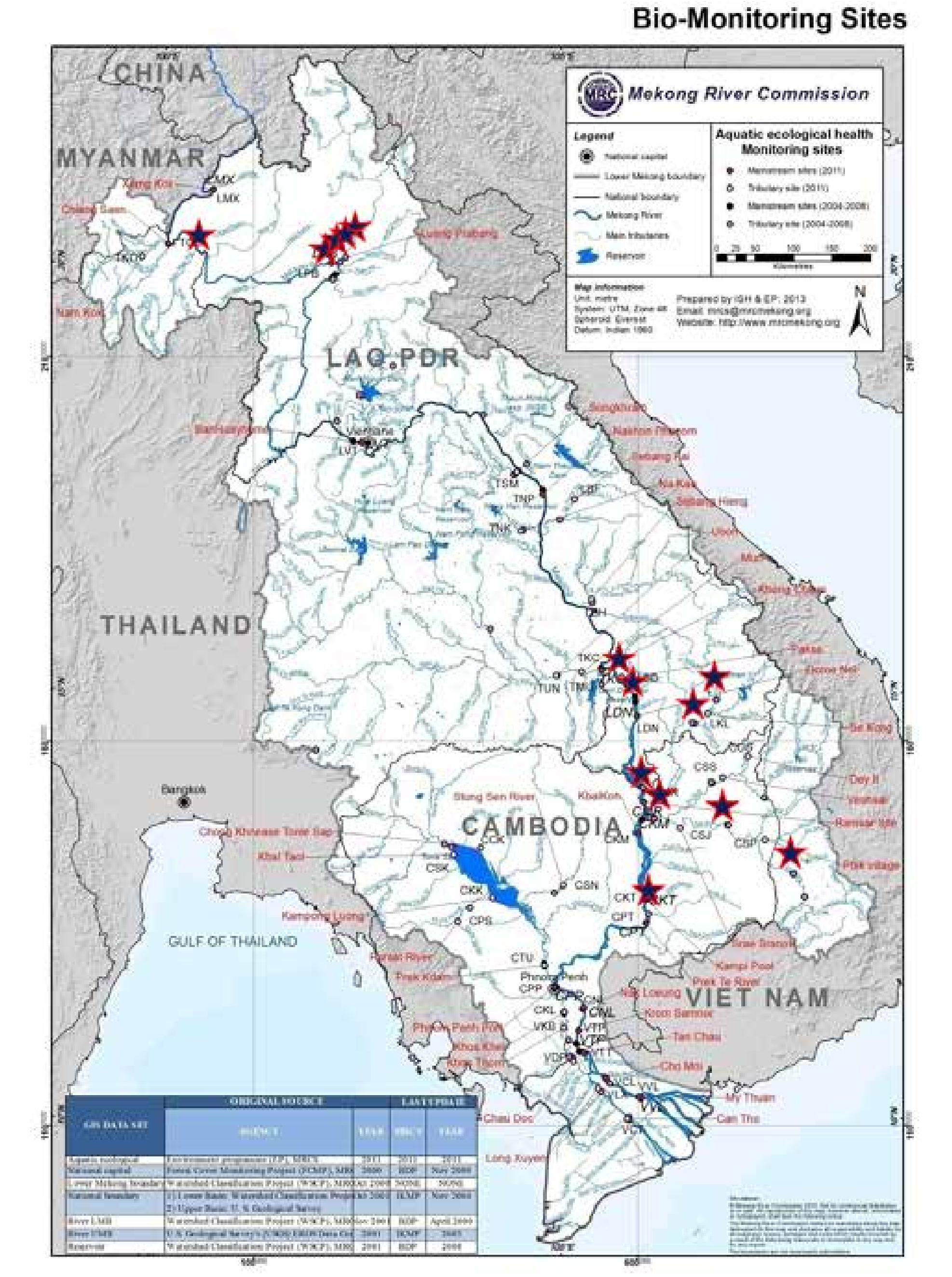
The purposes of this report are to (i) describe the biological indicator groups sampled during 2017; (ii) use this information to calculate biological metrics for the sites examined in 2017; and (iii) use biological metrics to evaluate sites. Of notice, this report has mainly been written based on the raw data provided within the national reports provided by the national teams in each Member Country, To improve accuracy, consistency and clarity of the analysis, the biological metrics were reevaluated. Thus, the detailed information and analysis might differ within this report from the national reports.  At the end, suggestions will also be given to optimize and structure data collection for future monitoring periods, based on previous reports and findings.

# 2. Materials and methods

## 2.1. Sampling sites

In the 2017 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–June 2017. Eight sampling sites each were surveyed in Lao PDR, Thailand and Viet Nam, while Cambodia surveyed on 17 sampling sites. These sites are the same as in the monitoring study conducted in 2015. Site details and survey activities are given below and are summarized in *Table 2.1* to *Table 2.4* and *Figure 2.1*, respectively. Sites are presented in sequence from upstream to downstream.

*Figure 2.1. Sampling sites of aquatic EHM in the Lower Mekong Basin surveyed in 2017.*



***Sites in Lao PDR***

Sampling sites in 2017 (as shown in *Figure 2.1*) 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 north to alluvial channel systems in central and southern Lao PDR. 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 and LBH. Other sites are located next to fields where crops are grown. LKL is situated upstream of several dams while LMX is placed next to a gold sieving area. The site LBP, on the other hand, is disturbed by sand and gravel collection and LDN and LSD experience numerous fishing and navigation activities. Details of the 2017 survey sites are described below, and summary in *Table 2.1*.

*Table 2.1. Sites sampled from 2007-2017 during biomonitoring surveys in Lao PDR*

| Site | Location | Mekong River/ Tributary | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 | Date of collection |
|---|---|---|---|---|---|---|---|---|---|
| LMX | Ban Xiengkok, Luangnamtha | Mekong River | | x | x | x | x | x | 29th May 2017 |
| LPB | Done Chor, Luang Prabang | Mekong River | | x | x | x | x | x | 31st May 2017 |
| LVT | Ban Huayhome, Vientiane | Mekong River | x | x | x | x | x | x | 2nd June 2017 |
| LBF | Se Bang Fai, Khammouan | Tributary, Se Bang Fai River | x | x | x | x | x | x | 19th May 2017 |
| LBH | Songkhone, Savannakhet | Tributary, Se Bang Hieng River | x | x | x | x | x | x | 24th May 2017 |
| LSD | Ban Hae, Pakse | Tributary, Se Done River | x | x | x | x | x | x | 23rd May 2017 |
| LKL | Ban Somsanouk, Attapeu | Tributary, Se Kong River | x | x | x | x | x | x | 21st May 2017 |
| LDN | Done Ngiew, Champasak | Mekong River | x | x | x | x | x | x | 22nd May 2017 |

LMX, Mekong River, Ban Xiengkok, Luangnamtha

LPB, Mekong River, Done Chor, Luang Prabang

LVT, Mekong River, Ban Huayhome, Vientiane

LBF, Tributary, Se Bang Fai River, Se Bang Fai, Khammouan

LBH, Tributary Se Bang Hieng River, Songkhone, Savannakhet

LSD, Tributary, Se Done River, Ban Hae, Pakse

LKL, Tributary, Se Kong River, Ban Somsanouk, Attapeu

LDN, Mekong River, Done Ngiew, Champasak

LMX (Mekong River, Ban Xiengkok, Luangnamtha)

The sampling site LMX is located on the Mekong River, 200 meters north from Ban Xiengkok in Long District, Luangnamtha Province. Here the right river bank belongs to Myanmar while the left side is part of Lao PDR. The village is located on the left riverbank with a few guesthouses, in addition to 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 is 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 from Souphanouvong University. It shows secondary forest on the right side of the island with some grass, minor shrubs and sandy areas. Villages, roads in addition to 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 covered with algae. A pond with standing water can be found in south of the island 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. Particularly, the newly planned railway has induced new disturbance to the site.

LVT (Mekong River, Ban Huayhome, Vientiane)

The sampling site locates in Ban Huayhome, Sikhottabong District, around 5 km upstream from Vientiane Capital. Thailand is on the right bank and Lao PDR on the left (looking downstream) where large vegetable gardens and a boat dock can be found. Samples were only collected from the left side, on Lao territory and close to the edge of the island Don Sing Sou in the middle of the river. The main substrata are 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 locates 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 (old house pieces), sand, mud and debris. This location is frequently disturbed by village activities.

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

This sampling site locates next to the bridge at the Se Bang Hieng River in Ban Se Bang Hieng, Songkhone District, Savannaket Province, a tributary of the Mekong. Vegetable gardens and houses occur on both banks. The substratum is comprised of a mix of boulders, concrete, sand and mud. This location was moderately disturbed by village activities. In 2015, it was reported that small sandy islands had emerged, which was no longer the case in 2017, due to higher water levels.

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 large maize fields and the left additionally consisted of houses, a school and gardens. This site is often disturbed by fishing and pumping water 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. Due to previous flooding and mining activities the banks show major signs of bank erosion. This site is moderately disturbed by domestic waste and fishing activities. In 2015, this site was still prone to the accumulation of sand and gravel from upstream, resulting in a sandbar on the right-hand side and an island in the middle of the river. However, this accumulation has stopped, and the previous existing island and sandbar have disappeared, also due to higher water levels. Substrata present in the faster-flowing current are pebbles and gravel, with sand and debris accumulating in the pool where the current is slower. Due to lower current on the left-hand side the surface is covered with algae.

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. A steep slope showing bank erosion is found on the right bank where vegetable gardens and riparian shrubs (dominated by *Homonoia riparia*) can also be seen. The left-hand side is made up of tobacco plants and more vegetable gardens. A few houses and restaurants are scattered along the bank at a distance of 100-200 m. Substrata of the site were mainly bedrock with some sand and mud patches. Due to high sand accumulation small islands have also built up in the channel.

### *Sites in Thailand*

Sampling sites in Thailand include localities on the Mekong and its major tributaries and are mostly in the northern and north-eastern parts, with two sites in the north and six in the north-east. 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 farmlands and ranches; some are upstream or downstream of dams or weirs, and some are exposed to moderate to heavy river traffic. Details of the 2017 survey sites are described below, and summary in *Table 2.2*.

*Table 2.2. Sites sampled in 2017 and earlier biomonitoring surveys in Thailand*

| Site | Location | Mekong/ Tributary | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 | Date of Collection |
|---|---|---|---|---|---|---|---|---|---|
| TCS | Chiang San, Chiang Rai | Mekong River | | x | x | x | x | x | 8th May 2017 |
| TKO | Chiang Rai City | Tributary, Kok River | | x | x | x | x | x | 9th May 2017 |
| TSM | Songkram and Mekong River junction, Nakorn Phanom | River junction | x | x | x | x | x | x | 3rd May 2017 |
| TNP | Nakorn Phanom City | Mekong River | | x | x | x | x | x | 2nd May 2017 |
| TNK | Na Kae Mukdaharn | Tributary, Nam Kham River | x | x | x | x | x | x | 4th May 2017 |
| TUN | Ubon Rachathani City | Tributary, Mun River | | x | x | x | x | x | 6th May 2017 |
| TMU | Kong Chiam Ubon Rachathani | Tributary, Mun River | | x | x | x | x | x | 5th May 2017 |
| TKC | Mun and Mekong River junction, Ubon Rachathani | River junction | | x | x | x | x | x | 5th May 2017 |

TNP, Mekong River, Nakorn Panom

TSM, Songkram and Mekong River junction, Nakorn Phanom

TNK, Tributary, Nam Kham River, Na Kae Mukhadarn

TUN, Tributary, Mun River, Ubon Rachathani City

TKC, Mun and Mekong River junction, Ubon Rachathani

TMU, Tributary, Mun River, Kong Chiam, Ubon Rachathani


TCS, Mekong River, Chiang San, Chiang Rai


TKO, Tributary, Kok River, Chiang Rai City

TCS (Mekong River, Chiang Saen, Chiang Rai)

This site locates 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. 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 (Thailand). 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. During sampling a recent landslide was visible undermining the high erosion rate in this site. More areas 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 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 lies in the center of the river. The substrata are made up of sand, cobbles and gravel. Different to 2015, a cobble dune was present in the center of the river. Human influences include agricultural runoff and navigation in the forms of large tourist boats and ships causing the bank to erode due to waves.

TSM (Tributary, Songkram River at Mekong junction, Nakorn Phanom)

This site is on the border between Thailand and Lao PDR. Both sites have a steep slope of 40 degrees. Since the previous monitoring period a new embankment was constructed on the right hand side while the left side showed great sign of erosion, leading to the steepening of this site. The site is surrounded by medium-sized villages in Chiyaburi Sub-District, with a total of about 500 inhabitants. The riparian zone consists of forest, landslides, a few houses, small-scale agricultural plots, piers, floating houses and fish cages. Also, bamboo is found within the river. Human impacts are high due to human waste from restaurants, fish cages, solid- and farm waste, and agricultural runoff. Further, the banks have been damaged by livestock. The amount of fish cages has dramatically increased compared to the last monitoring activity in 2015. Most of the substrata at the site are sand and clay, firm mud and firm sand.

TNP (Mekong River, Nakorn Phanom City)

This site locates on the border between Thailand and Lao PDR about 1.5 km upstream from Nakorn Phanom City. It is surrounded by small villages, with a total of about 300 inhabitants. 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 35-45 degree slope. The riparian zone consists of temporary agricultural sites and floating fish cages. Disturbance through human activities are moderate with rubbish disposal, agricultural runoff, fish farming and bank erosion being the most dominant. To note is the higher water level in 2017 compared to previous monitoring periods. The substrata are predominantly made up of sand, clay and rock at the riverbank.

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

This site locates about 5 km downstream of a water supply dam. 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 due to disposal of human waste and rubbish from upstream.

TUN (Tributary, Mun River, Ubon Rachathani City)

This site locates 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 but shows signs of soil erosion. The substratum is made up of mud, aquatic plants, sand, clay and firm sandy gravel. Disturbances are moderate due to disposal of human and animal wastes, navigation and agriculture.

TMU (Mun River at the Kong Chiam District, Ubon Rachathani)

This site locates downstream from the Pak Mun Dam, and about 3 km above the confluence of the Mun and Mekong Rivers in Ubon Rachathani Province. It is surrounded by a small fishing village with approximately 200 inhabitants. The banks have a 30-degree slope and the riparian zone consists of grass fields, temporary agricultural sites, temporary- 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-Mekong River junction, Ubon Rachathani)

This site locates 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 (Thailand) slopes at a 45-degree angle and is made up of a constructed rocky river embankment being 8-10 km long. The riparian vegetation is made up of bamboo woodlands and the site is surrounded by fishing villages, with a total population of about 800 inhabitants. 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 affected by rubbish disposal and animal/fish farm waste. A large pier for boat shipping is also present for transportation between the two countries.

### *Sites in Cambodia*

The sites were selected in an attempt to include a diversity of habitats in the Cambodian part of the Mekong River within different types of ecosystems, comprising the mainstream of the Mekong, the Bassac River, Tonle Sap River, Tonle Sap Lake and its tributaries. Each ecosystem is characterized by specific types of substrata. The substrata of the sampling sites are characterized by rock, sandy clay, mud, sand, clay, boulders and gravel. Details of the 2017 survey sites are described below, and summary in *Table 2.3*.

*Table 2.3. Sites sampled in 2017 and earlier biomonitoring surveys in Cambodia*

| Site | Location | Mekong/ Tributary | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 | Date of Collection |
|---|---|---|---|---|---|---|---|---|---|
| **CMR** | Ramsar Site, Stung Treng | Mekong River | x | x | x | x | x | x | 30th March 2017 |
| **CKM** | Kbal Koh, Stung Treng | Tributary, Se Kong River | x | x | x | x | x | x | 31st March 2017 |
| **CUS** | Dey It Rattanakiri | Tributary, Se San River | x | x | x | x | x | x | 3rd April 2017 |
| **CSS** | Veunsai, Ratanakiri | Tributary, Se San River | | | x | x | x | x | 2nd April 2017 |
| **CSP** | Phik, Rattanakiri | Tributary, Srepok River | x | x | x | x | x | x | 4th April 2017 |
| **CSJ** | Downstream of Srepok River junction, Stung Treng | Tributary, Se San River | x | x | x | x | x | x | 1st April 2017 |
| **CKT** | Mekong River, Kampi Pool, Kratie | Mekong River | | x | x | x | x | x | 29th March 2017 |
| **CPT** | Preh Kanlong, Kratie | Tributary, Prek Te River | | | x | x | x | x | 28th March 2017 |
| **CCK** | Tonle Sap Lake, Chong Khnease, Siem Reap | Tonle Sap | | | x | x | x | x | 7th April 2017 |
| **CKL** | Tonle Sap Lake, Kampong Luong, Pursat | Tonle Sap | | | x | x | x | x | 9th April 2017 |
| **CSN** | Kampong Thom | Tributary, Stung Sen River | | | x | x | x | x | 5th April 2017 |
| **CSK** | Battambang | Tributary, Stoeng Sangke River | | x | x | x | x | x | 6th April 2017 |
| **CTU** | Prek Kdam Ferry, Kandal | Tributary, Tonle Sap River | | | x | x | x | x | 22nd April 2017 |
| **CPP** | Phnom Penh Port | Tributary, Tonle Sap River | | | x | x | x | x | 24th April 2017 |
| **CPS** | Damnak Ampil, Pursat | Tributary, Pursat River | | | x | x | x | x | 8th April 2017 |
| **CNL** | Mekong River, Neak Loeung, Prey Veng | Mekong River | | | x | x | x | x | 21st April 2017 |
| **CKK** | Khos Khel, Kandal | Tributary, Bassac River | | x | x | x | x | x | 20th April 2017 |

CMR, Mekong River, Ramsar Site, Stung Treng

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

CUS, Tributary, Se San River, Dey It Rattanakiri

CSS, Tributary, Se San River, Veunsai, Ratanakiri

CKT, Mekong River, Kampi Pool, Kratie

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

CCK, Tonle Sap Lake, Chong Khnease,
Siem Reap

CKL, Tonle Sap Lake, Kampong Luong, Pursat

CSN, Tributary, Stung Sen River, Kampong Thom

CSK, Tributary, Stoeng Sangke River Battambang

CTU, Tributary, Prek Kdam Ferry, Kandal

CPP, Tributary, Tonle Sap River, Phnom Penh Port

CPS, Tributary, Pursat River Damnak Ampil, Pursat

CNL Mekong River, Neak Loeung,
Prey Veng

CKK, Tributary, Bassac River, Khos Khel, Kandal

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 corresponds to a steep slope covered by flooded forest and farmland, and on the left bank a pier for tourist boats, fishing boats and a market can be found. Human disturbance in this area is small. The river is characterised by strong currents and algae are present. The substrata are grasses, sand, pebbles, and boulders.

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

This site is next to Phdao Village on the Se Kong River in Stung Treng Province. The sampling point locates 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 locates on the left bank of the 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 from the ferry and the dam. The substrata are boulders, cobbles and sand. In the middle of the river, there are boulders. The water of the river is clear despite of the strong currents.

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

This site on the 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 for about 30 m. A house and trail with planted trees and woodland can be found at the top. The right bank is comprised of 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 are sandy areas with pebbles.

CSP (Tributary, Srepok River, Phik, Rattanakiri)

This site on the Srepok River locates 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 of from some houses. Both banks slope steeply and are covered with bamboo and forest. The substrata are sandy soil, sand and boulders.

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

The sampling site locates on the 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 wood- and farmland with additional bamboo only on the right bank. The water is clear despite of 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 merges into only 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, with no fishing activities 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 other farmland. 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 of the strong currents.

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

This site is on 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 activities 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. Disturbances are high 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, freshwater clam 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 the Tonle Sap Lake in Kampong Luong Village. The sampling point is about 800 m from 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 (a large area of morning glory) and floating houses. Various gillnet-sticks, gillnets and other fishing gear were found while sampling, indicating an increase in human activities in this area compared to previous years. 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 Stung Sen River, close to Somrong Village in Kampong Thom Province. The sampling site is on the right bank with houses at a 300 m distance. About 700 m downstream from the site, the river is highly disturbed by sand exploitation activities while upstream 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 sandy soil and sand. The water is turbid with slow currents.

CSK (Tributary, Stoeng Sangke River, Battambang)

The sampling site is on the Stoeng Sangke River, in Muthbangkang Village, Battambang Province. The sampling point locates on the right bank, about 800–900 m from the village and about 1–2 km upstream from Tonle Sap Lake. This site is often 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 the Tonle Sap Lake. The substrata of the area are muddy soil, bricks, wooden twigs and debris.

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

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

CPP (Tributary, Tonle Sap River, Phnom Penh Port)

The sampling site locates 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 additional two or three fishing boats. The right bank is made up of water hyacinth, riparian shrubs, some large trees and the National Road and houses can be found on this side. On the left bank the Phnom Penh Ferry Port is located in addition to the National Road. The substrata are pebbles and muddy soil. The water current is slow.

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

This site is on the 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 park for villagers, boulders, riparian grasses, and 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, sandy soil, boulders and cobbles. The water is clear with gentle currents and is slightly disturbed by gillnet fishing activities.

CNL (Mekong River, Neak Loeung, Prey Veng)

The sampling site locates on the lower eastern part of the Mekong River in Prek Svay Village, Prey Veng Province. The sampling point is on the left bank, 500 meters 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 and shrubs and farmland are found on the right bank.

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

The site locates in Khpouk Village, Kandal Province on the Bassac River. The sampling point is 300 m upstream of the Khos Khel ferry dock on the left-hand site. 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 consists of riparian grasses and shrubs and the National Road and some houses can be found on this site.

***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. The six downstream sites are affected by tides. All sites are moderately to heavily impacted by human activities. Sample collection was carried out by the end of March 2017 and the details of the survey sites are described below, and are summarized in *Table 2.4*.

*Table 2.4. Sites sampled in 2017 and earlier biomonitoring surveys in Viet Nam*

| Site | Location | Mekong River/ Tributary | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 | Date of collection |
|---|---|---|---|---|---|---|---|---|---|
| VTP | Thuong Phuoc, Dong Thap | Mekong River | | x | x | x | x | x | 12th April 2017 |
| VTT | Thuong Thoi, Dong Thap | Mekong River | | x | x | x | x | x | 13th April 2017 |
| VKB | Khanh Binh, An Giang | Tributary, Bassac River | | x | x | x | x | x | 11th April 2017 |
| VDP | Da Phuoc, An Giang | Tributary, Bassac River | | x | x | x | x | x | 10th April 2017 |
| VCL | Mekong River, Cao Lanh, Dong Thap, | Mekong River | | x | x | x | x | x | 14th April 2017 |
| VLX | Long Xuyen, An Giang, | Tributary, Bassac River | | x | x | x | x | x | 9th April 2017 |
| VVL | Mekong River, My Thuan, Vinh Long, | Mekong River | | x | x | x | x | x | 7th April 2017 |
| VCT | Phu An, Can Tho | Tributary, Bassac River | | x | x | x | x | x | 8th April 2017 |


VTP, Mekong River, Thuong Phuoc, Dong Thap


VTT, Mekong River,  Thuong Thoi, Dong Thap


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


VDP,Tibutary, Bassac River Da Phuoc, An Giang

VCL, Mekong River, Cao Lanh, Dong Thap,

VVL (left side), Mekong River, My Thuan, Vinh Long

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

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

VTP (Mekong River, Thuong Phuoc, Dong Thap)

The site is located in Thuong Phuoc Commune, Dong Thap Province, and slopes gently and is covered by wild weeds. Water hyacinth is present on the alluvial land on the left-hand site. The right river bank consists of shrubs and macrophytes. Approximately 700 m upstream, the river bank is consolidated by cement and multiple houses are present. The substrata on both banks are made up of an intermix of sand, silty mud and organic matter. The site is highly disturbed from pollution from markets, industrial and household activities, navigation and increased sand exploiting activities.

VTT (Mekong River, Thuong Thoi, Dong Thap)

The site is located in Thuong Thoi Commune, Dong Thap Province. Houses, grasslands and fruit orchards are found at this site. The right river bank in this area consists of predominantly wild vegetation while the left bank is made up of agricultural tree plantations and scattered wild weeds. The substratum is mostly sand with some clay and detritus on the left-hand side and additional sand in the middle of the river. More agricultural activities occur along the right-hand side and additional water traffic and fishing is found in the river. Occasional sand exploitation also takes place here.

VKB (Bassac River, Khanh Binh, An Giang)

This site at Khanh Binh Commune, An Giang Province on Bassac River, slopes gently with many wild weeds and water hyacinths present on the alluvial land on the left-hand site. The right river bank consists of shrubs and macrophytes. Approximately 700 m upstream the river bank is consolidated by cement and multiple houses are present. The most common substratum is sand getting finer towards the sites and intermixing with clay, mud and detritus. Traffic on the waterway is average. Catching and culturing fish at small scale in addition to sand exploiting activities are happening strongly. Daily washing and bathing activities of local residents also affect the local river condition.

VDP (Bassac River, Da Phuoc, An Giang)

This site at Da Phuoc Commune, An Giang Province, consists of farmlands and housing. Strong bank erosion is present, reaching up to the foundations of the local houses. The riparian area is covered by water hyacinth, sunken bushes and trees. The substrata are made up of mud and rubbish on the bank and mud, sand and detritus on the river bed. Predominantly, high erosion is found on the left river site where the community lives, while agricultural activities are carried out on the right-hand side. The river is affected by high density fish farms 500 meters downstream from the sampling site.

VCL (Mekong River, Cao Lanh, Dong Thap)

The site located at Cao Lanh City, Dong Thap Province, is dominated by farmlands and housing, with scattered grasslands, and water hyacinth growing in the river. Large areas of erosion are developing along the left-hand side of the river. The substratum is made up of an intermix of sand and clay in addition to water hyacinth present on the riverside. This site is marked by agricultural activities on both sites with additional small-scale fishing culture being practiced. Water traffic is average but oil membranes were present on the water surface near the shore.

VLX (Bassac River, Long Xuyen, An Giang)

This site at Long Xuyen City, An Giang Province and largely covered by houses and farmland Traffic and navigation activities occurs in very high density, mainly in the middle and right bank part of the river. Numerous boats and ships are also anchored here. Other activities such as passenger ferry transport, fish culture in cages, non-treated influents from settlements accompanied with direct bathing and washing activities are also occurring at this site.

VVL (Mekong River, My Thuan, Vinh Long)

The site is at My Thuan Commune, Vinh Long Province and largely covered by houses, orchards and hyacinth bands near the shore. Various cork trees are found along the shore line. Activities on the river are fish farming and capture fisheries. A predominant activity is the culturing of Asian catfish. The substratum of the right and the left banks is silty mud prograding to sand in the middle of the river. The density of fish cages is extremely high, and the riverbed shows clear signs of pollution from agricultural runoff and household waste. The water traffic is high amplifying the high pollution.

VCT (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 and cork trees. A small harbor locates 200 m further upstream. The river has water hyacinth, and is also polluted with domestic solid waste. Main activities include water transportation, landing and storage of goods in addition to fishery capture. A brick factory is found close by. The riverbanks and the river bed are mainly made up of sand, mud and detritus. Decayed vegetables and bricks are commonly found.

## 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). All variables were measured and reported in accordance to MRC's EHM guidelines (MRC, 2010a)

### *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. All specimen collected during the 2017 monitoring period were collected in accordance to the MRC monitoring guidelines (MRC,2010a). An example of a collected specimen and the field work activities are shown below. Additional information of the sampling procedure and the fieldwork activities in specifically 2017 can be found in the guidelines (MRC, 2010a) chapter 5 and in Annex 1 and Annex 2, respectively.

*Figure 2.2. Diatom collected in 2017 - Geissleria decussis*

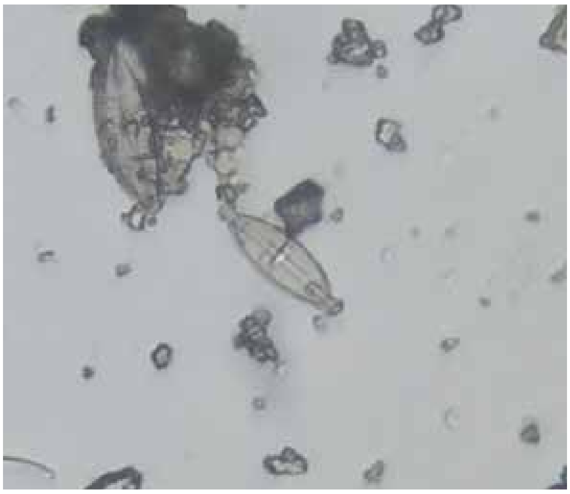


*Figure 2.3 Field Methods Diatoms*

***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. All specimen collected during the 2017 monitoring period were collected in accordance to the MRC monitoring guidelines (MRC,2010a). An example of a collected specimen and the field work activities are shown below. Additional information of the sampling procedure and the fieldwork activities in specifically 2017 can be found in the guidelines (MRC, 2010a) chapter 6 and in Annex 1 and Annex 2, respectively.

*Figure 2.4. Zooplankton collected in 2017 - Polyathara vulgaris*

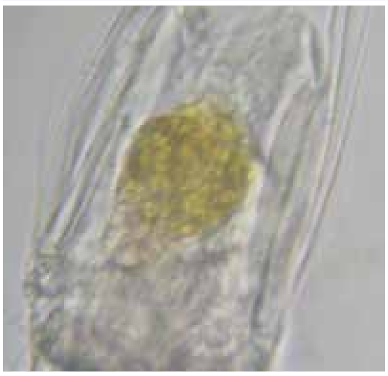


*Figure 2.5. Field methods zooplankton in 2017, Thailand.*

***Littoral Macroinvertebrates***

Littoral macroinvertebrates are monitored as they are good indicators for human disturbance and the status of the riparian zones as littoral macroinvertebrates are typically found near the shorelines. Usually, samples are taken on the depositional, rather than erosional sites due to favorable habitat conditions. Hence, the abundance and richness of the invertebrates are a good indicator for the quality of the riparian zone. All specimen collected during the 2017 monitoring period were collected in accordance to the MRC monitoring guidelines (MRC,2010a). An example of a collected specimen and the field work activities are shown below. Additional information of the sampling procedure and the fieldwork activities in specifically 2017 can be found in the guidelines (MRC, 2010a) chapter 7 and in Annex 1 and Annex 2, respectively.

*Figure 2.6. Littoral Macroninvertebrate collected in 2017 - Stenelmis sp.)*

*Figure 2.7. Field methods littoral macroinvertebrates in Thailand (2017)*

***Benthic macroinvertebrates***

Benthic macroinvertebrates are 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 the deeper-water areas away from the shoreline. Additional information of the sampling procedure and the fieldwork activities in specifically 2017 can be found in the guidelines (MRC, 2010a) chapter 8 and in Annex 1 and Annex 2, respectively.

*Figure 2.8. Benthic Macroinvertebrate collected in 2017 - Lammelligomphu sp.*

*Figure 2.9 Sample Collection of Benthic Macroinvertebrates in 2017*

## 2.3. Calculation of biometric metrics

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

***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. For this report, the average abundance corresponds to the average number of individuals per site.

***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. For this report, average richness corresponds to the average of individual species at each 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. The actual determination of an ATSPT is calculated and derived in 5 steps. (1) A visual method for determining the SDS is described in MRC (2010a).

(2) 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. (3) 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.

(4) The ATSPT is then calculated for each sample collected. (5) ATSPT is the average tolerance of all taxa recorded in a sample, calculated without regard to their abundance. A worked example on the calculations is given in MRC (2010a).

## 2.4. Using biological metrics to evaluate sites

The three metrics of the health of the aquatic ecosystem are calculated for each of the four indicator groups included in the biomonitoring programme (diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates). 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 ATSPT where a high value indicates harm to the ecosystem (tolerance) the guideline is set at the 90th 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 2.5*. 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.

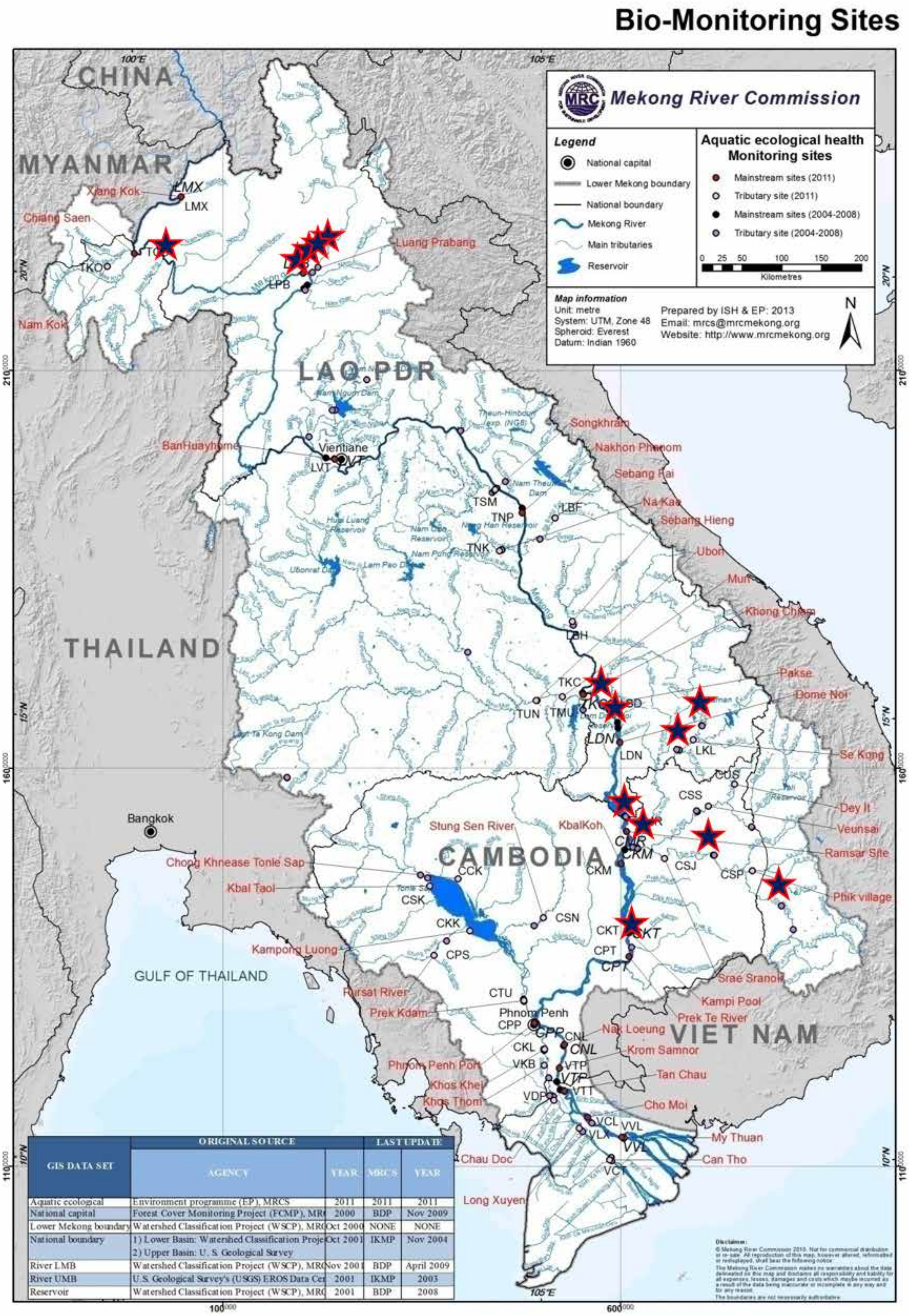
*Table 2.5. Guideline for biological indicators of ecosystem health based on 2004–2007 baseline studies*

| Metrics | Biological indicator groups | | | | | | | | Guideline of healthy ecosystem |
|---|---|---|---|---|---|---|---|---|---|
| | Diatoms | | Zooplankton | | Littoral macroin-vertebrates | | Benthic macroin-vertebrates | | |
| | 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 |

## 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 2.5*).

*Figure 2.10. Reference Sites in the LMB chosen based on good water quality, habitat and minimal disturbance from human activities*



***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 regard 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. For the exact requirements to be considered as a reference site, a detailed classification can be found in MRC's guidelines for "*Biomonitoring Methods in the Lower Mekong Basin*".

*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 are compared to the values at the 14 MRC reference sites (MRC, 2008, 2010a). A total of 12 biological results were determined for each site after which they were classified 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.

# 3. Results

Chapter 3 summarizes the regional results of the Ecological Monitoring Procedure in 2017. It is to be noted that due to the varying monitoring time frames, Viet Nam (7-14 April), Thailand (2-9 May) and Lao PDR (19 May – 2 June), the weather conditions were not consistent and may have biased the results and impacted the distribution of collected species. (The sampling period for Cambodia remains unknown).

## 3.1. Environmental Variables

The physical environmental variables measured in each site included site altitude, depth and width of the river, transparency, water temperature and general chemical parameters; Dissolved Oxygen (DO), pH and Conductivity (EC) (as shown in *Table 3.1*). The variables showed a broad range of values across the study sites. Site Disturbance Scores (SDS) were determined by the physical condition of sites, and the method used for calculated SDS was presented comprehensively in the Biomonitoring Handbook (MRC, 2010a). Hereafter, the all results are presented by mainstream order, Lao PDR, Thailand, Cambodia and Viet Nam.

***River Profile***

**Lao PDR**

The sampling sites were located across altitudes spanning from 441 meters at the first sample site in the North of Lao PDR at Ban Xiengkok, Luangnamtha (LMX), to 86 m above sea level at Se Kong River, Ban Somsanouk, Attapeu (LKL). The morphology of the river varied considerably between sites ranging from 150 m (LBF) to 2,000 m (LDN) in width and average depths from 3 (LBH) to 7 meters (LDN). Noticeable was the increase in river width by 75 meters (from 125 to 200 meters) while the depth decreased from 19.17 to 5.1 meters in 2017 at site LMX.

**Thailand**

River width and altitude data were not measured in sampling during 2017. However, these details were included in the 2015 report which demonstrated altitudes ranging from 85 m at the Mun River and Mekong Junction, Udon Rachathani (TKC) to 395 m on Kok River, Chiang Rai City (TKO) at study sites in Thailand. The river width ranged from 38 m at the Nham Kham River (TNK) to 1,250 m on the river junction of Mun- and Mekong River at Khong Chiam (TKC).

**Cambodia**

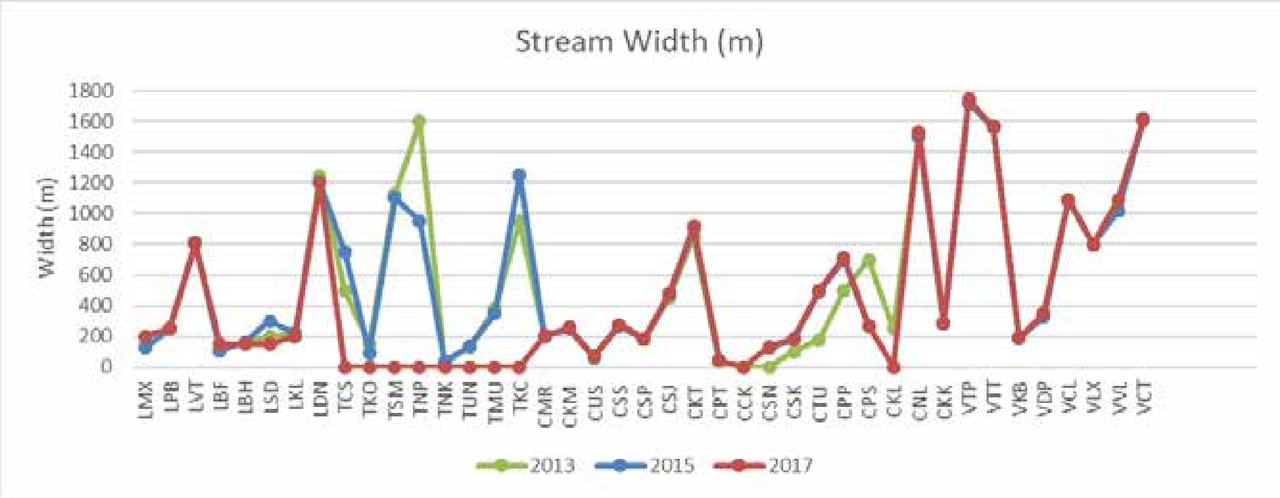
Sites in Cambodia were located at altitudes from 5 m at sites CSK, CTU and CCK to 134 at CUS meters above sea level. The average depth of the river at sample sites ranged from 0.6 m at Tonle Sap, Chong Khnease, Siem Reap (CCK) to 25.3 m at Neak Loeung, Prey Veng (CNL) with low water levels reflecting the mid-dry season sample collection period. The width of the river at the different sample points was measured to vary between 41 meters at CPT and 1531 meters at CNL, which is 31 meters compared to 2015.

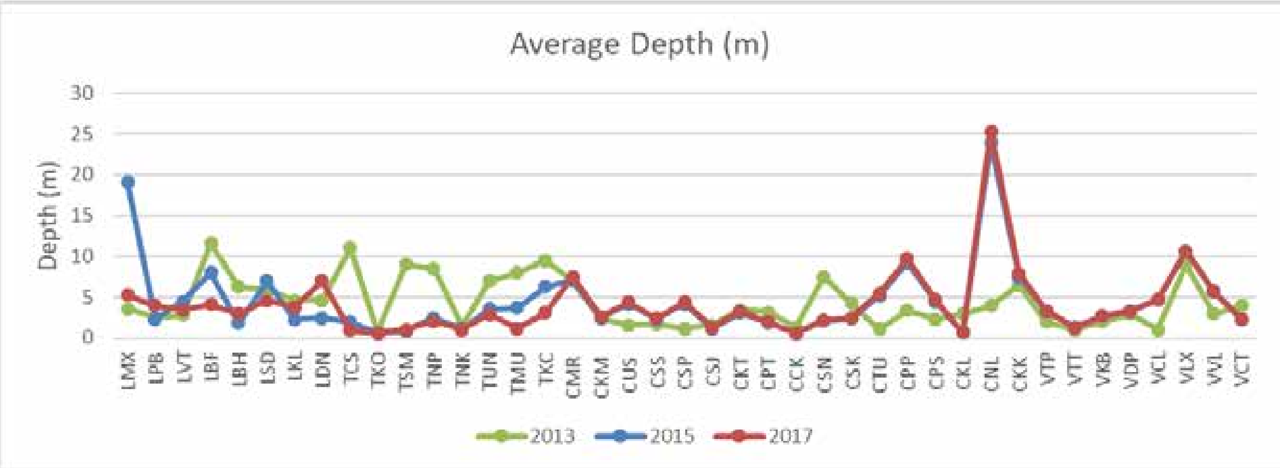
**Viet Nam**

The width of the river at the sample sites was, on average, larger in Viet Nam, reflecting its position at the lower end of the watercourse, ranging from 187 m at Khanh Binh Commune, An Giang Province on Bassac River (VKB) to 1,747 m at the site located on Mekong River in Thuong Phuoc, Dong Thap (VTP). The depth, on the other hand, ranged from of 1.3-2.3 m on the Bassac River in the Phu An Commune, Can Tho City (VCT) while being up to 10.7 meters in the Mekong River at Long Xuyen, An Giang (VLX). Compared to 2015, both the depth and width of the rivers did not show significant changes during the two monitoring periods.

The altitude and river width at all sample sites are presented in ***Figure 3.1***.

*Figure 3.1 Altitude and river width at all sample sites from 2013, 2015 and 2017*




*Note: the values corresponding to 0 m for the 2017 measurements of the stream width from Thailand correspond to 'not measured' as these measurements could not be taken during that period.*

#### *Water temperature*

Water temperatures varied dependent largely on altitude, latitude and season of monitoring period, generally increasing with distance downstream. In Lao PDR, temperatures varied from 24°C on the Mekong River at Ban Xiengkok, Luangnamtha (LMX) to 31°C at the Se Done River, Ban Hae, Pakse (LSD) (mean= 27.6 °C (± 2.5 °C)) (as shown in *Table 3.1*). Sample sites in Thailand fell within the normal range for the dry season (22.3°C – 33.2°C). In Cambodia, water temperatures at the sample sites ranged between 26.8-32.5°C (mean = 30.5°) reflecting the ambient temperature. There was little variation in temperature across the sample sites in Viet Nam, ranging between 29.7 and 30.3°C (average T ° = 29.90 ºC).

#### *Dissolved Oxygen (DO)*

Dissolved oxygen (DO) at sites across Lao PDR was much higher than generally expected in tropical regions (mean=8.2 mg/L (± 1.2 mg/L), with a maximum concentration of 10.85 mg/L measured recorded at Se Bang Hieng River, Songkhone, Savannakhet (LBH). This is also higher than the average DO in 2015 which was 6.2 mg/L (± 0.3). The lowest DO concentration was at LKL at 7.2 mg/L, which is greater than the minimum DO concentration to maintain a healthy ecosystem of 5 mg/L according to the MRC Water Quality Guidelines (Kongmeng and Larsen, 2012).

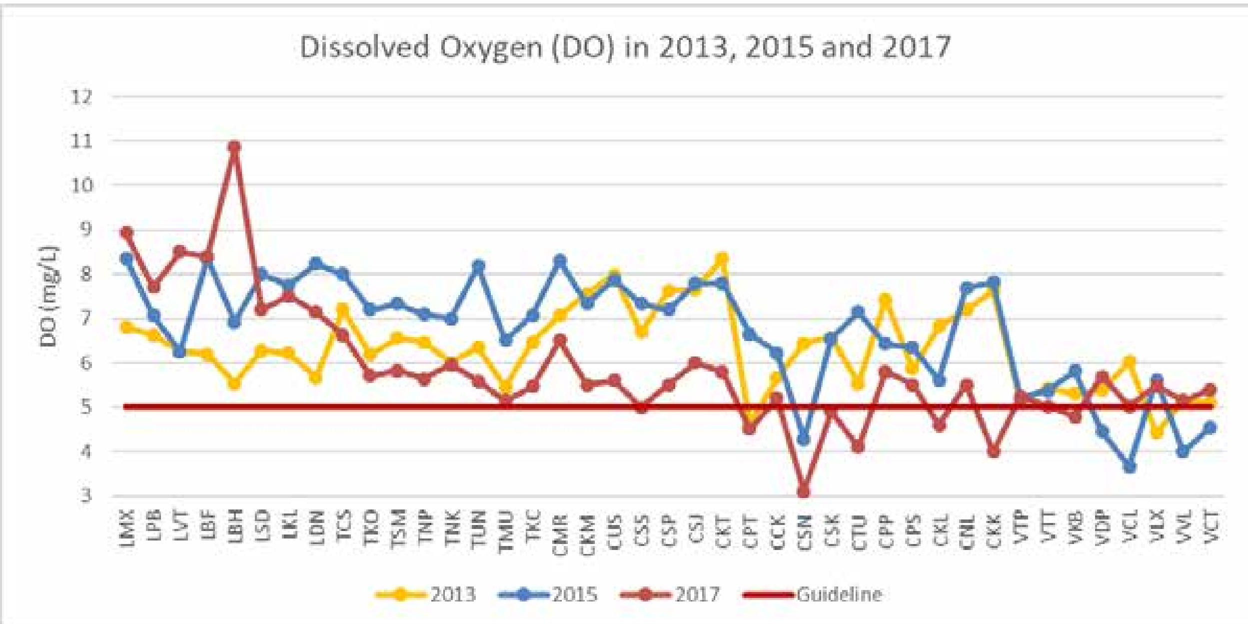
The DO was generally moderate compared to those typically reported for tropical running water in Thailand, with values from 5.15 – 6.63 mg/L (as shown in ***Table 3.1*** and ***Figure 3.2***). The highest DO values from sites in Thailand were recorded on the Mekong River at Chiang San (TCS = 6.63 mg/L), which is consistent with the 2015 ecological health monitoring results. The lowest DO values were found at sites at Mun River (TMU= 5.15 mg/L) However, mean DO values at all sites reached the threshold concentration for ecological heath by the MRC guidelines.

In Cambodia, DO was varying between 3.1-6.5 mg/L (mean = 5.12 mg/L). Concentrations were lower than the MRC water quality guidelines at sites CSN, CSK, CKL, CPT, CKK, CTU with the lowest DO concentration recorded at Stung Sen River at Kampong Thom (CSN). Whereas, In comparison, during the 2015 sampling period, only site CPT at Prek Te River, Preh Kanlong, Kratie had DO below 5 mg/L.

DO concentrations ranged from 4.79-5.690 mg/L (mean = 5.22 mg/L (± 0.29) at sites across Viet Nam, with the lowest DO recorded at site VKB (Bassac River, Khanh Binh, An Giang). This is also the only site that does not meet the water quality threshold of 5 mg/L as specified in MRC's Guideline.

Generally, the DO concentration has increased compared to 2015, which could be due to the lower water level of the river a great change in temperature or due to increased run-off and waste from human activities. Particularly, Cambodia and Thailand show a decrease in oxygen values than in the previous monitoring period. As it can further be seen, the DO decreases towards the downstream. In all three monitoring years 2013, 2015 & 2017 starting slightly alkaline and becoming more and more acidic.

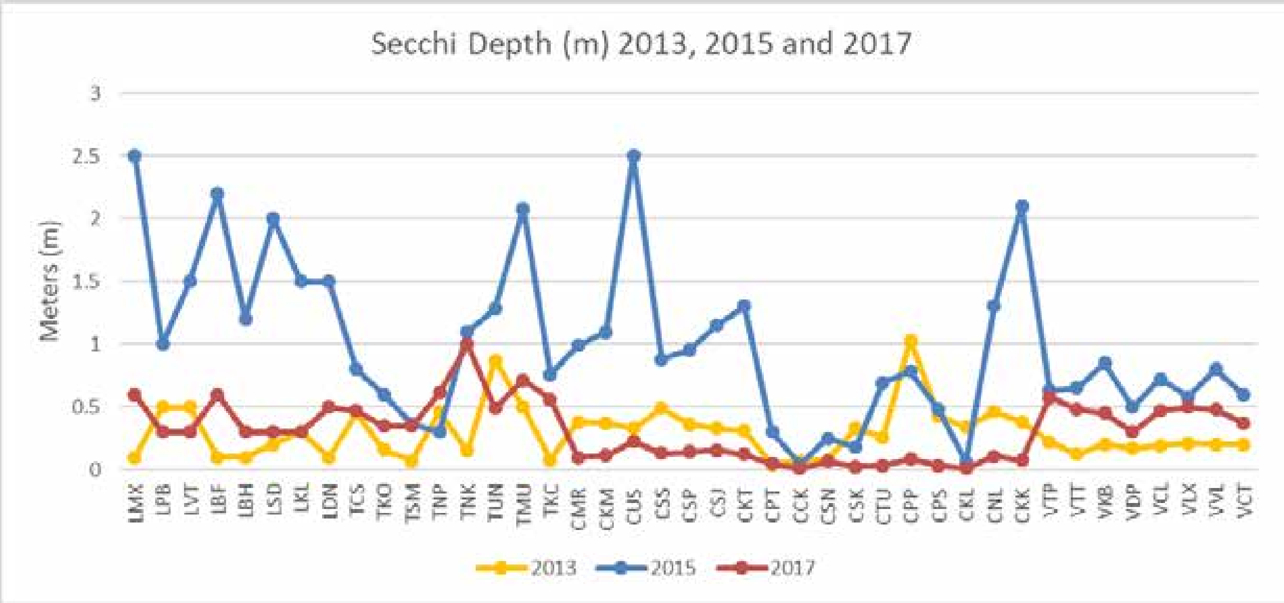
*Figure 3.2. Comparison of Dissolved Oxygen (DO) measurements at sites across the Lower Mekong basin (LMB) in 2013, 2015 and 2017.*




### *Transparency*

Water transparency measured as Secchi Depth was lowest in Cambodia with Secchi depths between 0.008 m (CCK, CKL) and 0.225 m (mean = 0.085 ± 0.057m) as can be seen in ***Figure 3.3***. Transparency was greater in Lao PDR compared to Cambodia, ranging from 0.300 m at sampling sites LSD, LKL, LBH, LVT and LPB to 0.600 m at site locations LMX and LBF (mean = 0.400 m ( ± 0.132 m)). Secchi depth was between 0.350 m (TKO, TNP, TSM) and 1 (TUN) at sites in Thailand (mean = 0.540 ± 0.200 m ). Viet Nam had the greatest transparency on average, with sites VKB and VVL having the highest values from Viet Nam sites with Secchi depths of 0.500 m (VDP) and 0.850 m (VKB) respectively (mean = 0.670 m), while VDP has the lowest levels of transparency in Viet Nam with an average secchi depth of 0.500 m. When comparing these results with 2015, it is found that particularly Lao PDR and Cambodia show great decreases in water transparency, which could be explained by the different sampling times, compared to the last monitoring year.

*Figure 3.3. Comparison of Secchi depth (m) of all sample sites in the LMB in 2013, 2015 and 2017*




***pH***

The pH at all sites in Lao PDR was neutral to slightly alkaline and within the expected range for inland freshwaters, between 7.2 and 7.87 (mean = 7.5 ± 0.2) and therefore not a limiting factor for aquatic life (MRC WQ guidelines: pH=6-9). The first 3 upstream sites, LMX, LPB and LVT were slightly alkaline with a pH (7.5-7.87) compared to the remaining 4 sites in varying between 7.2-7.45 (LBF, LBH, LSD, LKL).

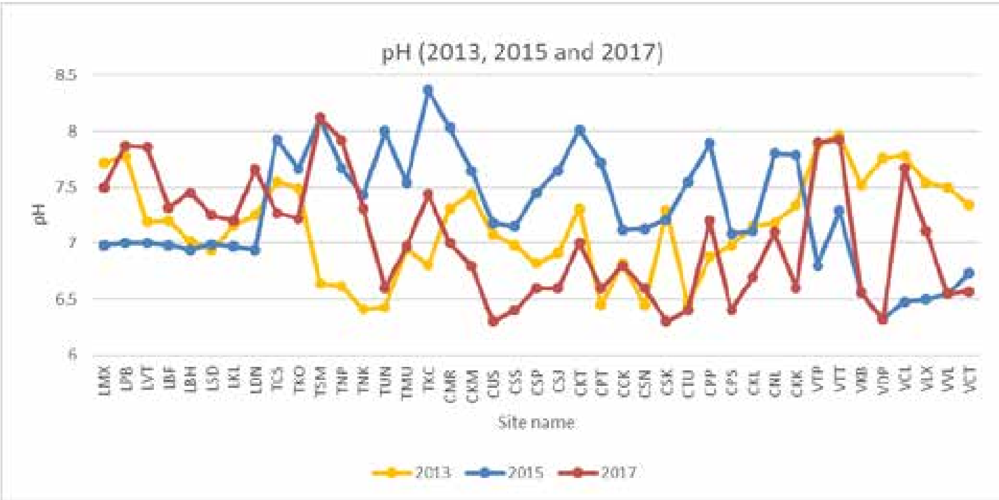
In Thailand pH values varied more significantly between sites, ranging between 6.6 and 8.12 (mean=7.36 ± 0.49). The first two sites along the course of the river, TCS and TKO, had pH values of 7.27 and 7.22 respectively. The next sites TSM (Songham River and Mekong Junction, Nakorn Phanom) and TNP were more alkaline with values of 8.12 and 7.92, which is consistent with the measurements taken at the Lao PDR sites. Here after, pH gets more acidic again with the lowest pH found at Mun River, Ubon Rachathani City (TUN) at 6.6, which could reflect the presence of human activities such as waste disposal.

Whereas, in Cambodia pH was generally more acidic ranging between pH 6.3 and 7.2 (mean= 6.67 (±0.28)), (slightly acidic to neutral) but still within the accepted range of MRC's guidelines on water quality for aquatic life of pH 6-9 (MRC, 2013). It was noted that compared to the previous monitoring period, all sites showed a decline in pH between 0.32 at CCK to 1.15 at CTU.

In Viet Nam, pH at the sample sites was in a similar range to sample sites in Cambodia, ranging from pH 6.32-7.29 (mean= 6.65 (± 0.3)). All measured pH values were within criteria A1 (6 – 8.5) of QCVN 08:2008 (6.50 – 8.03) and almost all sites have pH in compliance of surface water criteria (QCVN 08:2008 - column A).

In comparison to 2015, the pH in general seems to be lower in 2017. Furthermore, when looking at ***Figure 3.4*** below, there is a distinct decline visible for the sites in Cambodia, while fluctuating for Thailand and Viet Nam respectively. Lao PDR's pH values seem to be more alkaline than in the previous monitoring period, which could be due to higher water levels in Lao PDR because of the late sampling period during this year.

*Figure 3.4. Comparison of pH measurements for all sites in 2013, 2015 and 2017*




### *Electrical Conductivity (EC)*

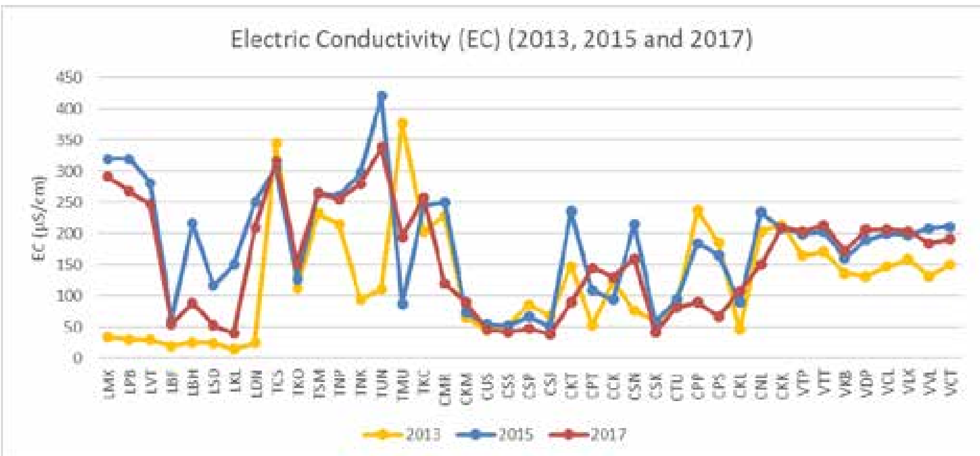
In 2017, the mean Electrical Conductivity (EC) measurement was lower in Lao PDR with 156.5 ± 107.4 µS/cm, compared to 214.6 ± 96.8 µS/cm in 2015. The range was between 40 and 291 µS/cm. Sites LSD, LKL, LBH and LBH were all under 100 µS/cm and all the other sites were above 200 µS/cm. All sites in Lao PDR had EC concentrations that did not meet with the MRC WQ Guidelines for protection of aquatic life (700 - 1500 µS/cm). It is, however, noted that the Mekong and the Bassac rivers are low-saline, hardly ever reaching above 500 µS/cm.

The EC had a wide range in sites across Thailand from 151.9 µS/cm at Kok River, Chiang Rai City (TKO) to 338.3 µS/cm at Mun River, Ubon Rachathani City (TUN) (mean= 257.5 ± 60.5 µS/cm).

In Cambodia, EC ranged between 39 and 210 µS/cm with the lowest measurement recorded at the Se San River, Stung Treng (CSJ) and the highest at Tonle Sap, Siem Riep (CKK) (mean= 97.5 ± 48.1 µS/cm), which is in the same sort of range as 2015 where the average EC was 131.64 ± 74.49 µS/cm.

In Viet Nam the EC ranged from 161- 211 µS/cm (mean=196.3 ± 14.6 µS/cm), which is higher than in Cambodia, but on average lower than in the upstream sites in Thailand and in Lao PDR. EC values at sites VLX, VDP, VKB, VTP, VCL and VTT have increased nearly continuously from 2011 to 2017, indicating an increase in total dissolved solids over time.

*Figure 3.5. Comparison of Electric Conductivity (EC) Measurements for all sites in 2013, 2015 and 2017*



### *Site Disturbance Score*

Sites had Site Disturbance Scores (SDS) from 1.66 (LDN) to 2.06 (LMX) in Lao PDR, 1.72 (TNK) to 2.34 (TCS) in Thailand, (CUS) 1.37-2.55 (CKL) in Cambodia and between 1.8 (VTT) to 2.1 (VLX) in Viet Nam, indicating moderate human disturbance at most sites (as shown in ***Table 3.1*** and ***Figure 3.3***). Human activities observed across the LMB influencing the environment included agriculture, navigation, mining construction, bank modification, trading activities and the presence of communities (waste and run-off).

*Table 3.1 Physical and chemical conditions and Site Disturbance Score (SDS) for sampling sites in 2017*

| Site | Altitude (m) | Width (m) | Average depth (m) | Secchi depth (m) | Temperature (°C) | DO (mg/L) | pH | EC (µS/cm) | SDS |
|---|---|---|---|---|---|---|---|---|---|
| LMX | 441 | 200 | 5.3 | 0.600 | 24 | 8.93 | 7.5 | 291 | 2.06 |
| LPB | 276 | 250 | 4 | 0.300 | 25 | 7.7 | 7.87 | 268 | 2.02 |
| LVT | 178 | 800 | 3.5 | 0.300 | 25 | 8.5 | 7.86 | 247 | 1.86 |
| LBF | 140 | 150 | 4.1 | 0.600 | 27 | 8.4 | 7.32 | 54.8 | 1.86 |
| LBH | 137 | 150 | 3 | 0.300 | 30 | 10.85 | 7.45 | 89 | 1.86 |
| LSD | 96 | 150 | 4.6 | 0.300 | 31 | 7.2 | 7.25 | 53 | 1.88 |
| LDN | 86 | 200 | 3.8 | 0.300 | 29 | 7.5 | 7.2 | 40 | 1.86 |
| LKL | 115 | 1200 | 7 | 0.500 | 30 | 7.14 | 7.66 | 209 | 1.66 |
| TCS | N/A | N/A | 0.98 | 0.470 | 22.27 | 6.63 | 7.27 | 316.83 | 2.34 |
| TKO | N/A | N/A | 0.57 | 0.350 | 29.73 | 5.7 | 7.22 | 151.93 | 2.17 |
| TSM | N/A | N/A | 1.02 | 0.350 | 29.8 | 5.82 | 8.12 | 264.6 | 2.17 |
| TNP | N/A | N/A | 2.03 | 0.610 | 29.17 | 5.64 | 7.92 | 255.2 | 2.14 |
| TNK | N/A | N/A | 1.05 | 1.000 | 33.23 | 5.96 | 7.31 | 280.2 | 1.72 |
| TUN | N/A | N/A | 2.87 | 0.490 | 33 | 5.59 | 6.6 | 338.3 | 1.93 |
| TMU | N/A | N/A | 1.18 | 0.710 | 32.8 | 5.15 | 6.97 | 195.07 | 2.11 |
| TKC | N/A | N/A | 3.11 | 0.560 | 30.33 | 5.46 | 7.44 | 258.23 | 2.22 |
| CMR | 58 | 204 | 7.5 | 0.097 | 28.7 | 6.5 | 7 | 120 | 1.52 |
| CKM | 48 | 255 | 2.6 | 0.113 | 31.7 | 5.5 | 6.8 | 90 | 1.53 |
| CSS | 134 | 71 | 4.4 | 0.225 | 26.8 | 5.6 | 6.3 | 46 | 1.37 |
| CSJ | 126 | 276 | 2.4 | 0.133 | 28.8 | 5 | 6.4 | 42 | 1.78 |
| CUS | 100 | 184 | 4.4 | 0.139 | 29.2 | 5.5 | 6.6 | 47 | 1.6 |
| CSP | 50 | 480 | 1.3 | 0.154 | 30 | 6 | 6.6 | 39 | 1.5 |
| CKT | 12 | 918 | 3.3 | 0.121 | 30.4 | 5.8 | 7 | 90 | 1.71 |
| CPT | 39 | 41 | 2 | 0.046 | 31.5 | 4.5 | 6.6 | 145 | 2.46 |
| CCK | 5 | 0 | 0.6 | 0.008 | 31.9 | 5.2 | 6.8 | 130 | 1.42 |
| CSK | 5 | 0 | 0.7 | 0.008 | 30 | 4.6 | 6.7 | 108 | 2.55 |
| CPS | 16 | 128 | 2.2 | 0.066 | 30.4 | 3.1 | 6.6 | 160 | 1.79 |
| CKL | 5 | 184 | 2.5 | 0.024 | 30.3 | 4.9 | 6.3 | 42 | 2.52 |
| CSN | 16 | 500 | 5.5 | 0.033 | 32.5 | 4.1 | 6.4 | 82 | 1.42 |
| CTU | 8 | 714 | 9.7 | 0.084 | 31.9 | 5.8 | 7.2 | 90 | 1.7 |

| Site | Altitude (m) | Width (m) | Average depth (m) | Secchi depth (m) | Temperature (°C) | DO (mg/L) | pH | EC (µS/cm) | SDS |
|---|---|---|---|---|---|---|---|---|---|
| CPP | 23 | 270 | 4.7 | 0.033 | 31.2 | 5.5 | 6.4 | 67 | 1.69 |
| CKK | 6 | 1531 | 25.3 | 0.108 | 31.5 | 5.5 | 7.1 | 150 | 1.71 |
| CNL | 5 | 291 | 7.9 | 0.076 | 32.1 | 4 | 6.6 | 210 | 1.42 |
| VTP | 7 | 1.747 | 3.3 | 0.630 | 30 | 5.24 | 6.8 | 199 | 2 |
| VTT | 6 | 1.562 | 1.3 | 0.650 | 30 | 5.02 | 7.29 | 203 | 1.8 |
| VKB | 6 | 187 | 2.7 | 0.850 | 29.7 | 4.79 | 6.56 | 161 | 2 |
| VDP | 5 | 350 | 3.3 | 0.500 | 30 | 5.69 | 6.32 | 190 | 2 |
| VCL | 7 | 1.09 | 4.7 | 0.720 | 30 | 5.03 | 6.48 | 200 | 1.9 |
| VLX | 7 | 798 | 10.7 | 0.580 | 30.3 | 5.48 | 6.5 | 198 | 2.1 |
| VVL | 8 | 1.089 | 5.7 | 0.800 | 30 | 5.14 | 6.55 | 208 | 1.9 |
| VCT | 10 | 1.617 | 2.3 | 0.600 | 29.7 | 5.4 | 6.73 | 211 | 1.9 |

## 3.2. Benthic Diatoms

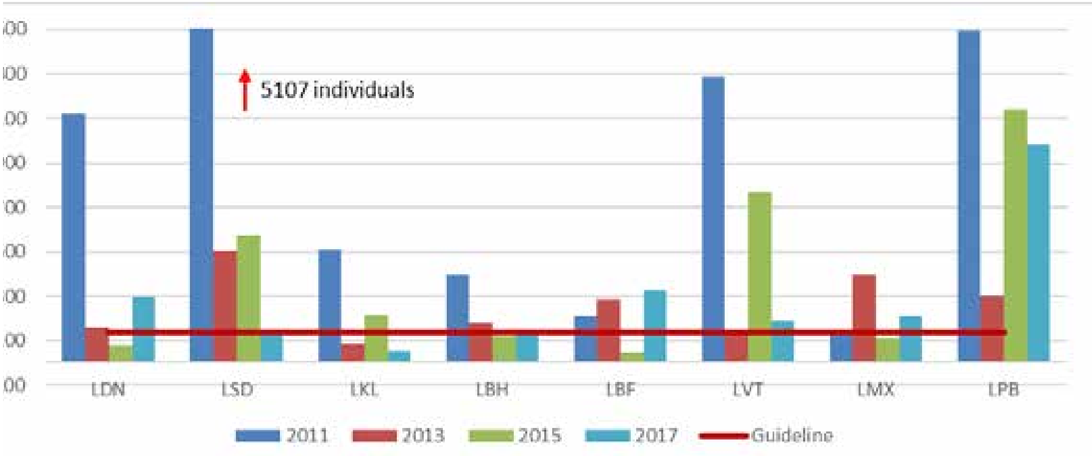
***Average abundance***

### Lao PDR

The 80 samples collected at 8 sites in Lao PDR in 2017 contained 23,175 diatoms. The identification process revealed that these consisted of 2 Orders (Bacillariales, Biddulphiales), 11 Families, 31 genera and 65 species. The average abundance of benthic diatoms at site locations in Lao PDR ranged from 54.5 – 984.5 individuals per site with a mean of 289.69 ± 275.79, with the highest number on the Mekong River, Done Chor in Luang Prabang (LPB). The two most often occurring species were *Fragilaria ulna var. acus (Kützing) Lange-Bertalot* and *Gomphomena gracile Ehrenberg*. Three of the sites (LKL, LSD and LBH) could not meet the threshold value of the MRC guideline for a healthy ecosystem (average abundance of greater than 136.22 individuals per sample). Of these, the lowest diatom abundance was recorded at the Se Kong River, Ban Somsanouk, Attapeu (LKL) where abundance was measured at 54.5 individuals per site. (as shown in ***Table 3.2*** and ***Figure 3.6***).

In comparison to 2015, sites at LDN (Mekong River, Done Ngiew, Champasak); Se Bang Hieng River, Songkhone, Savannakhet (LBH); Se Bang Fai River, Se Bang Fai, Khammouan (LBF) and the Mekong River, Ban Xiengkok, Luangnamtha (LMX) all exhibited an increase in benthic diatom abundance. This may have been due to the favorable conditions in the 2017 sampling period such as suitable substrate, and low water levels. For instance, LBH exhibited higher water levels compared to the last monitoring period, providing habitat on inundated rocks. All other sites had lower levels of diatom abundance than 2015 LKL, LVT and LPB. Sites LVT and LSD showed a significantly lower value of diatoms compared to 2015 and other sampling years. This could be due to changing environmental conditions. It was found that for both LSD and LVT there was a two degrees difference compared to the last monitoring period and a big difference in relative secchi depth. Furthermore, at site LSD, the number of diatoms has decreased by a 3 fold most likely because of more sewage and rubbish disposal from the villagers into the water. The increased amount of rubbish may affect living organisms such as diatoms. Additionally, most of the suitable substrata were flooded and at LVT, the site was disturbed by sand and gravel accumulation, more navigation and waste water from the individual households, leading to disruptive environment. Only five of the eight monitoring sites met the threshold value for a healthy ecosystem (***Figure 3.6***).

*Figure 3.6. Comparison of Benthic Diatom Results - Average Abundance in Lao PDR (2011, 2013, 2015 and 2017)*



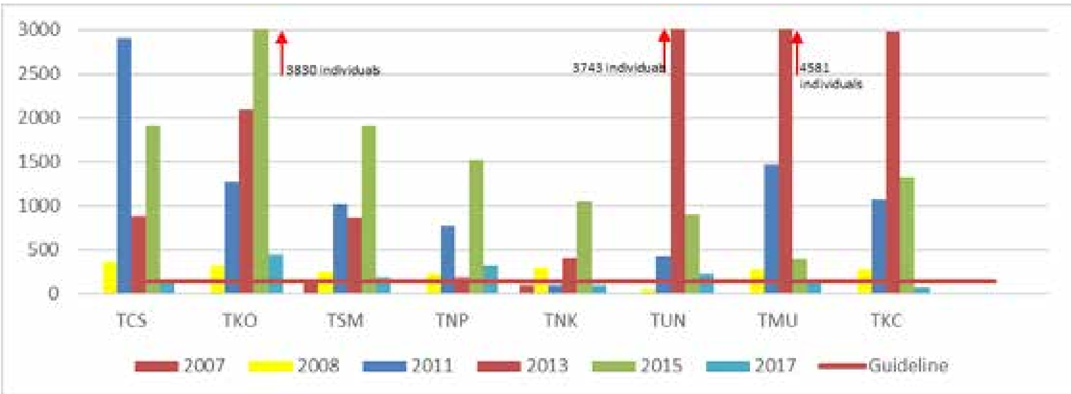

*(the arrow and number of individuals indicate the actual number of individuals for this site in 2011. Due to scaling and the fact that the report focuses on data from 2017, it was decided to show the data like this.)*

**Thailand**

The 8 sites that were sampled in 2017, yielded a total of 144 different species of benthic diatoms out of the 16,671 cell counts that were collected. The average abundance of diatoms per site ranged from 74.4 to 444.5 individuals/site between the different sampling sites in Thailand (as shown in ***Figure 3.7*** and ***Table 3.2***) with a mean of 201.6 ± 118.5 individuals/site . Benthic diatom abundance was lower than the reference standard (136.2 individuals/site) at three sites, TNK, TKC and TMU. One explanation for this observation could be due to the relative substrata at those sites, which are mud and bedrock. Furthermore, the appropriate living conditions for the diatoms at TMU might also have been affected by Pak Mun dam, which is located further upstream of the sample site. Davidson *et al*., (2006), found that dam impacts on diatom communities are not uniform as they depend on the nature of the dammed river, which makes further analysis on possible impacts complex and would require more intensive research.

The highest abundance was found at site TKO (444.5 individuals/site). The lowest abundance was found at the Mekong River main channel with the bedrock riverbank and the substrate covered by sand, leaves and wood debris at Khong Chiam (TKC) (74 individuals/site). The results show that benthic diatom abundance has decreased in 2017 sampling compared to years 2013 and considerably since 2015, suggesting some form of disturbance, which could either be natural or anthropogenic. At site TSM, for instance, it may be likely that the higher abundance of fish cages have led to a decreased number of diatom individuals. Future monitoring is required to confirm this statement. *Nitzschia palae*. *Cymbella turgidula, Cocconius placentula* were the species most often occurring at all sites and with the highest numbers.

*Figure 3.7. Comparison of Benthic Diatom Results – Average Abundance in Thailand in 2007, 2008, 2011, 2013, 2015 and 2017*

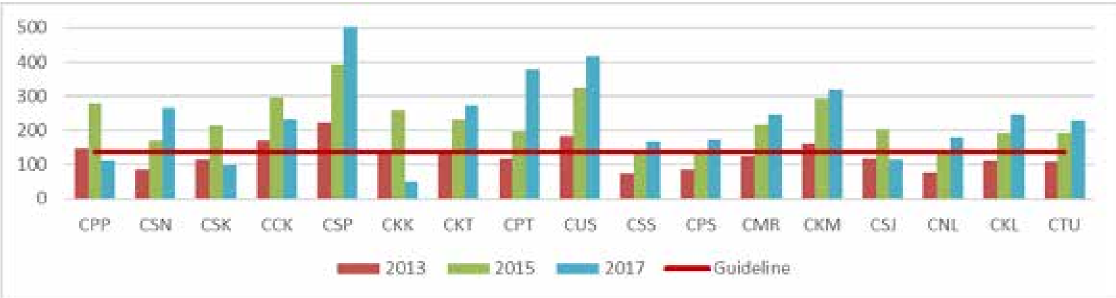



*(the arrows and number of individuals indicate the actual number of individuals for these sites. Due to scaling and the fact that the report focuses on data from 2017, it was decided to show the data like this.)*

**Cambodia**

A total of 20,004 individuals were collected in Cambodia during the sampling period in 2017. Average abundance ranged from 48.5 (CKK) – 505.9 (CSP) diatoms per site, in Cambodia (mean = 235.5 ± *116.5* individuals per site). Four sites (CSJ, CSK, CKK, CPP) did not meet MRC's guidelines of a healthy ecosystem for benthic diatom abundance. Both CKK and CPP are geographically close to each other, which could possibly indicate a downstream connection between the sites. At both sites, a great decrease in pH and visibility was observed. Interestingly, both sites were evaluated and assigned a lower SDS compared to the last monitoring source. Hence, the source of possible pollution affecting the diatom abundance may be originating from further upstream. A great increase in abundance, on the other hand, was observed for sites CSP, CPT and CUS, respectively. Here, the species *Navicula cryptocephala* and *Gomphonema augur var turris* were found in large numbers. The Navicula genus is known for its adaptive capability (Akbulut, 2003).

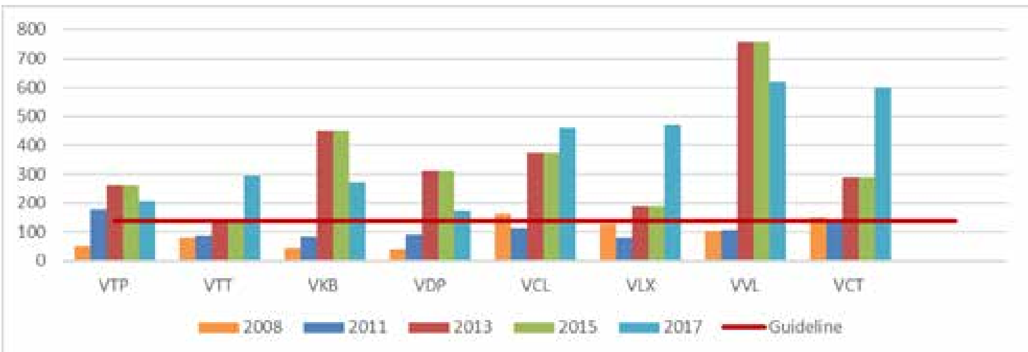
*Figure 3.8. Comparison of Benthic Diatom Results – Average Abundance in Cambodia in 2013, 2015 and 2017*




**Viet Nam**

A total of 147 species were found in samples taken at sites across Viet Nam, belonging to 34 genus, 24 families, 15 orders and 3 classes. The most abundant class was Bacillariophyceae with 126 species belonging to 22 genus, 16 families and 8 orders. Benthic diatom abundance in Viet Nam was considerably higher both compared to the other countries and compared to the last monitoring periods, ranging from 174.8 individuals per site on the Bassac River, Da Phuoc, An Giang (VDP) to an average of 617.0 individuals per sample at site VVL on the Mekong River, My Thuan, Vinh Long and a total mean of 387.5 ± 162.0 individuals per site (as shown in ***Figure 3.9*** and ***Table 3.2***).This could be as a result of a greater extent of suitable substrate for diatom habitat or a slower river flow rate compared to the other sample sites. Alternatively, it could be due to EC and/or temperature, which are both factors that have previously been established as important in determining diatom assemblages (MRC, 2008). All sampling sites met with the MRC diatom guideline abundance levels for a healthy ecosystem. In general, benthic diatom abundance increased in a downstream direction, with the exception of VDP. One possible explanation could be the direct impact of the upstream conditions. Notably, VDP is located close to the sites CKK and CPP, which both showed a significant decrease in individuals.

*Figure 3.9. Comparison of Benthic Diatom Results – Average Abundance in Viet Nam in 2008, 2011, 2013, 2015 and 2017*

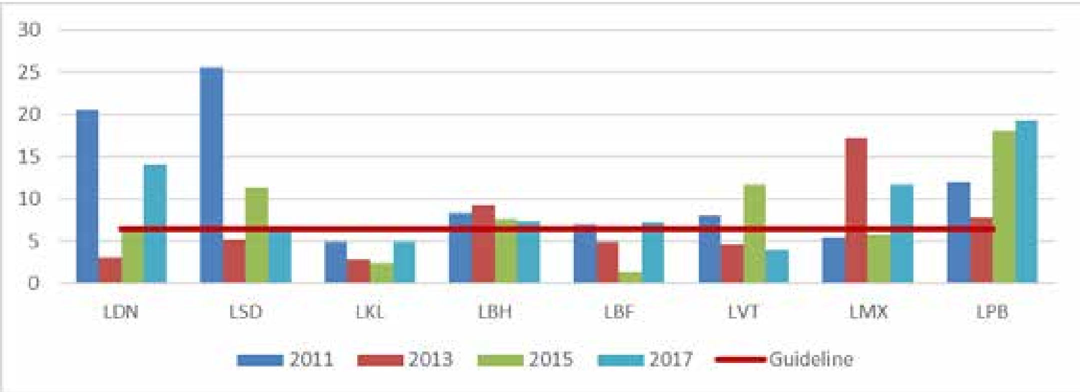


***Benthic Diatom Richness***

**Lao PDR**

Average benthic diatom richness across the sites in Lao PDR ranged between 4.00 taxa per site at LVT with *Gomphonema gracile Ehrenberg* being the most abundant to 19.30 taxa per site at LPB, Mekong River, Luang Prabang (as shown in ***Figure 3.10***) (mean= 9.50 ± 5.28 taxa per site). Potentially, diatom assemblages at LVT were affected by urban runoff and pollution from human activities. Average benthic diatom richness was lower than the guidelines set out with the reference sites (>6.54) at site LVT, LKL and LSD but guidelines were met at the other sites (LBF, LBH, LMX, LDN and LPB). One possible explanation could be the decreased visibility representing, which is not uncommon for this period. It was noted that the monitoring was carried out a month later than in 2015. Furthermore, the substrate may have been unsuitable for diatoms due to increased sedimentation resulting from the beginning of the wet season. Five out of the 8 sites had higher richness than reported in 2015, which also meet the threshold value for the healthy ecosystem. Site LVT shows a significant drop in richness compared to the last monitoring period. There was also the reoccurrence of some taxa that had ceased to be present in the previous monitoring period such as *Eunotia* sp. and *Meloseira varians Agardh*. Species *Gomphonema* sp.1, on the other hand, occurred in all samples of four sites (LKL, LBF, LMX and LPB), while frequently being sampled at all the other sides.

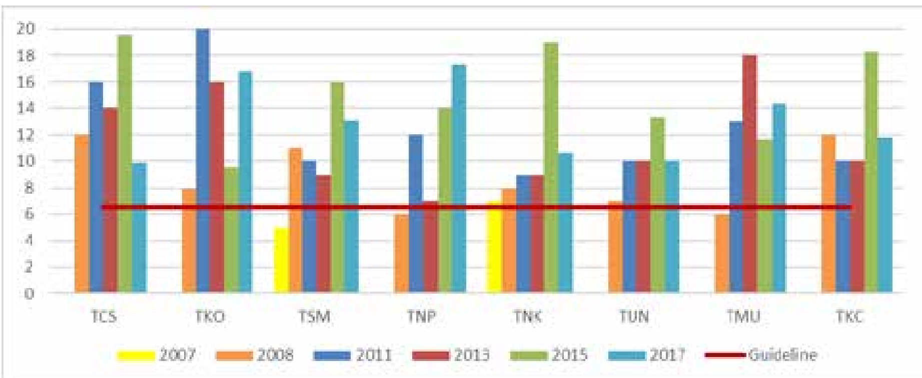
*Figure 3.10. Comparison Benthic Diatom Results - Average Richness in Lao PDR in 2011, 2013, 2015 and 2017*




**Thailand**

Benthic diatom species richness ranged from 9.90 taxa per site on the Mekong River at Chiang San, Chiang Rai (TCS) to 17.30 taxa per site at Nakorn Phanom City (TNP) (mean = 13.00 ± 2.75 taxa per site). Therefore, every site met guideline minimum benthic diatom richness levels for a healthy ecosystem of 6.54 taxa per site. Five sites showed lower values compared to the previous monitoring period in 2015 (as shown in ***Figure 3.11***), which directly reflects the decrease in the number of individuals. Predominantly, monitoring sites in Thailand have been increasingly impacted by human disturbances, which affects the diatom population and diversity.

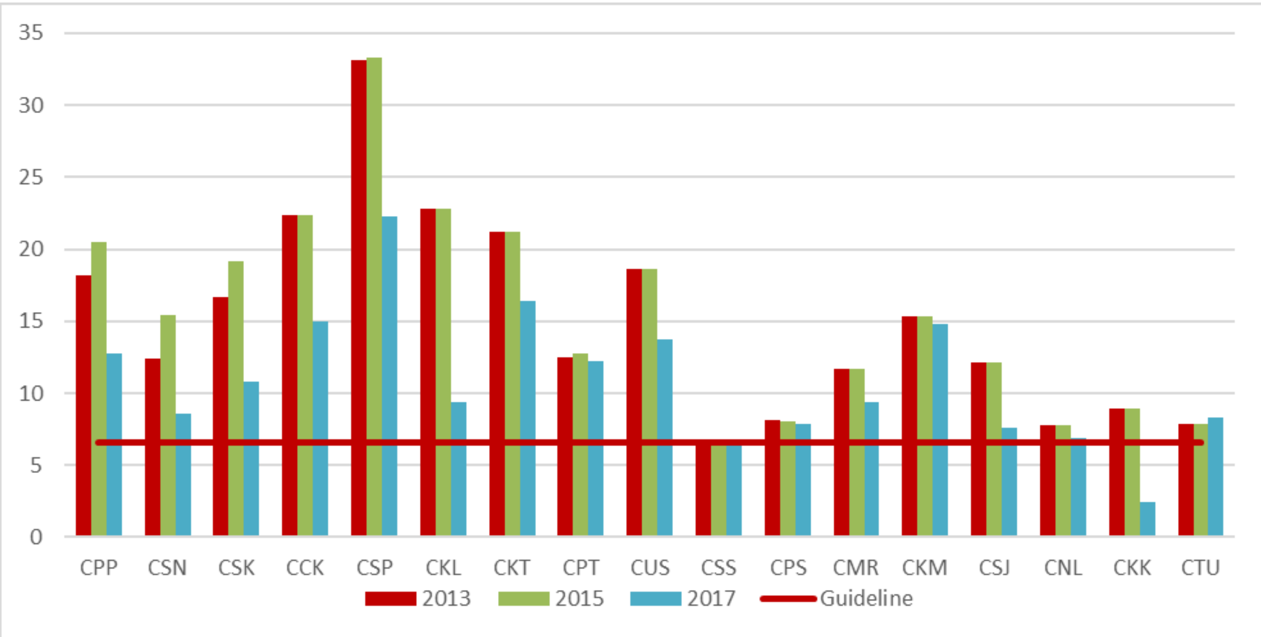
*Figure 3.11. Comparison of Benthic Diatom Results - Average Richness in Thailand in 2007, 2008, 2011, 2013, 2015 and 2017*



### Cambodia

Average benthic diatom richness at the study sites in Cambodia ranged between 2.40 and 22.30 taxa per site (mean = 10.90 ± 4.50 taxa per site). The highest average richness was found at Pursat River site (CPS), Damnak Ampil, Pursat. The lowest richness was at CKK in the Bassac River, Koh Khel, Kandal which was the only site in Cambodia not to meet benthic diatom richness requirements to qualify as a healthy ecosystem (>6.54) (***Figure 3.12***). This site showed a significant decrease in richness compared to 2015, which can be correlated to the unsuitable substrate in addition to the presence of algae blooms and human waste. Other sites that significantly decreased in average richness are sites CPP, CSN and CSK compared to 2015. For CPP and CSK this could be due to a general decrease in diatom abundance. At site CSN an increase in abundance of individuals may indicate an unfavorable habitat for the majority of other diatom species. The site on the Se San River, Veunsai, Rattanakiri (CSS) was only marginally above guideline levels with 6.70 taxa per site. The two former sites had high levels of disturbance, particularly from navigation, fishing and tourism activities. The average abundance for CSP on the Srepok River, Phik, Rattanakiri was also reasonably low with 7.90 taxa per site. Further downstream at the river junction between the Se San River and the Srepok River at Stung Treng (CSJ), the abundance continued to be low 7.60 taxa per site. One species, which was found in all sites in a majority of the samples was *Cymbella turgidula*. It needs to be mentioned that predominantly the sites in the Tonle Sap Lake and River show a decrease in richness compared to the last monitoring period. This should be kept in mind when sampling during the next monitoring investigate whether a continuous decline in taxa at those sites can be observed.

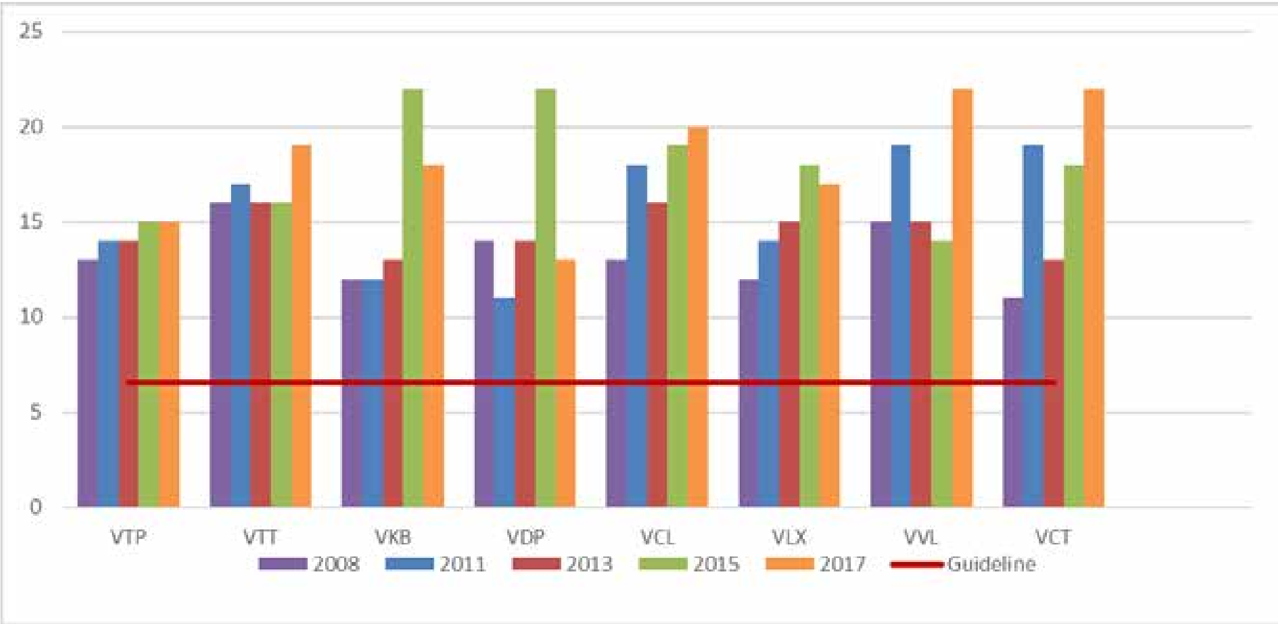
*Figure 3.12. Comparison of Benthic Diatom Results - Average Richness in Cambodia in 2013, 2015 and 2017*




### Viet Nam

Average richness ranged from 13.00 – 22.00 taxa (mean = 18.25 ± 2.90 taxa per site). Most of the species identified in samples from 2017 have been previously found in other sampling years. The *Navicula* genus had the largest number of species (27), followed by *Nitzschia* (22 species). VCT and VVL had the highest richness levels, both with 22 species. Both these sites receive high amounts of waste and agricultural inputs, causing fluctuations in nutrient levels in the river and changing environment conditions. Both the *Navicula* and *Nitzschia* genus are known to be tolerant towards variations in water quality (Muscio, 2002). VDP had the lowest level of richness at the time of sampling with only 13 species. As previously mentioned, the alluvial substrate at this site may be unsuitable to provide diatom habitat, preventing their settlement. Species richness varies considerably at sites through the monitoring years, likely to be reflecting response to some forms of disturbances. All sample sites in Viet Nam met the criteria for the healthy ecosystem in terms of benthic diatom richness (***Figure 3.13***). It can be seen that in 2015 there was a significant decrease in average richness at sites VDP and VKB, respectively which also reflects the drop in abundance. This could be due to the observed erosion rate and thereby increased sediment load at those sites.

*Figure 3.13. Comparison of Benthic Diatom Results - Average Richness in Viet Nam in 2011, 2013, 2015 and 2017*

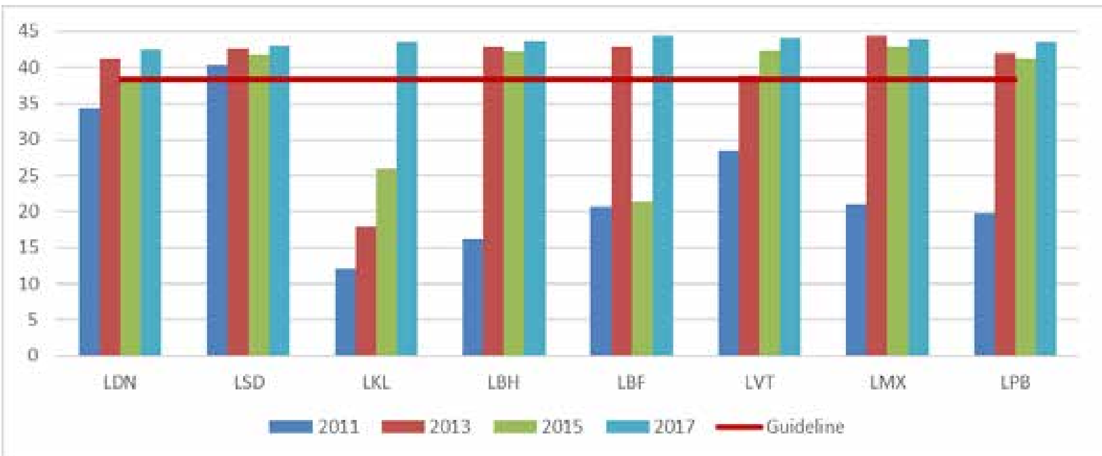



***Benthic diatom Average Tolerance Score Per Taxon (ATSPT)***[1]

**Lao PDR**

The ATSPTs ranged from 42.5 – 44.4 in Lao PDR (mean = 43.6 ± 0.6). All sites' ATSPT exceeded guideline recommendations (< 38.8). The highest value was found at LBF (44.4) whereas the lowest were found in LDN (42.5). As it can be seen, the trend for ATSPT has been rising over the last 4 monitoring periods (***Figure 3.14***). The increase in ATSPT may reflect the increase in human disturbance, in addition to an intensification of unfavorable habitat for a majority of taxa. Only sites LKL and LBF seem to have varying conditions, which may be due to sudden environmental changes at those sites. Both sites are not located on the mainstem of the Mekong River and could additionally be impacted by the local conditions from upstream.

*Figure 3.14. Comparison of Benthic Diatoms Results - ATSPT for Lao PDR in 2011, 2013, 2015 and 2017*

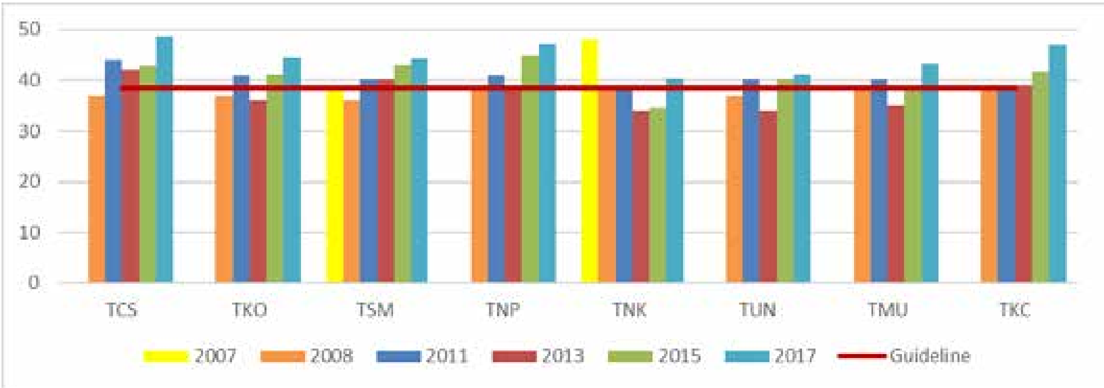



1 It is to be noted that the guidelines for a healthy ecosystem for ATSPT differ from the other two assessment indicators. For instance, the recommended value for the ATSPT should be BELOW 38.8 (above the 90th percentile), which differs from the average abundance and richness, which is being compared to the lowest 10th percentile, respectively.

### Thailand

The ATSPT in Thailand ranged from 40.3 at site TNK to 48.7 at TCS (mean = 44.5 ± 2.8), higher than tolerance scores in Lao PDR (***Figure 3.15***). This year, the ATSPT was slightly higher than in previous investigations and every site had ATSPT scores for diatoms that exceeded the threshold to be considered a healthy ecosystem. As for the abundance and for the richness of diatoms in Thailand, the rise in ATSPT could be explained by the higher impact of human activities (see SDS) and an increase in taxa that are more tolerable towards extreme environments. The trend of a rising ATSPT follows the same trend as in Lao PDR confirming the above statement. More monitoring is required, and focus should be laid on the key species that dominate at every site.

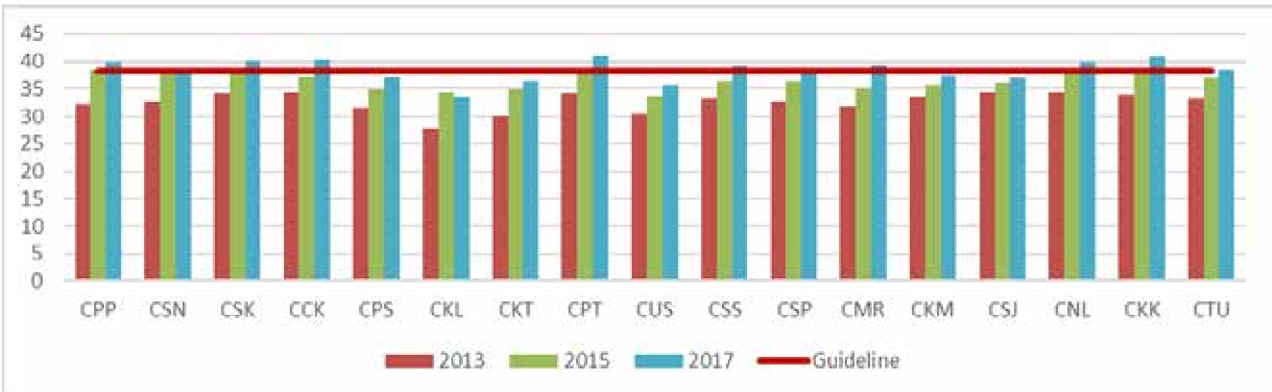
*Figure 3.15. Comparison of Benthic Diatom Results - ATSPT for Thailand in 2007, 2008, 2011, 2013, 2015 and 2017)*




### Cambodia

ATSPT scores ranged from 33.5 - 41.0 (mean=38.5 ± 2.0), with the highest score at CPT. The lowest tolerance level was recorded at CKL, which is also the only site with a decrease in ATSPT compared to 2015. All other sites' ATSPT values have steadily risen since 2013. It should be mentioned that this year is the first where 11 sites out of the 17 monitored sites in Cambodia exceeded the threshold value for being a healthy ecosystem. It is alarming that the same trend has been observed across the whole river (as shown in ***Figure 3.16***). Particularly, at CKK the increase in ATSPT may reflect the increase in human disturbance, in addition to an intensification of unfavorable habitat conditions for a majority of taxa, which is also consistent with the results from Thailand and Lao PDR.

*Figure 3.16 Comparision of Benthic Diatom Results - ATSPT for Cambodia in 2013, 2015 and 2017*




### Viet Nam

ATSPT scores ranged from 47.0 - 52.0 (mean = 48.3 ± 1.6), with the highest score at VVL and the lowest values recorded at VDP, VKB and VTT. The other sites ranged between scores of 48.0 - 49.0. All sites had ATSPT scores higher than the guideline levels of < 38.8 set out by the 90$^{th}$ percentile of the reference site. This shows that there is a high degree of environmental stress from human activities and furthermore, it is likely that there is an increased number of tolerable species present in the sites, which outnumber the less tolerable ones. Since the beginning of the EHM monitoring programme, the ATSPT values in Viet Nam have reflected high values, exceeding MRC's ecological health system's guideline. Since Viet Nam is located in the delta of the Mekong and the Bassac River, a possible explanation of the high ATSPT value is the accumulation of pollutants from upstream, which are further amplified by the additional local pollutants and human impacts.

*Figure 3.17. Comparison of Benthic Diatoms Results - ATSPT for Viet Nam in 2011, 2013, 2015 and 2017*

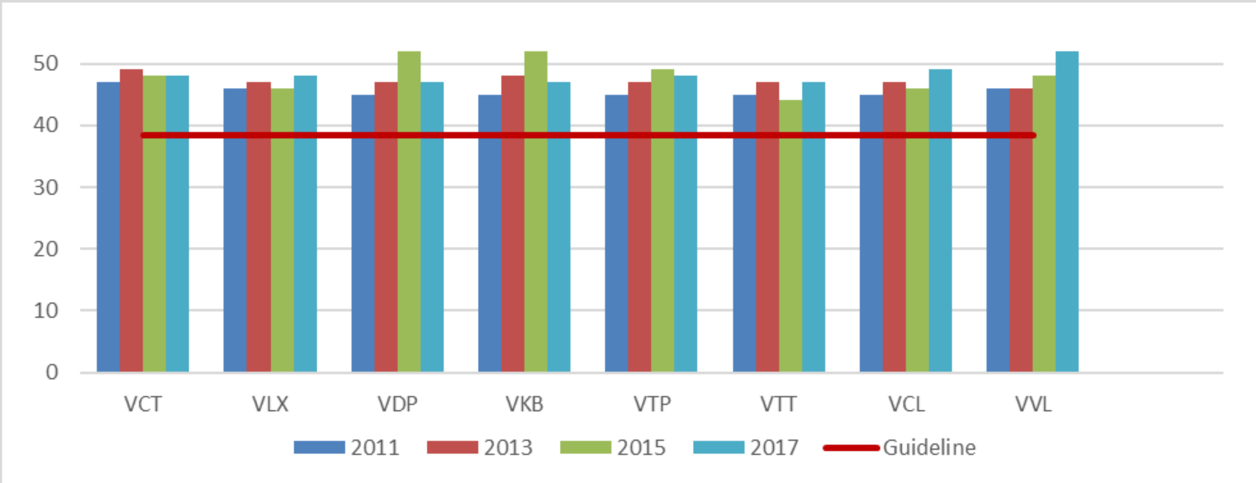



*Table 3.2. Comparison of Diatoms - Average Abundance, Average Richness and ATSPT scores for sample sites of the Lower Mekong Basin in 2011, 2013, 2015 and 2017*

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** |
| **LMX** | 128.5 | 397.5 | 112.0 | 210.5 | 5.40 | 17.20 | 5.80 | 11.8 | 21.0 | 44.4 | 42.8 | 43.9 |
| **LPB** | 1,493.0 | 300.0 | 1,139.0 | 985.0 | 12.00 | 7.80 | 18.10 | 19.3 | 19.8 | 41.9 | 41.3 | 43.5 |
| **LVT** | 1,288.0 | 125.0 | 768.0 | 188.0 | 8.10 | 4.60 | 11.80 | 4.0 | 28.5 | 38.8 | 42.3 | 44.0 |
| **LBF** | 210.0 | 284.0 | 46.0 | 328.5 | 7.00 | 4.90 | 1.40 | 7.2 | 20.6 | 42.9 | 21.5 | 44.4 |
| **LBH** | 397.0 | 180.0 | 118.0 | 127.0 | 8.40 | 9.30 | 7.70 | 7.4 | 16.1 | 42.9 | 42.1 | 43.6 |
| **LSD** | 5,107.0 | 503.0 | 575.0 | 130.0 | 25.60 | 5.20 | 11.30 | 6.1 | 40.3 | 42.6 | 41.8 | 43.1 |
| **LDN** | 1,120.0 | 161.0 | 78.0 | 296.0 | 20.60 | 3.10 | 6.50 | 14.1 | 34.3 | 41.3 | 38.3 | 42.5 |
| **LKL** | 510.0 | 83.0 | 213.0 | 55.0 | 2.80 | 2.80 | 2.50 | 4.9 | 12.2 | 17.9 | 26.0 | 43.5 |
| **TCS** | 2,911.0 | 888.0 | 1,913.0 | 150.0 | 16.00 | 14.00 | 19.60 | 9.9 | 44.0 | 42.0 | 42.8 | 48.7 |
| **TKO** | 1,275.0 | 2,098.0 | 3,830.0 | 445.0 | 20.00 | 16.00 | 9.50 | 16.8 | 41.0 | 36.0 | 41.1 | 44.6 |
| **TSM** | 1,028.0 | 869.0 | 1,909.0 | 187.0 | 10.00 | 9.00 | 16.00 | 13.1 | 40.0 | 40.0 | 43.0 | 44.3 |
| **TNP** | 777.0 | 192.0 | 1,518.0 | 323.0 | 12.00 | 7.00 | 14.02 | 17.3 | 41.0 | 39.0 | 44.9 | 47.1 |
| **TNK** | 103.0 | 411.0 | 1,047.0 | 101.0 | 9.00 | 9.00 | 19.00 | 10.6 | 38.0 | 34.0 | 34.7 | 40.3 |
| **TUN** | 434.0 | 4,743.0 | 897.0 | 224.0 | 10.00 | 10.00 | 13.30 | 10.0 | 40.0 | 34.0 | 40.2 | 41.2 |
| **TMU** | 1,471.0 | 4,581.0 | 404.0 | 109.0 | 13.00 | 18.00 | 11.70 | 14.3 | 40.0 | 35.0 | 38.0 | 43.1 |
| **TKC** | 1,069.0 | 2,981.0 | 1,325.0 | 74.0 | 10.00 | 10.00 | 18.30 | 11.8 | 38.0 | 39.0 | 41.7 | 46.9 |
| **CMR** | | 124.4 | 218.4 | 245.6 | | 11.7 | 11.70 | 9.4 | | 31.77 | 35.1 | 39.17 |
| **CKM** | | 159.7 | 294.1 | 318.3 | | 15.3 | 15.30 | 14.8 | | 31.8 | 35.1 | 39.2 |
| **CSS** | | 73.5 | 128.6 | 167.5 | | 6.8 | 6.80 | 6.7 | | 33.5 | 35.7 | 37.5 |

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CSJ | | 118.2 | 204.2 | 113.9 | | 12.1 | 12.10 | 7.6 | | 33.4 | 36.4 | 39.0 |
| CUS | | 181.4 | 325.6 | 416.5 | | 18.6 | 18.60 | 13.7 | | 34.5 | 36.2 | 37.0 |
| CSP | | 86.5 | 391.9 | 505.9 | | 8.1 | 33.30 | 22.3 | | 30.5 | 33.7 | 35.7 |
| CKT | | 135.5 | 232.1 | 272.6 | | 21.2 | 21.20 | 16.4 | | 32.7 | 34.8 | 37.4 |
| CPT | | 117.9 | 197.1 | 377.4 | | 12.5 | 12.80 | 12.2 | | 30.0 | 34.8 | 36.5 |
| CCK | | 169.3 | 297.3 | 231.5 | | 22.4 | 22.40 | 15.0 | | 34.2 | 38.3 | 41.0 |
| CSK | | 113.5 | 215.1 | 98.7 | | 16.7 | 19.20 | 10.8 | | 34.3 | 37.4 | 40.3 |
| CPS | | 224.5 | 146.9 | 172.1 | | 33.1 | 8.00 | 7.9 | | 34.2 | 38.2 | 40.2 |
| CKL | | 145.8 | 260.3 | 246 | | 22.8 | 22.80 | 9.4 | | 31.5 | 36.5 | 38.4 |
| CSN | | 85.4 | 170.6 | 266.1 | | 12.4 | 15.40 | 8.6 | | 27.9 | 34.5 | 33.6 |
| CTU | | 108.8 | 193.6 | 227.9 | | 7.9 | 7.90 | 8.3 | | 32.6 | 37.8 | 38.7 |
| CPP | | 147.7 | 278.9 | 111.4 | | 18.2 | 20.50 | 12.8 | | 33.4 | 37.2 | 38.4 |
| CKK | | 111.2 | 193.5 | 48.5 | | 8.9 | 8.90 | 2.4 | | 32.1 | 38.3 | 40.0 |
| CNL | | 78 | 139.9 | 181 | | 8 | 7.80 | 6.9 | | 33.9 | 38.3 | 40.9 |
| VTP | 50.2 | 177.2 | 261.6 | 205 | 14.00 | 14.00 | 15.00 | 15.0 | 45.0 | 47.0 | 49.0 | 48.0 |
| VTT | 79 | 86.2 | 143.2 | 297.8 | 17.00 | 16.00 | 16.00 | 19.0 | 45.0 | 47.0 | 44.0 | 47.0 |
| VKB | 45.8 | 84.4 | 450.2 | 272.2 | 12.00 | 13.00 | 22.00 | 18.0 | 45.0 | 48.0 | 52.0 | 47.0 |
| VDP | 42.4 | 88.6 | 311.8 | 174.8 | 11.00 | 14.00 | 22.00 | 13.0 | 45.0 | 47.0 | 52.0 | 47.0 |
| VCL | 162.2 | 116.2 | 373.8 | 461 | 18.00 | 16.00 | 19.00 | 20.0 | 45.0 | 47.0 | 46.0 | 49.0 |
| VLX | 125 | 81 | 188 | 471.8 | 14.00 | 15.00 | 18.00 | 17.0 | 46.0 | 47.0 | 46.0 | 48.0 |
| VVL | 104.8 | 108.4 | 757.4 | 617.4 | 19.00 | 15.00 | 14.00 | 22.0 | 46.0 | 46.0 | 48.0 | 52.0 |
| VCT | 149.8 | 134.4 | 288.8 | 599.2 | 19.00 | 13.00 | 18.00 | 22.0 | 47.0 | 49.0 | 48.0 | 48.0 |

(the yellow highlight indicates the sites not located on the mainstem.)

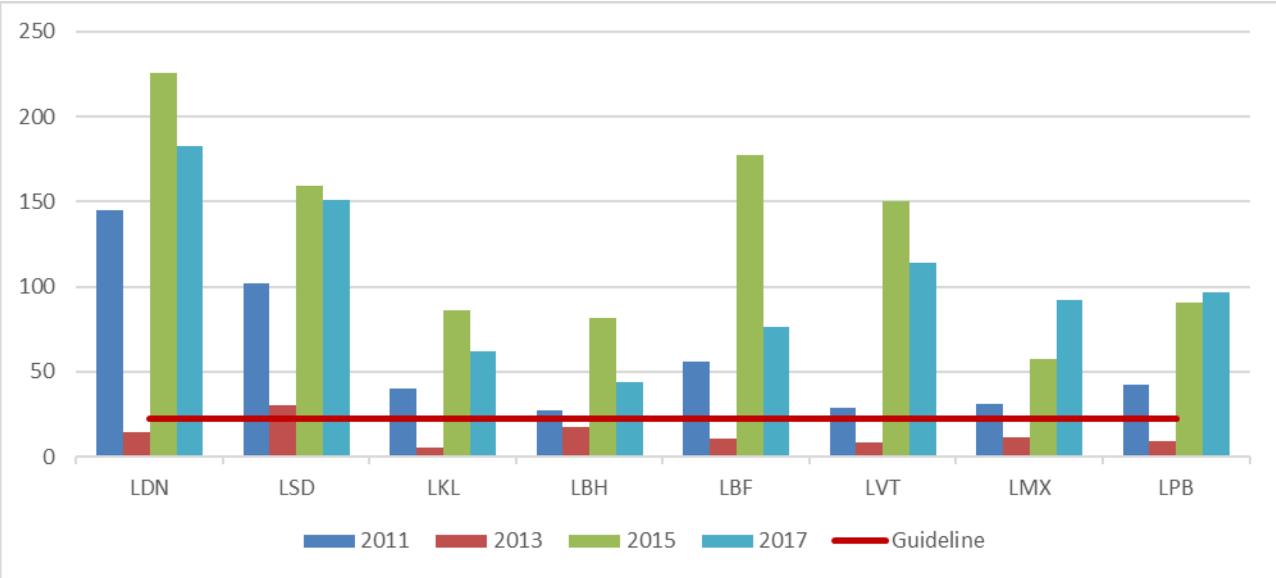
## 3.3. Zooplankton

### *Zooplankton Abundance*

#### Lao PDR

The total number of individuals of zooplankton found across sites in Lao PDR was 2,489 individuals, including larvae specimens. These consisted of 99 taxa, 7 orders, 25 families and 47 genera. The average zooplankton abundance in Lao PDR was between 44.0 and 183.0 individuals per site (mean = 104.8 ± 41.2 individuals per site) ranging between 134.0 – 560.0 individuals per sample within each site (as shown in ***Figure 3.18*** and ***Table 3.3***). The highest abundance was found at site LDN on the Mekong River, Done Ngiew, Campasak, which is consistent with the previous monitoring period. The lowest number of zooplankton was at Se Bang Hieng River in Savannakhet Province (LBH). Two possible reasons for the limited number of present zooplankton could be 1) due to strong currents during sample collection affecting a reliable zooplankton distribution or 2) a change in the ecological condition of the river compared to the previous monitoring period. All abundances across sites had decreased in comparison to 2015, except LMX and LPB where abundance had slightly increased. One possible explanation for this increase could be better sampling conditions at those sites, as both LMX and LPB had pools of standing water, allowing direct sampling. These two sites are the most northern sites being monitored and are not significantly impacted by upstream activities. On the other hand, the decrease of the zooplankton at the other sides could be related to the intensification of human activities, causing environmental changes. It needs to be noted, however, that all sites met with MRC zooplankton abundance guidelines suggesting the first justification might be valid.

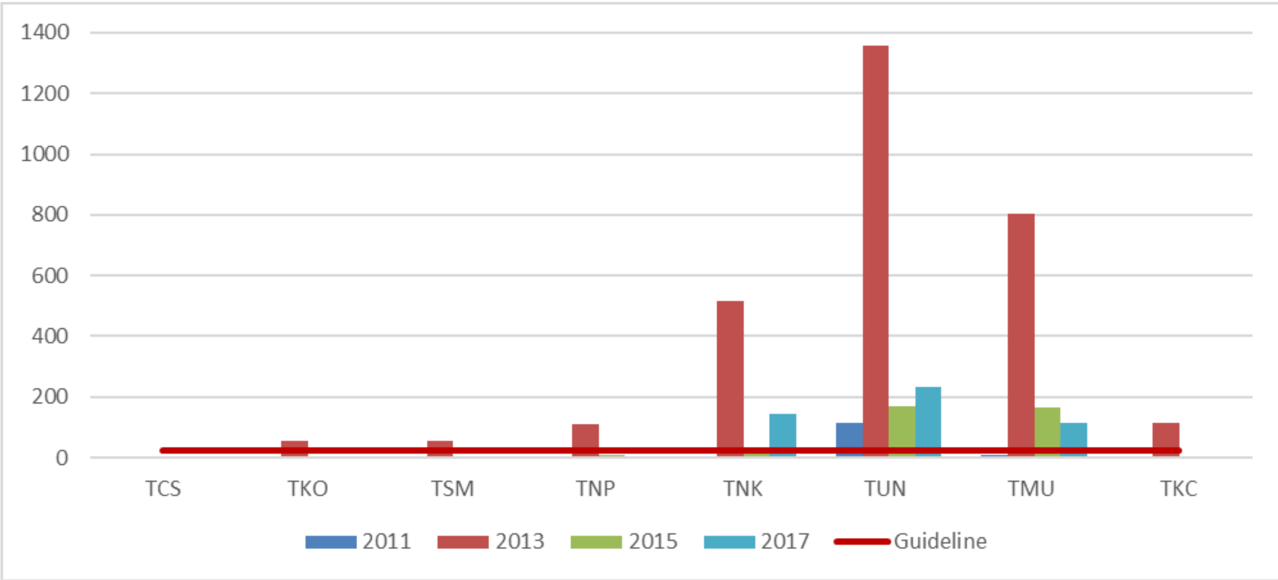
*Figure 3.18 Comparison of Zooplankton Results - Average Abundance for Lao PDR in (2011, 2013, 2015 and -2017*




**Thailand**

1,472 individual zooplankton were collected over the sample sites across Thailand. The zooplankton abundance was significantly lower than the previous years 2015 and 2013. This may be due to that the sampling was undertaken in the beginning of the rainy season impacting the present nr. of zooplankton as a result of higher water velocity and turbidity. The average abundance of zooplankton ranged from 0 to 230.7 individuals from the 8 study sites across Thailand (mean = 61.3 ± 84.4 individuals per site). The highest abundance was recorded at site TUN on Mun River, Ubon Rachathani (230.7 individuals), while no zooplankton was found at the sites TCS, TKO and TNP (the Mekong River at Nakorn Phanom, Kong Chiam and Kok River) (***Figure 19***). This could be due to the fast flow-rate and the high turbidity at the time of sampling. It seems that some form of disturbance occurred between sites LMX and TCS. At both sites TCS and TKO are located on the mainstem of the Mekong River and between the two monitoring sites in Lao PDR, LPB and LMX, respectively, which both had shown a rise in numbers of individual zooplankton. TCS and TKO also show high SDS scores, which also could explain the lack of zooplankton and indicate some form of local disturbance making the environment unsuitable for zooplankton. TCS, for instance is located in an area that is impacted by human activities, while further up and downstream from this site, mountains surround the river, providing additional freshwater. Additionally, the decrease of diatoms may also have contributed to a declined number of zooplankton, since they provide a source of food for numerous zooplankton species. *Brachionus angularis* and *Copepoda* (nauplius and copepodite) were the most abundant and distributed species found among the sites. Except for TNK, TUN and TMU all sites failed to meet the guideline level of zooplankton abundance to signify a healthy ecosystem. The just mentioned sites are located on tributaries, possibly having a lower flowrate.

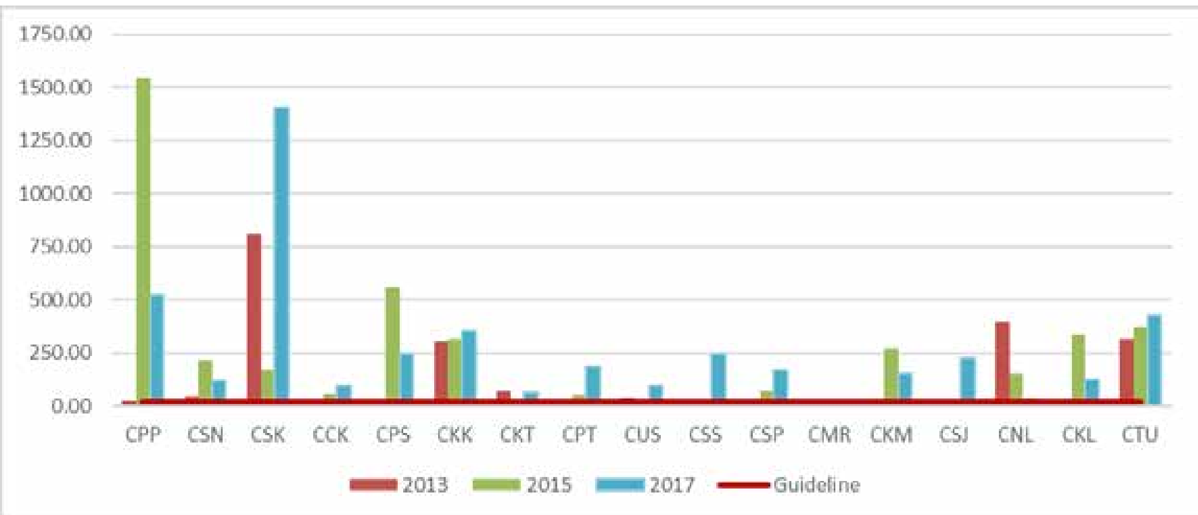
*Figure 3.19. Comparison of Zooplankton Results - Average Abundance for Thailand in 2011, 2013, 2015 and 2017*




**Cambodia**

Overall, the zooplankton abundance across the Cambodian sites ranged from 17.8 to 1,407.3 individuals per site (mean = 1,258.7 ± 314.5 individuals per site). 40% of the sites had zooplankton abundance levels between 200 and 450 individuals per site. The highest level of abundance was much higher than at other sample sites, found at CSK (Stoeng Sangke River, Kampong Thom) with 1,407 individuals per site (***Figure 3.20***). The most abundant species at this site were *Cyclopidae* sp., *Pompholyx complanate* and *Trichocerca pusilla* with more than 2,000 individuals at just that site (in total 10 samples). Moreover, these species were frequently found at other sites. Only CMR (Mekong River, Ramsar Site, Stung Treng) did not adhere the guideline threshold abundance level for a healthy ecosystem of > 22.3 individuals per site, which could be explained by the increased amount of algae present at this site. Also, CMR (17.8), CNL (35.9) and CKT (65.0) are the only sites located directly on the mainstem of the Mekong River. The low abundance could thereby be due to the constant changing conditions (flow rate, sediment load etc.). This is consistent with the same pattern observed in Thailand. Compared to the previous monitoring periods no trend can be observed. The individual spikes in abundance that can be seen on ***Figure 3.20*** represent a biased abundance with several species dominating at the site during sampling. The varying number of individuals could reflect an everchanging environment.

*Figure 3.20. Comparison of Zooplankton Results - Average Abundance for Cambodia in 2013, 2015 and 2017*

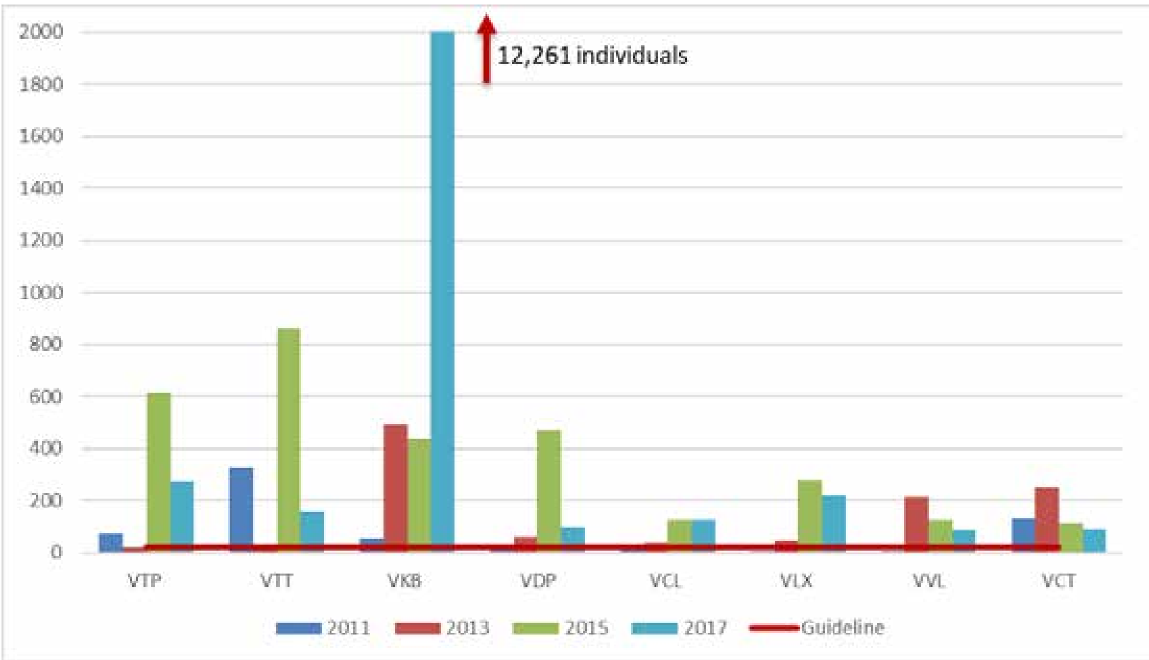


**Viet Nam**

The average abundance of zooplankton in Viet Nam ranged from 89-12,261 individuals per site (mean = 1,664.8 ± 4,005.5 individuals per site). ***Figure 3.21*** showes that predominantly the sites varied from 89.0-274.0 individuals in average, however, sampling site VKB (Bassac River, Khanh Binh, An Giang) had a notably higher average zooplankton abundance than all other sites being monitored in the LMB, with an average abundance of 12,261 individuals per site. It must be noted that Family Volvocaceae (Protozoa) made up most of this population (12,000 individuals in average). These species are known to thrive in environments with high levels of decomposing matter and abundant bacteria present, especially phosphate. Often, eutrophication may occur due to their presence (Kirk, D. , 1997).

On the other hand, a large decrease in abundance was observed at 6 of the other sites compared to 2015. The largest decrease was seen at VTT which decreased from 2,587 in 2015 to 468 individuals per sample in 2017. These decreases in abundance could be due to increased turbulence due to bank erosion. Apart from VKB, VCL had a slight increase in average since 2015. All sample sites had met the threshold value of 22.3. The species distribution ranges across 6 groups and 26 families. While there has not been an overall decrease in occurring species and individuals, there has been a shift in the frequency in which the species are present. For instance, the group Protozoa has been declining since 2013, while phylum Rotifera has been increasing by 10 %, which could imply that Rotifera favours the changing environmental conditions.

*Figure 3.21. Comparison of Zooplankton results - Average Abundance for Viet Nam in 2011, 2013, 2015 and 2017*



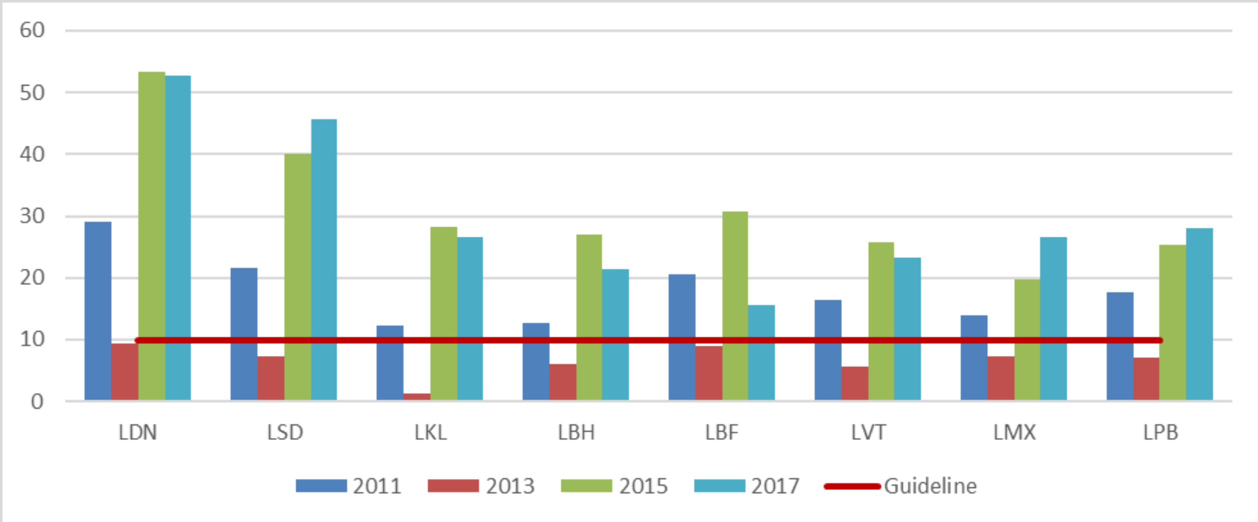

*Note the y-axis was modified to show further detail on other all sites. Site VKB is not fully displayed here.*

***Zooplankton Average Richness***

**Lao PDR**

There were four main zooplankton groups found at sites across Lao PDR. These were Protozoa, Rotifera, Cladocera and Copepoda. No new taxa had established themselves since the previous sampling period. Measuring the average richness found that the number of species per site ranged from 23.3-52.7 (mean = 31.0 ± 10.9 species per site) (as shown in ***Figure 3.22*** and ***Table 3.3***). Most species were found at site LDN. The lowest levels of richness were located at LBF . Some sites exhibited a slight decrease in richness in comparison to 2015 (LKL and LVT). However, all sites met the guidelines for the minimum level of richness (> 9.8).

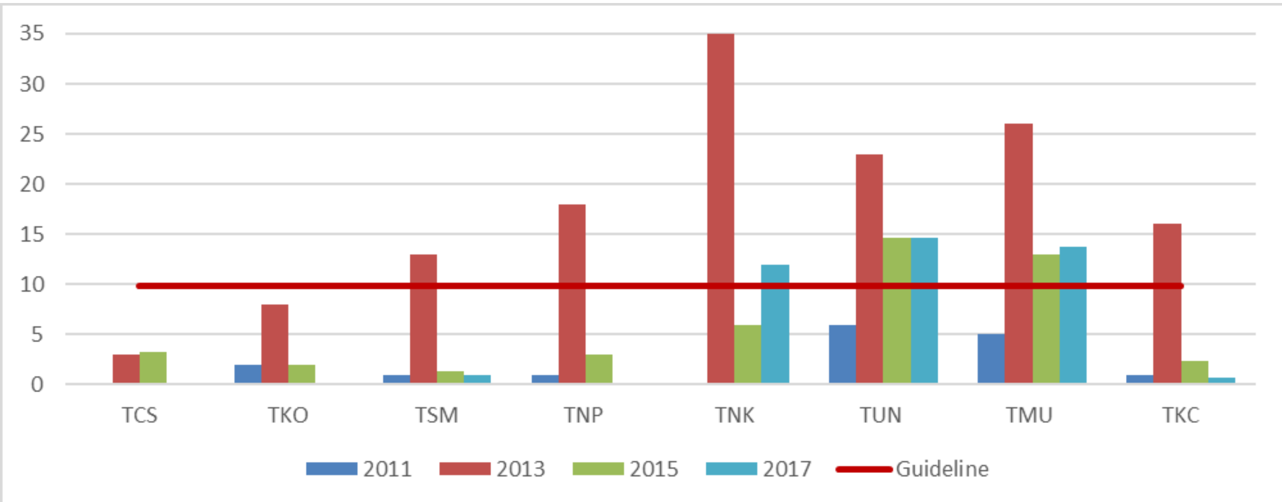
*Figure 3.22. Comparison of Zooplankton Results - Average Richness for Lao PDR in 2011, 2013, 2015 and 2017)*




### Thailand

The eight sites sampled in 2017 yielded a total of 41 different species of zooplankton. Species richness per site ranged from 0 to 14.7 taxa per site (mean = 5.3 ± 6.4 species per site) (as shown in ***Figure 3.23*** and ***Table 3.3***). *Brachionus angularis* and *Copepoda* spp. (nauplius and copepodite) were the most abundant and widely distributed among the sites. Reflecting the results obtained in the previous section, the same sites that failed to meet the threshold value of the MRC's guideline, also had low a low number of species diversity. Hence, sites TNP, TSM, TKC, TCS and TKO did not meet the guideline's threshold value of 9.8 species. Most likely, the sampling procedure was affected by the high turbidity of the river at the time of sampling. The highest richness was recorded at site TUN (14.7 species per site), which was also the site with the highest species richness in the 2015 sampling period.

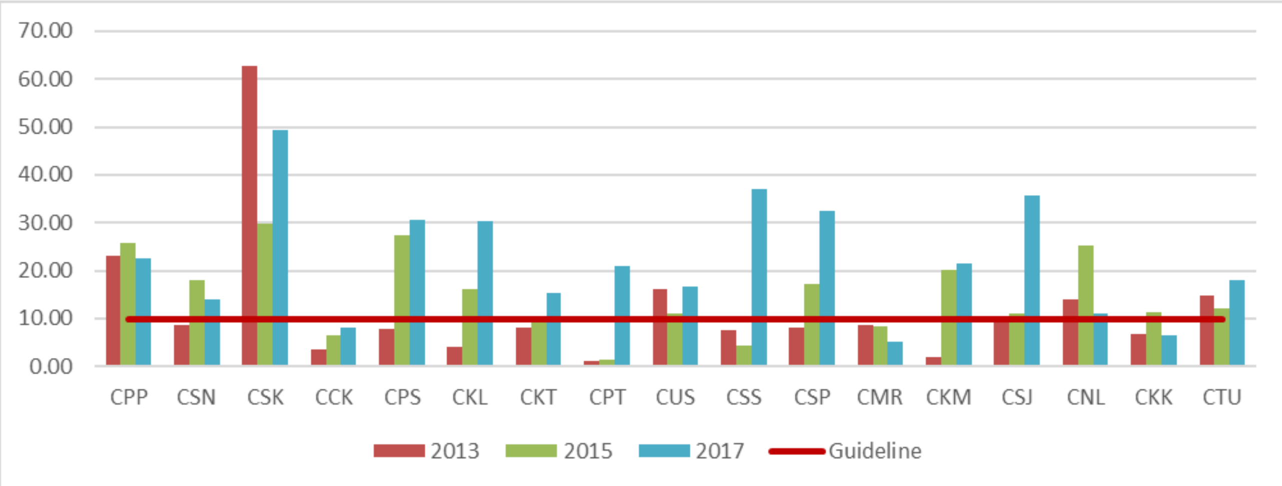
*Figure 3.23. Comparison of Zooplankton Results - Average Richness for Thailand in 2011, 2013, 2015 and 2017*




### Cambodia

The species richness in Cambodia during the 2017 monitoring period ranged from 5.6 - 49.44 species per site (mean = 22.1 ± 12.3 species per site). The highest average zooplankton species richness was measured at CSK with 49 species. Three sites (CMR, CCK and CKK) did not meet the required average threshold value of 9.8 species per site. The most dominant species present in Cambodia are *Arcella discoides,* which was found at all sites and was among the ten most abundant species. Furthermore, *Cephalodella auriculate* and *Culurella obtuse* were present at 16 of the sampling sites with the exception of CSN. It is likely that the high flow rate at the site CMR may have affected the result. On the other hand, CKK and CCK may have suffered from incentive farming and navigation activities, causing a higher nutrient content leading to algae blooms and a reduced amount of DO in the water (as shown in ***Figure 3.24*** and ***Table 3.3***), which increases the likelihood of their presence. As it can be seen, the number of species has predominantly increased throughout the last monitoring period indicating that overall the environmental conditions are in favor for a number of zooplankton species. Only 5 sites (CPP, CKK, CSN, CMR and CNL) show a relative decrease in species diversity. As for the diatoms, CPP and CKK show a great decrease, which may indicate less food for individual zooplankton species.

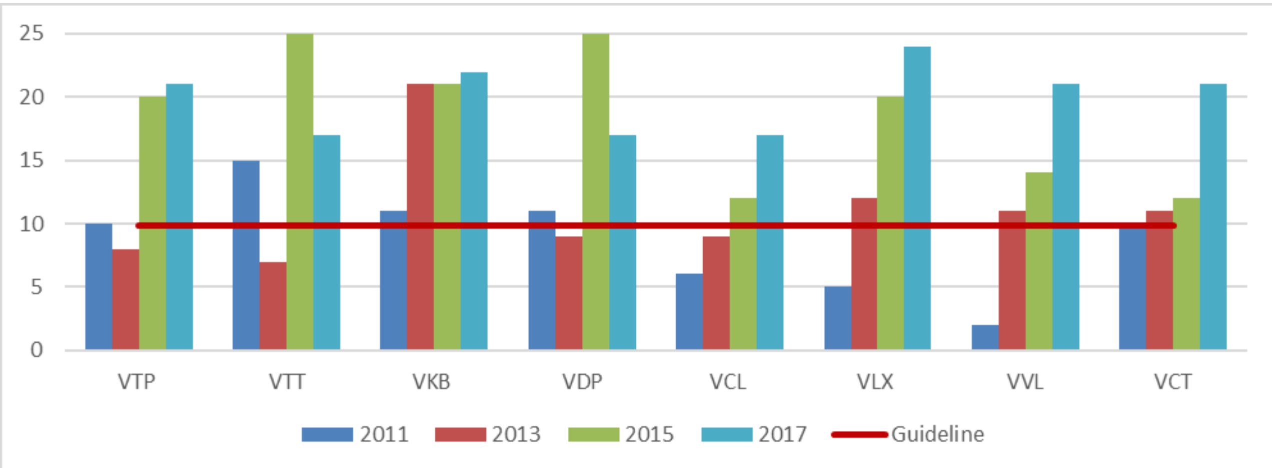
*Figure 3.24. Comparison of Zooplankton Results - Average Richness for Cambodia in 2013, 2015 and 2017*




**Viet Nam**

Average richness of zooplankton across the sample sites in Viet Nam in 2017 ranged from 17.0 to 24.0 species per site (mean = 20 ± 2.5 species per site). Among the recorded species, *Copepoda* sp. (nauplius), the larva of *Bivalvia* sp. and *Volvox aureus* occurred during all sample occasions. The highest level of richness was found at site VLX (Bassac River, Long Xuyen, An Giang) (24 species per site) while VDP (Bassac River, Da Phuoc, An Giang), VTT (Mekong River, Thuong Thoi, Dong Thap) and VCL (Mekong River, Cao Lanh, Dong Thap) had the lowest richness with 17 species per site (as shown in ***Figure 3.25***). These sites potentially had low levels of richness due to the major erosion observed at the sites, combined with discharge from agriculture residuals. Since the beginning of the monitoring in 2008, the amount of different species is increasing across all sites with the exception of VDP and VTT. As indicated above, these sites were prone to more erosion during this monitoring period, which may be an explanation for the two sites not following the general trend. All sites met the reference value for zooplankton richness of 9.8.

*Figure 3.25. Comparison of Zooplankton Results - Average Richness for Viet Nam in 2011, 2013, 2015 and 2017*

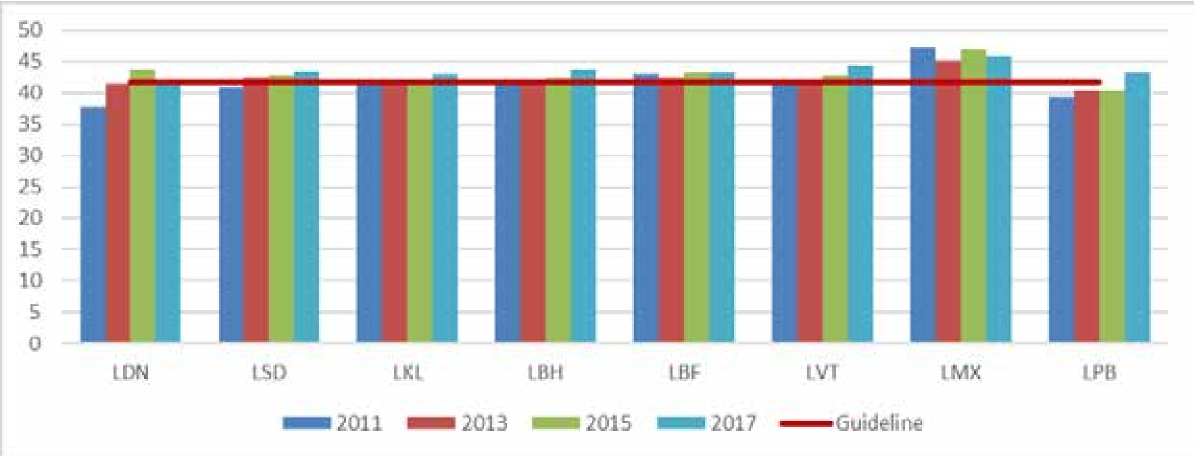


***Zooplankton Average Tolerance Score Per Taxon (ATSPT)***

**Lao PDR**

The ATSPT values for Lao PDR ranged from 42.22 at LDN to 45.95 at LMX. The high ATSPT at LMX could further be explained by the strong current at that site, making sampling additionally difficult. For the first time, also site LPB failed to meet the threshold value of MRCs guideline for being a healthy ecosystem. During the last 3 monitoring periods, all sites seem to follow an overall trend of increasing ATSPT with the exception of LMX, which since 2011 has been exceeding the guideline as shown in ***Figure 3.26***. This suggests that mores species tolerable to rapid and extreme changes in the river environment dominate and all sites experience an increase in human activities.

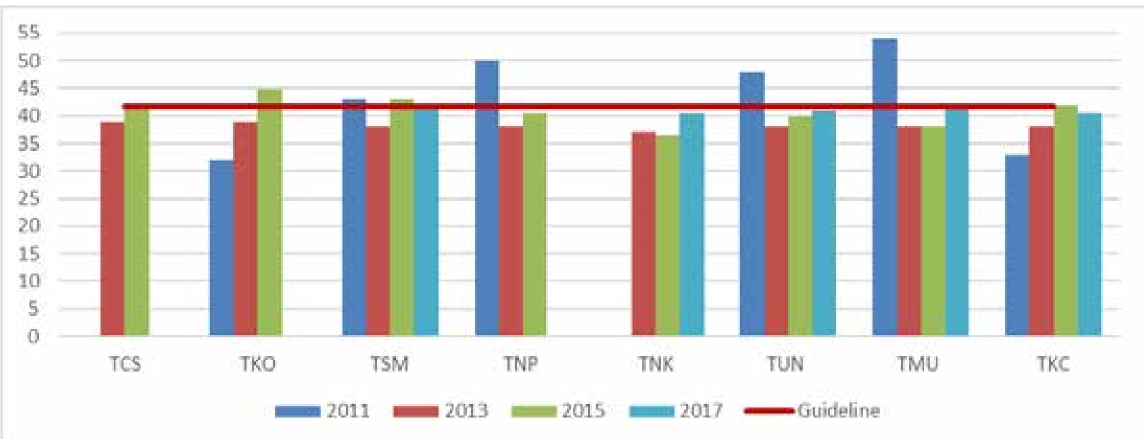
*Figure 3.26. Comparison of Zooplankton Results - ATSPT for Lao PDR in 2011, 2013, 2015 and 2017*




**Thailand**

In Thailand, the ATSPT values varied between 40.6 at TNK and 42.3 at TMU. These two sites were also above those of MRC's healthy ecosystem guideline (as shown in ***Figure 3.27***). Due to the absence of zooplankton at the three mainstem sites (TCS, TKO and TNP), an ATSPT score could not be obtained at those sites. The lack of zooplankton could be an indicative for an unhealthy ecosystem although it needs to be mentioned that conditions while sampling were not ideal and could have biased the results. The remaining 3 sites (TKC, TUN and TNK) showed ATSPT values that met the guidelines for a healthy ecosystem. Compared to the previous monitoring period, the overall trend has been similar than in Lao PDR steadily increasing although the absence of zooplankton at three out of eight monitoring suggests that the ecological status at those sites is not favourable for zooplankton. Focus should be put on the collection of zooplankton to give a better estimate of the health status.

*Figure 3.27. Comparison of Zooplankton Results - ATSPT for Thailand in 2011, 2013, 2015 and 2017*



**Cambodia**

Average Tolerance Score per taxon for the zooplankton species found at sites in Cambodia ranged between 13.7 at CCK and 42.2 at CSK (mean = 34.2 ± 9.1). Only one of the 17 sites (CSK) did not meet the ATSPT value of 41.8 being the threshold value of MRCs healthy ecosystem's guideline. This result directly reflects the high abundance of the most dominant species (*Cyclopidae* sp., *Pompholyx complanate* and *Trichocerca pusilla)* in addition to the high SDS value (2.53) allocated to CSK in 2017. Surprisingly, site CCK, despite of its high SDS of 2.58 had a low ATSPT value of only 13.7. It may be that due to the general low abundance of zooplankton at this site throughout the monitoring years, the overall tolerance score for CCK is low. A similar pattern is observed for CKL. This shows the necessity to include all biometric indicators in the assessment of a site.

*Figure 3.28. Comparison of Zooplankton Results - ATSPT for Cambodia in 2013, 2015 and 2017*


**Viet Nam**

ATSPT scores in 2017 for sites in Viet Nam ranged between 45-46 with a mean of 45.63 ± 0.48 (as shown in ***Figure 3.29*** and ***Table 3.3***). The sites with a score of 46 were VCT, VLX, VTP, VTT and VTL. The remainder of the sites had a score of 45. Therefore, all sites were above the reference level of 41 suggesting that also for the biological indicator zooplankton the more tolerable species dominate the overall abundancy of the present species. It has been speculated that high levels of erosion may have contributed to this having caused an increase in sediments and destroying some of the zooplanktons initial habitat. Since the beginning of the monitoring programme in 2008 the ATSPT scores for all Viet Nam sites have only varied slightly, being above the threshold value for a healthy ecosystem at all times.

*Figure 3.29. Comparison of Zooplankton Results - ATSPT for Viet Nam in 2011, 2013, 2015 and 2017*

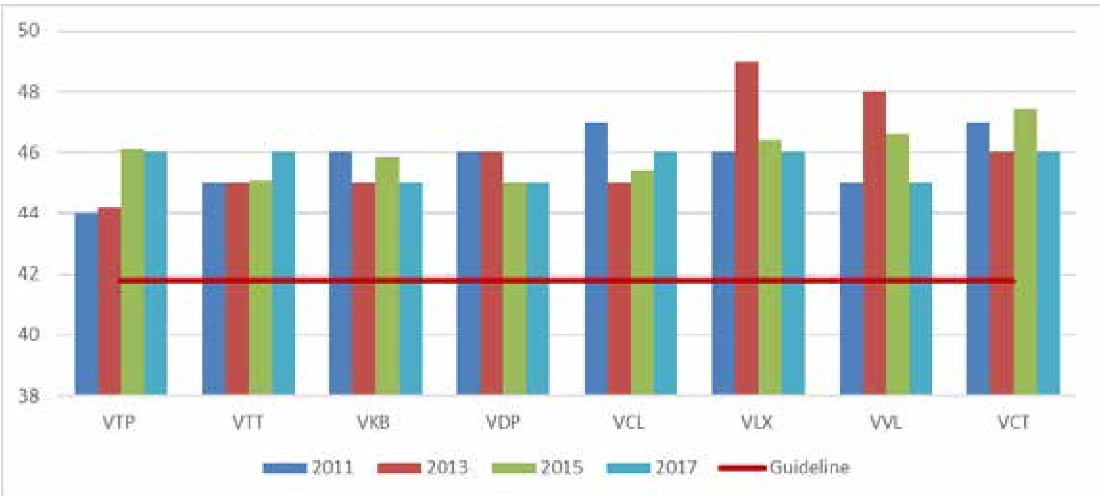


*Table 3.3. Comparison of Zooplankton Average Abundance, Average Richness and ATSPT scores for all monitoring sites of the Lower Mekong Basin in 2011, 2013, 2015 and 2017*

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 |
| LMX | 31.3 | 11.7 | 57.7 | 92.0 | 14.0 | 7.3 | 19.7 | 26.7 | 47.4 | 45.2 | 46.9 | 46.0 |
| LPB | 42.3 | 9.0 | 90.3 | 97.0 | 17.7 | 7.0 | 25.3 | 28.0 | 39.4 | 40.4 | 40.4 | 43.2 |
| LVT | 28.7 | 8.0 | 150.3 | 113.7 | 16.3 | 5.7 | 25.7 | 23.3 | 41.8 | 41.9 | 42.9 | 44.5 |
| LBF | 56.0 | 10.3 | 177.7 | 76.3 | 20.7 | 9.0 | 30.7 | 15.7 | 43.0 | 42.4 | 43.3 | 43.3 |
| LBH | 27.3 | 17.3 | 81.7 | 44.0 | 12.7 | 6.0 | 27.0 | 21.3 | 41.2 | 41.9 | 42.6 | 43.8 |
| LSD | 102.0 | 30.3 | 159.0 | 150.7 | 21.7 | 7.3 | 40.0 | 45.7 | 41.0 | 42.5 | 42.9 | 43.5 |
| LDN | 145.3 | 14.0 | 226.0 | 183.0 | 29.0 | 9.3 | 53.3 | 52.7 | 37.9 | 41.5 | 43.7 | 42.2 |
| LKL | 40.3 | 5.3 | 17.3 | 81.7 | 12.3 | 1.3 | 28.3 | 25.7 | 41.2 | 41.3 | 42.3 | 43.0 |
| TCS | 0.0 | 5.0 | 4.0 | 0.0 | 0.0 | 3.0 | 3.3 | 0.0 | - | 39.0 | 42.2 | 0.0 |
| TKO | 3.0 | 53.0 | 6.0 | 0.0 | 2.0 | 8.0 | 2.0 | 0.0 | 32.0 | 39.0 | 44.9 | 0.0 |
| TSM | 1.0 | 53.0 | 3.0 | 1.0 | 1.0 | 13.0 | 1.3 | 1.0 | 43.0 | 38.0 | 43.0 | 42.1 |
| TNP | 1.0 | 110.0 | 9.0 | 0.0 | 1.0 | 18.0 | 3.0 | 0.0 | 50.0 | 38.0 | 40.5 | 0.0 |
| TNK | 0.0 | 516.0 | 18.0 | 143.0 | 0.0 | 35.0 | 6.0 | 12.0 | - | 37.0 | 36.5 | 40.6 |
| TUN | 116.0 | 1,357.0 | 171.0 | 231.0 | 6.0 | 23.0 | 14.7 | 14.7 | 48.0 | 38.0 | 39.9 | 40.9 |
| TMU | 10.0 | 803.0 | 166.0 | 115.0 | 5.0 | 26.0 | 13.0 | 13.7 | 54.0 | 38.0 | 38.0 | 42.3 |
| TKC | 1.0 | 116.0 | 3.0 | 0.6 | 1.0 | 16.0 | 2.3 | 0.7 | 33.0 | 38.0 | 41.8 | 40.6 |
| CMR | | 15.8 | 27.4 | 17.9 | | 8.6 | 8.3 | 5.2 | | 39.9 | 41.8 | 38.5 |
| CKM | | 7.3 | 269.3 | 150.1 | | 2.0 | 20.2 | 21.6 | | 20.2 | 39.6 | 39.1 |
| CSS | | 12.8 | 7.1 | 247.6 | | 7.4 | 4.3 | 37.1 | | 36.6 | 33.2 | 39.2 |
| CSJ | | 22.1 | 25.6 | 226.9 | | 9.9 | 11.0 | 35.8 | | 38.7 | 39.3 | 39.1 |
| CUS | | 38.8 | 25.2 | 98.2 | | 16.0 | 11.1 | 16.8 | | 34.6 | 38.5 | 25.7 |
| CSP | | 12.4 | 66.7 | 171.2 | | 7.9 | 27.3 | 30.7 | | 38.1 | 38.8 | 38.8 |
| CKT | | 69.3 | 19.8 | 65.0 | | 8.0 | 10.0 | 15.2 | | 35.2 | 37.9 | 38.2 |
| CPT | | 4.1 | 49.0 | 187.6 | | 1.2 | 1.3 | 20.9 | | 11.6 | 13.4 | 28.4 |
| CCK | | 32.2 | 56.3 | 95.3 | | 3.6 | 6.6 | 8.1 | | 12.2 | 13.6 | 13.7 |
| CSK | | 810.3 | 170.8 | 1,407.3 | | 62.8 | 29.9 | 49.4 | | 39.1 | 41.7 | 42.2 |
| CPS | | 26.9 | 557.7 | 249.1 | | 7.9 | 27.3 | 30.7 | | 35.5 | 40.6 | 40.5 |
| CKL | | 28.7 | 339.1 | 121.8 | | 6.7 | 16.2 | 30.3 | | 12.1 | 13.7 | 13.8 |
| CSN | | 43.3 | 212.2 | 119.9 | | 8.7 | 17.9 | 49.4 | | 34.9 | 40.9 | 27.6 |
| CTU | | 318.1 | 372.0 | 429.9 | | 14.9 | 12.1 | 17.9 | | 36.7 | 40.9 | 39.3 |
| CPP | | 23.1 | 1,545.4 | 525.3 | | 23.1 | 25.8 | 22.6 | | 31.3 | 37.4 | 40.2 |
| CKK | | 303.2 | 313.9 | 353.6 | | 4.1 | 11.2 | 6.6 | | 34.2 | 41.5 | 38.7 |
| CNL | | 396.7 | 150.8 | 35.9 | | 14.1 | 25.2 | 11.1 | | 39.2 | 41.8 | 38.5 |
| VTP | 72.0 | 19.0 | 613.0 | 274.0 | 10.0 | 8.0 | 20.0 | 21.0 | 44.0 | 44.2 | 46.1 | 46.0 |

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 |
| VTT | 329.0 | 13.0 | 862.0 | 156.0 | 15.0 | 7.0 | 25.0 | 17.0 | 45.0 | 45.0 | 45.1 | 46.0 |
| VKB | 56.0 | 490.0 | 439.0 | 12,261.0 | 11.0 | 21.0 | 21.0 | 22.0 | 46.0 | 45.0 | 45.9 | 45.0 |
| VDP | 18.0 | 61.0 | 471.0 | 100.0 | 11.0 | 9.0 | 25.0 | 17.0 | 46.0 | 46.0 | 45.0 | 45.0 |
| VCL | 33.0 | 40.0 | 126.0 | 128.0 | 6.0 | 9.0 | 12.0 | 17.0 | 47.0 | 45.0 | 45.4 | 46.0 |
| VLX | 8.0 | 47.0 | 282.0 | 217.0 | 5.0 | 12.0 | 20.0 | 24.0 | 46.0 | 49.0 | 46.4 | 46.0 |
| VVL | 6.0 | 215.0 | 127.0 | 89.0 | 2.0 | 11.0 | 14.0 | 21.0 | 45.0 | 48.0 | 46.6 | 45.0 |
| VCT | 129.0 | 250.0 | 112.0 | 93.0 | 10.0 | 11.0 | 12.0 | 21.0 | 47.0 | 46.0 | 47.4 | 46.0 |

*(the yellow highlight indicates the sites not located on the mainstem.)*

## 3.4. Littoral Macroinvertebrates

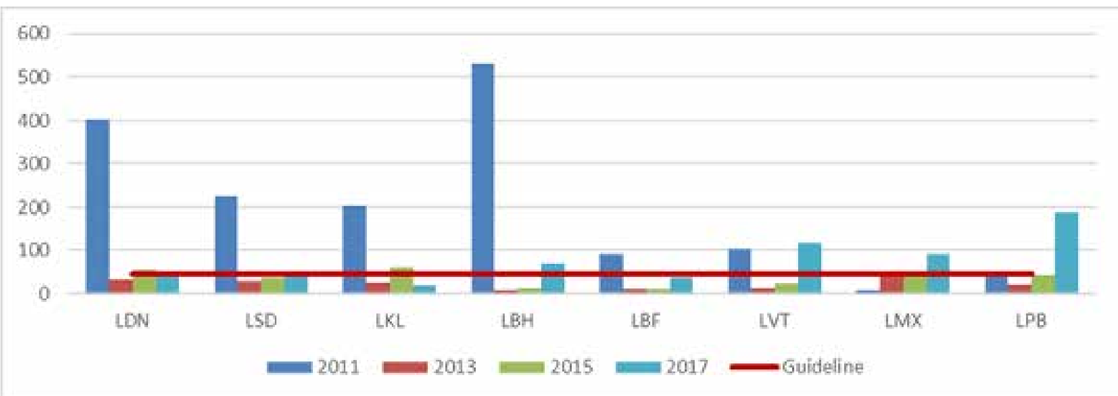
***Littoral Macroinvertebrate Abundance***

#### Lao PDR

Samples from the 8 sites across Lao PDR contained a total of 6,187 individuals of littoral macroinvertebrates. These were classified into 14 orders, 52 families, 104 genera, 104 taxa. Sampling in Lao PDR in 2017 found that average abundance ranged from 19.5 individuals per site at LBF to 187.0 individuals per site in LPB (mean= 77.4 ± 50.4 individuals per site) (***Figure 5.30*** and ***Table 3.4***). The most abundant Order was *Ephemeroptera*, particularly *Nigrobaetis sp*., and *Baetis sp.*

Overall, the average abundance was higher at most sites compared to 2015. Particularly, LVT and LPB showed a higher number of individuals. LKL and LDN, on the other hand, showed a slight decline compared to the previous monitoring period. This could be the result of increased human activities at this site compared to 2015. The initial accumulated sandbar that has built up over time providing a suitable habitat was no longer present in 2017. Furthermore, enhanced bank erosion and runoff disturbs the river environment. Considering that macroinvertebrates generally are indicators for long-term changes, this should be kept in mind in the next monitoring period to investigate whether this trend continues in the future. In comparison to the year 2011, the abundance at some sites is a lot lower than it was previously (LBF, LBH, LSD, LKL and LDN). The increase in abundance at sites LPB and LVT, on the other hand, may be due to the increased quantity of taxa with high tolerance levels such as the Mayfly (*Baetis* sp.), shrimp and flies. Interestingly to note is the first reoccurrence of the *Kiefferulus* sp. since 2011. Three sites did not meet the minimum abundance levels for a healthy ecosystem (LBF and LKL and LDN). LDN was just below the threshold value of 46.7. These sites showed signs of disturbance by human settlements and in addition to erosion in the littoral zone at site LKL (Se Kong River, Ban Somsanouk, Attepeu).

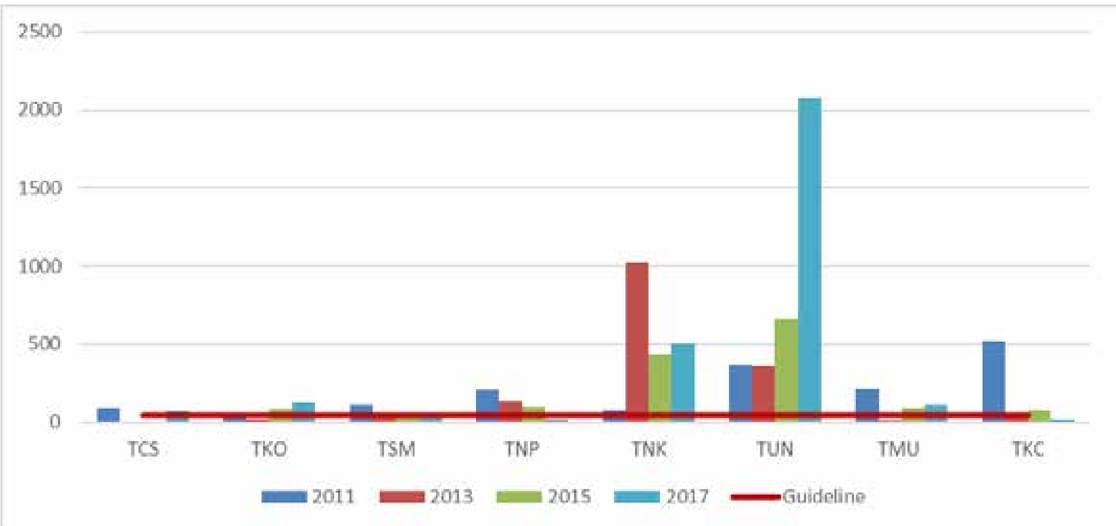
*Figure 3.30. Comparison of Littoral Macroinvertebrates - Average Abundance for Lao PDR in 2011, 2013, 2015 and 2017*



**Thailand**

The average abundance of littoral macroinvertebrates at study sites in Thailand had a wide range from 17.4 individuals at site TNP (Mekong River, Nakorn Phanom City) to 2,079.8 individuals at TUN (Mun River, Ubon Rachathani City (mean = 374.2 ± 660.9 individuals per site) (***Figure 3.31*** and ***Table 3.4***). TUN also had the highest littoral macroinvertebrate abundance out of all sample sites. Furthermore, the site showed a high concentration of DO and electrical conductivity, suggesting that a higher number of excess nutrients may be in the water from excess agriculture run-off, which is carried out around the riverbank. Other studies have shown that physical variables such as DO and EC can influence the abundance of this indicator. (Ikomi & Arimoro, 2014). In general, the average abundance was higher than the guideline minimum for healthy ecosystems (46.7) at most sites, except for sites TKC (Mun River and Mekong River junction, Ubon Rachathani) and TNP on the Mekong main channel where water currents were high, and the channel width was narrower than at other sites. These sites also showed signs of disturbance from nearby human settlements and bank erosion. In 2015, site TCS (Mekong River, Chiang San, Chiang Rai) had the lowest abundance of littoral macroinvertebrates. At site TNP the velocity and turbidity of the river were high this year, which may have impacted the distribution of littoral macroinvertebrates. However, the general average abundance per site this year study was similar in distribution compared to the previous study with the exception of TUN which showed a significant increase. This large increase was biased due to the large abundance of the shrimp *Caridina* sp. with an average of 2,000 individuals per sample at that site.

*Figure 3.31. Comparison of Littoral Macroinvertebrates Results - Average Abundance for Thailand in 2011, 2013, 2015 and 2017*




**Cambodia**

In Cambodia the average abundance of littoral macroinvertebrates in 2017 showed a high variance between 33.2 at CSN – 635.0 individuals per site at CKL (mean = 237.9 ± 168.2 individuals per site) (as shown *in **Figure 3.32** and **Table 3.4***). The highest number of individuals (635.0) was found in the Tonle Sap Lake, Kampong Luong (CKL), followed by site CKT on the Mekong River, Kampi Pool, Kratie (497.0 individuals) and CKK in the Bassac River at Koh Khel (416.0 individuals). The lowest abundance was found at CSN (33.2 individuals). Littoral macroinvertebrates were more abundant in samples than the other biota groups chosen for this study. For instance, at site CKK, the number of zooplankton was limited while littoral macroinvertebrates were abundant. As found by Ikomi and Arimoro (2014), it is very likely that a high concentration of DO and an abundance of organic debris and free ions (high EC) may positively influence the number of littoral macroinvertebrates at a sample site. CSN was the only site that had an average abundance lower than the guideline levels for a healthy ecosystem. At this site there was bank erosion, as well as sand pumping and disturbance from nearby villages. Comparing the results from 2017 with the previous monitoring period, it can be seen a significant decrease in abundance at sites CKK, CCK and CNL, respectively. These sites were dominated by individual species such as *Micronecta sp.* (CKK), *Manningiella polita* (CKK), *Kiefferulus sp.* (CNL). None of these species were found in 2017 corresponding to the 'decline' in abundance of littoral macroinvertebrates at those sites. On the other hand, at site CKL a high number of *Orthocladius sp.* and *Metrocoris sp.*was found leading to the high average of 635 individuals at this site.

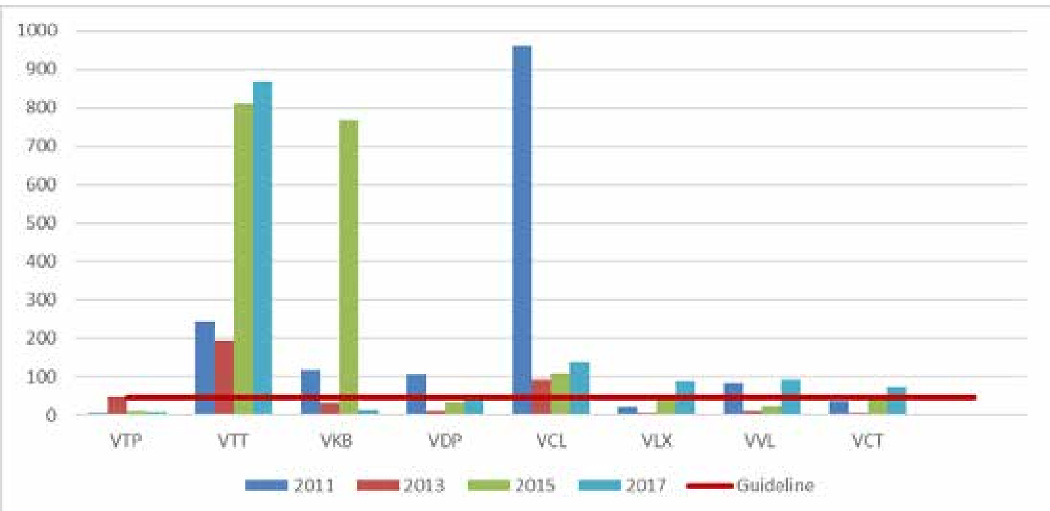
*Figure 3.32. Comparison of Littoral Macroinvertebrate Results - Average Abundance for Cambodia in 2013, 2015 and 2017*


**Viet Nam**

A total of 74 species were recorded across all monitoring sites, belonging to 41 families, 22 orders, 6 classes and 3 phyla. Average abundance of littoral macroinvertebrates ranged from 8.0 to 869.0 individuals per site, with the highest abundance reported at VTT (Mekong River, Thuong Thoi, Don Thap). The lowest abundance was observed at VTP, which also had the lowest abundance of all sample sites (Mekong River, Thuong Phoc, Dong Thap). This site is impacted by navigation, sand pumping, fish farming, and is as a result highly disturbed by bank erosion and pollution from domestic waste.

The threshold value according to the guideline for healthy ecosystems is greater than 46.7 individuals per sample which therefore renders sites VKB and VTP as ecologically unhealthy and the other as healthy ecosystems according to their littoral macroinvertebrate average abundance. Both sites have an extent of bank erosion, as well as domestic waste and pollution and other activities such as fishing sand pumping and agriculture. Compared with 2015 alone, the number of individuals was higher at 6 out of the 8 sample sites. VVL had increased greatly from 22 to 92 individuals per site. At two sites (VKB and VTP) a decrease in average abundance was observed. A drastic decrease was observed at site VKB from 769 individuals per sample in 2015 to 15 in 2017. This coincided with a disappearance of *Pachydrobia* species in 2017 which were abundant in 2015. Abundance trends appear in general to have decreased from 2008-2013 (7 out of 8 sites) and increased thereafter (6 out of 8 sites). This trend should be further monitored following the handbook on biomonitoring methodology for the Lower Mekong Basin (MRC, 2010a).

*Figure 3.33. Comparison of Littoral Macroinvertebrate Results - Average Abundance for Viet Nam in 2011, 2013, 2015 and 2017*

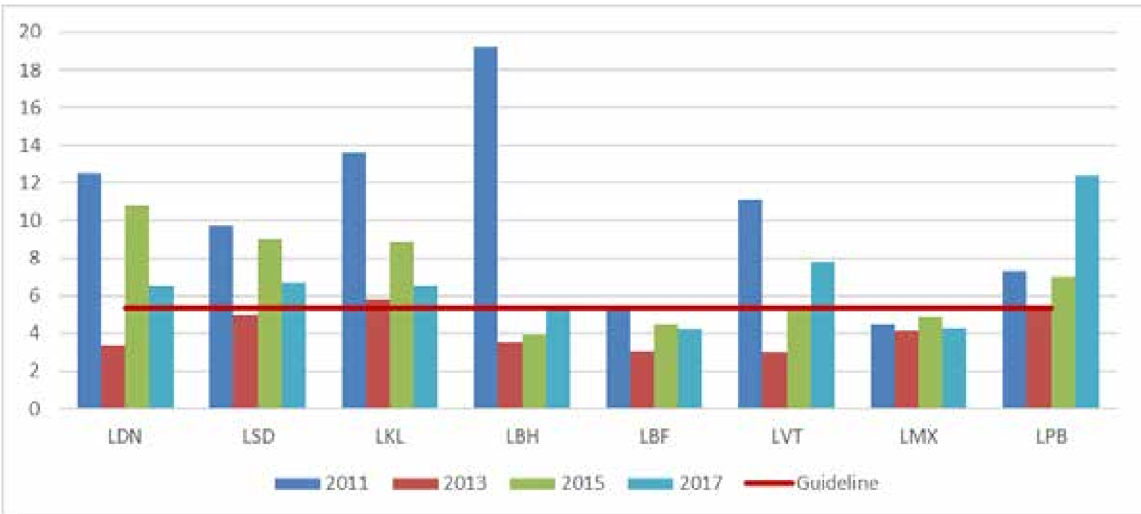


***Littoral Macroinvertebrates Average Richness***

**Lao PDR**

The highest number of species were found belonging to the Orders; Ephemeroptera, Coleoptera and Hemiptera. The most common species were the *Nigrobaetis* sp. (Ehemeroptera) and *Baetis* sp., which were present at all sample sites, indicating clean to moderately polluted water (Alhejoj *et al*., 2014). All species found in samples in 2017, had also been observed in previous sampling years. The average richness of littoral macroinvertebrates across the study sites in Lao PDR ranged between 4.2 - 7.8 (LBF and LMX) and 12 (LPB) species per site (mean = 6.7 ± 2.6 species per site) (as shown in ***Figure 3.34*** and ***Table 3.4***). Sites LMX and LBF were below the level of richness required by the reference site for ecological health of < 5.37 species per sample. The small diversity at these sites reflects directly the low abundance at those sites. This seems to be an ongoing trend indicating differing environmental conditions unfavorable for a majority of littoral macroinvertebrates. Continuous substrate assessment over the years showed a continuous change in environmental conditions. Richness was higher in sites LBH, LVT and LPB compared to samples taken in 2015 and lower on the remainder of the sites. For LBH and LPB a possible explanation could be the increase in river depth providing enhanced habitat while LVT's increase could be explained by a higher amount of nutrients present as indicated by a sudden increase of DO at this site.

*Figure 3.34. Comparison of Littoral Macroinvertebrate Results - Average Richness for Lao PDR in 2011, 2013, 2015 and 2017*

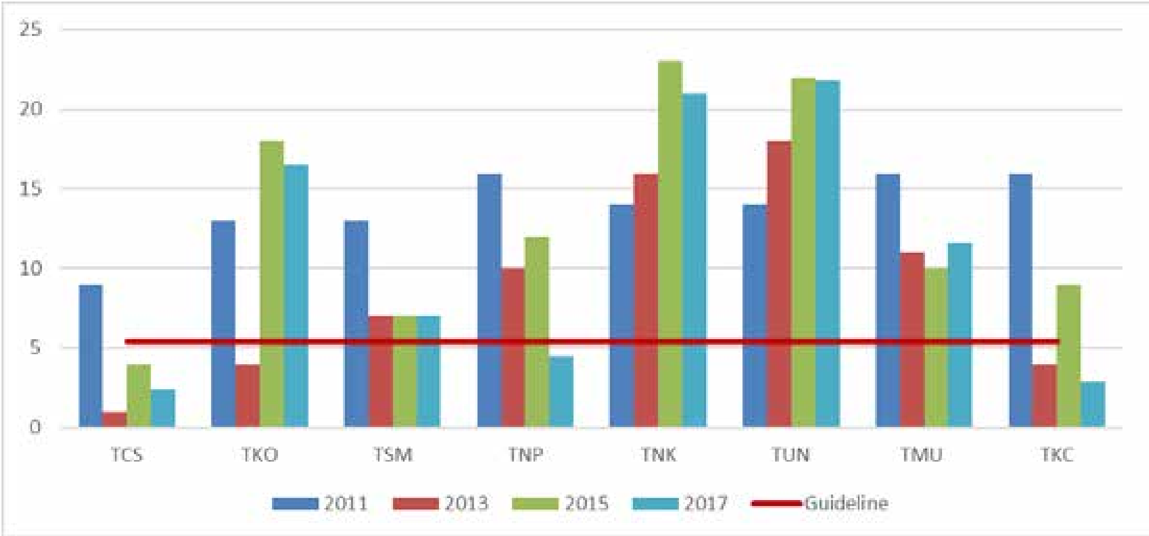



**Thailand**

The 8 sites sampled in 2017, yielded a total of 127 different species of littoral macroinvertebrates out of the 29,948 individuals collected. The *Caridina* sp. showed the highest distribution at all sites sampled especially at sites TUN and TNK. This species is known to be a very common species found throughout tropical waters. Both sites had a wide littoral area and low velocity. *Caridina* sp. also has a high tolerance to pollution which could explain its dominance at this site (Olomukoro and Dirisu, 2014). The TUN monitoring site exhibited the highest littoral macroinvertebrate distribution since 2013.

The littoral macroinvertebrate species richness per site ranged from 2.4 (TCS) to 21.8 (TUN) species per site (mean = 10.9 ± 7.5 species per site). TUN, therefore, had both high abundance and richness (as shown in ***Figure 3.35*** and ***Table 3.4***). The species richness at sites TNP, TCS and TKC was lower than the guideline for healthy ecosystems (> 5.37). All three sites locate on the section of the Mekong main channel that is deemed as inappropriate habitat for littoral macroinvertebrates. The predominantly fast flowing currents may result in changes of conditions and substrate during the monitoring years, affecting the population of invertebrates. Overall, macroinvertebrate richness was slightly lower than previous years.

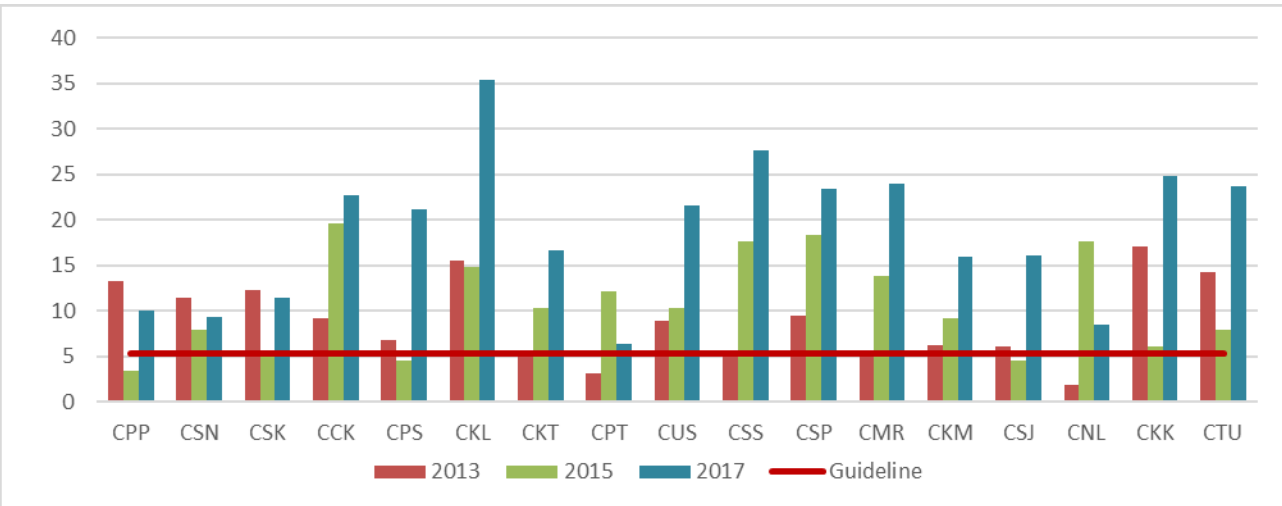
*Figure 3.35. Comparison of Littoral Macroinvertebrate Results - Average Richness for Thailand in 2011, 2013, 2015 and 2017*




**Cambodia**

The species richness observed at most sites in Cambodia seems to be on an upward trend, with the exception of CNL and CPT (as shown in ***Figure 3.36*** and ***Table 3.4***). The average richness ranged from 6.4 species per site at CPT (Prek Te River, Preh Kanlong, Kratie) to 35 species per site at CKL (Tonle Sap Lake, Kampong Luong, Pursat) (mean = 18.8 ± 7.7 species per site). Present at all sites are the species *Telagonodes* sp. and *Metrocoris* sp., which are also the most abundant (Dapas, Sunardi, Parikesit, Yusra, & Lananan, 2018). Site CPT is likely to be influenced by agricultural activities near the site but still had richness above the threshold of a healthy ecosystem. The low abundance of littoral macroinvertebrates at CNL could be due to the presence of the pumping station 1 km further upstream preventing a stable environment. In addition to more favorable habitat, it may also be possible that sampling methodology has improved over the years reflecting now the actual species richness of the waterbodies in Cambodia. Only CPT and CNL, as mentioned above showed a decreased number of littoral macroinvertebrates in 2017. This reflects the low abundance of sampled species at those sites. CNL particularly shows signs of enhanced human disturbance with more numerous gill nets at that site.

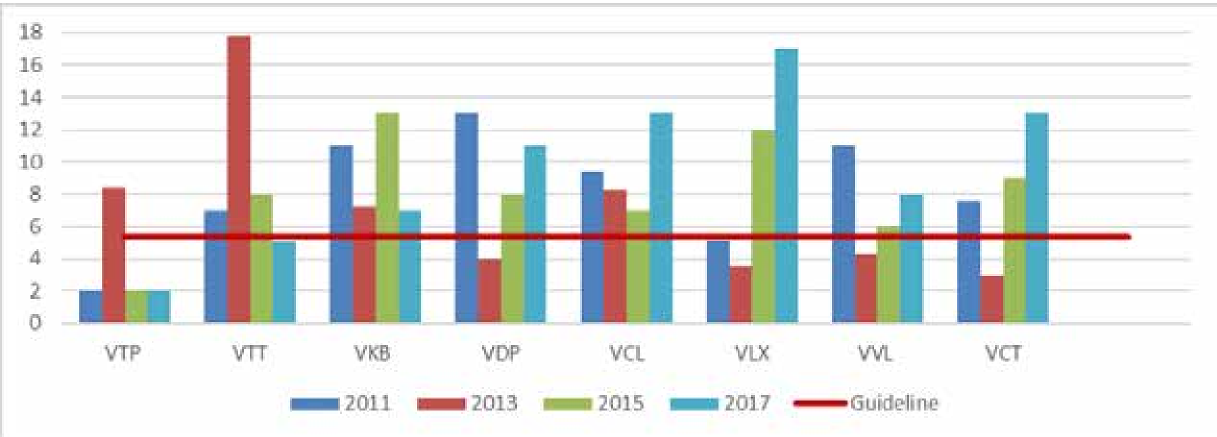
*Figure 3.36. Comparison of Littoral Macroinvertebrate Results - Average Richness for Cambodia in 2013, 2015 and 2017*



### Viet Nam

Average macroinvertebrate richness at the sites in Viet Nam ranged between 2.0 and 17.0 species per site in the monitoring year 2017 (mean = 9.5 ± 4.6 species per site) (as shown in ***Figure 3.37*** and ***Table 3.4***). The highest average richness was recorded at VLX while the lowest species diversity was found at VTP. In comparison to 2015, littoral macroinvertebrate average richness had increased at 5 sites (VDP, VCL, VLX, VVL, VCT) and decreased at 2 sites (VKB and VTT). The former 5 sites showed a stable nearshore substrate providing suitable habitat while increased erosion at VLB and VTT was observed, decreasing the distribution of species. Since monitoring began, the diversity has varied but has been overall increasing since the last three monitoring periods. The guidelines for a healthy ecosystem (average richness of > 5.37 species per site) was met at 6 out of 8 monitoring sites. The 2 sites that did not qualify were VTP and VTT. It needs to be pointed out that VTT had a high number of individuals but was low in species richness, due to the dominance of the *Thiaridae* family. The variation in species richness across the sites reflects the different site specific environments and disturbances. At four of the eight sites, an upward trend in species diversity was observed since 2011. These sites correspond to the downstream located sites (VLX, VCT, VVL) but also VDP, which is less disturbed than other sites located in the upper part of Viet Nam's monitoring area. VTT and VTP, both located on the Mekong mainstem are prone to human disturbance in forms of increased fishing- and navigation activities.

*Figure 3.37. Comparison of Littoral Macroinvertebrate Results - Average Richness for Viet Nam in 2011, 2013, 2015 and 2017*

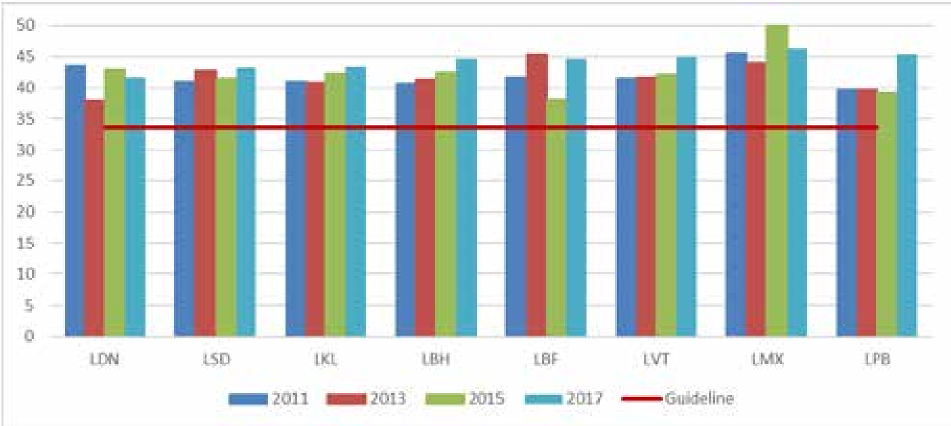



***Littoral Macroinvertebrate Average Tolerance Score Per Taxon (ATSPT)***

### Lao PDR

ATSPT scores in Lao PDR ranged from 41.7 - 46.4 at (mean = 44.3 ± 1.4) (as shown in ***Figure 3.38*** and ***Table 3.4***), meaning that none of the sites met the guideline value of < 33.58. The highest value was at LMX whereas the lowest was found at sites LDN. Apart from sites LMX and LDN, all sites' ATSPT has increased. Considering that littoral macroinvertebrates are indicating long-term changes it may be that both sites are recovering from previous disturbing factors. However, more monitoring is required to confirm this statement. Overall, the increasing trend of ATSPTs is consistent with the other biological indicators, suggesting a more stressed and human impacted environment unsuitable for a great number of species in comparison to the reference sites as per MRCs guideline.

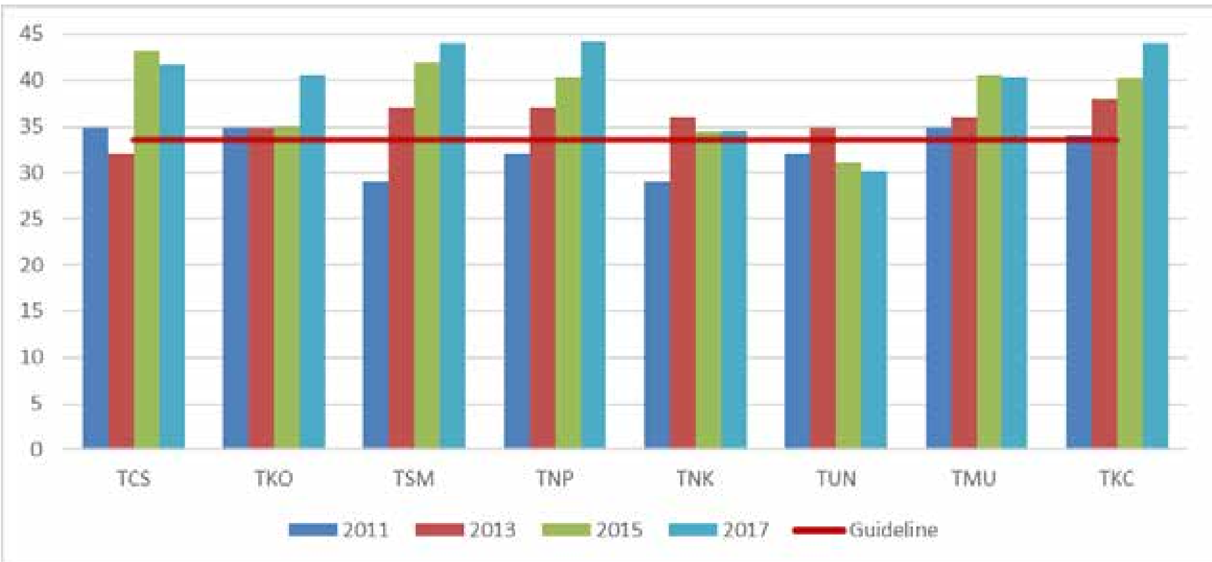
*Figure 3.38. Comparison of Littoral Macroinvertebrate Results - ATSPT for Lao PDR in 2011, 2013, 2015 and 2017)*




**Thailand**

In Thailand, the highest scores were at sites TNP (44.2), TSM and TKC (both with ATSPT scores of 44.1). The mean ATSPT score was 39.9 ± 4.7. Every site except TUN (ATSPT= 30.2) had an ATSPT score above that considered the maximum for a healthy ecosystem (***Figure 3.39*** and ***Table 3.4***). As it can be seen, also in Thailand an upward trend in ATSPT can be seen at most sites, with the exception of TCS and TUN. TUN, being located in one of the tributaries of the Mekong may have a more suitable environment compared to the other sites. Also TNK being located downstream from a dam in one of the tributaries shows a lower ATSPT value, suggesting that current flow may impact the ideal habitat environment of littoral macroinvertebrates. Furthermore, sampling becomes more difficult on the mainstem than in the tributaries and easily accessible sites such TCS, which may have impacted the sampling outcome. Regardless, the continuity of increasing ATSPT should be monitored with care.

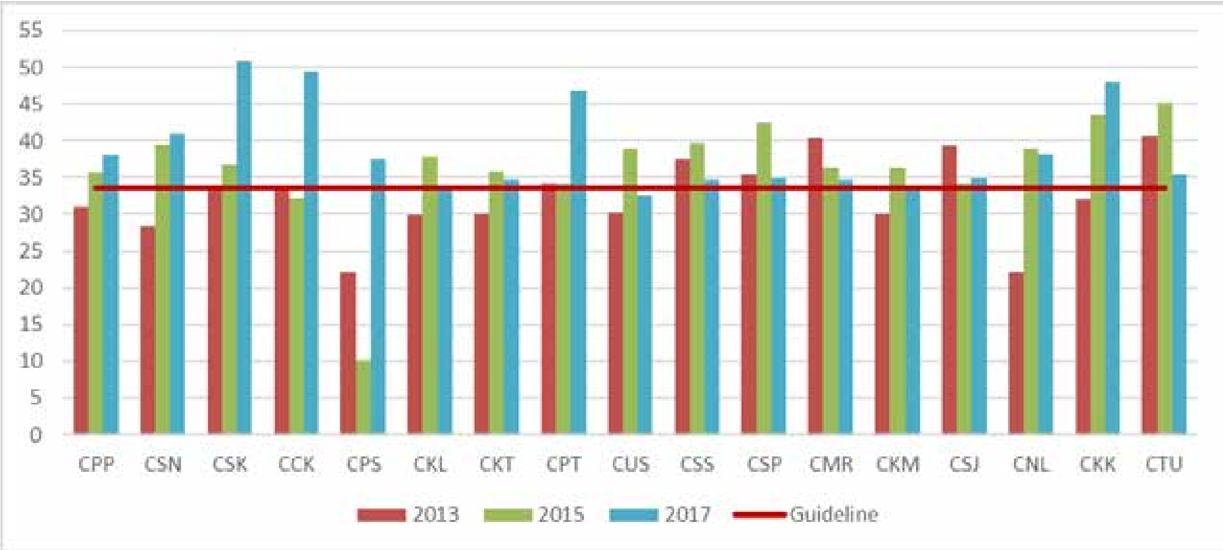
*Figure 3.39. Comparison of Littoral Macroinvertebrate Results - ATSPT for Thailand in 2011, 2013, 2015 and 2017*




**Cambodia**

The ATSPT score for littoral macroinvertebrates across Cambodia was between 32.6 and 50.8 (mean = 38.8 ± 6.1). The highest score was CSK followed by CCK located at the northern end of the Tonle Sap (as shown in ***Figure 3.40*** and ***Table 3.4***). These sites show great signs of pollution and heavy disturbance and require careful monitoring in the future. Eight out of 17 sampled sites follow an upward going trend in ATSPT while the remaining show continuous variability of ATSPT since 2013. Sites from the southern end of the country had higher scores in general than the upper section of the river. Particularly, the sites in the tributaries showed reasonable low values. The higher ATSPT scores may be due to the fact that further downstream more pollution has accumulated and the currents are slower in the Tonle Sap Lake, and more saline conditions leading to species with tolerance being more abundant. As littoral macroinvertebrates respond to long-term changes three monitoring periods may not be sufficient to define a trend for this indicator.

*Figure 3.40. Comparison of Littoral Macroinvertebrate Results - ATSPT for Cambodia in 2013, 2015 and 2017*




**Viet Nam**

In 2017, the values of ATSPT at sites ranged between 42.0 – 48.0 (mean = 45.6 ± 1.9) (as shown in ***Figure 3.41*** and ***Table 3.4***). ATSPT was highest at VLX (48.0) and lowest at VTP (42.0). All study sites had ATSPT scores higher than the guideline value for health ecosystem of 34, thus suggesting high levels of environmental disturbance. The amount of variance between sites in 2017 was less than that in 2015 study. At 4 of the sites (VCT, VDP, VTT and VCL), ATSPT scores were greater than 2015 and at 2 of the sites saw a decrease (VKB and VVL), with the remaining sites scores left unchanged.

*Figure 3.41. Comparison of Littoral Macroinvertebrate Results - ATSPT for Viet Nam in 2011, 2013, 2015 and 2017*

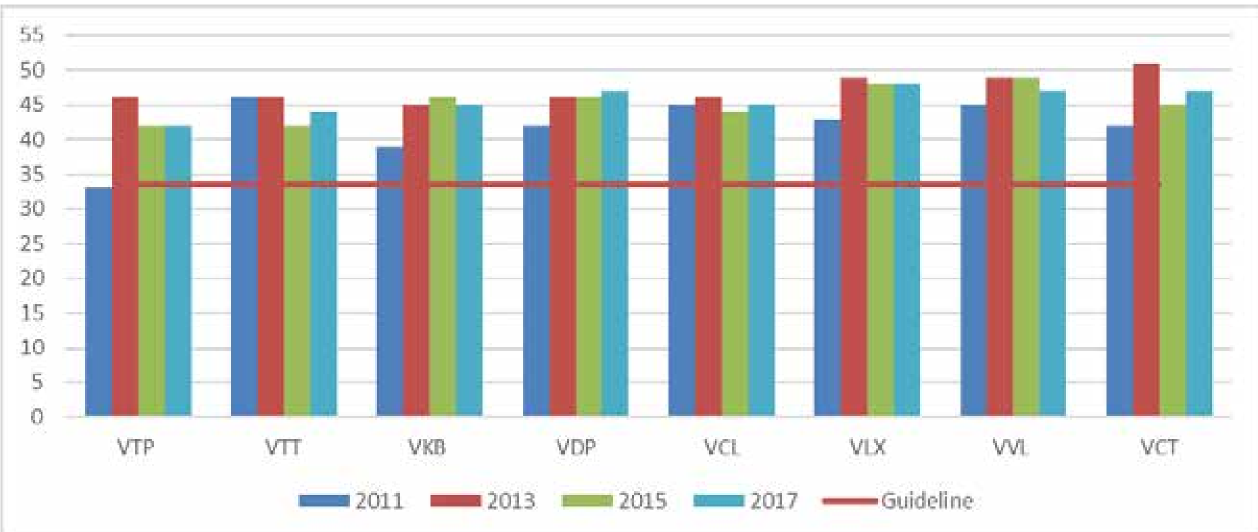


*Table 3.4. Comparison of Littoral Macroinvertebrates - Average Abundance, Richness and ATSPT scores of the Lower Mekong Basin in 2011, 2013, 2015 and 2017*

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 |
| LMX | 7.9 | 48.0 | 46.0 | **90.9** | 4.5 | 4.1 | 4.9 | **4.3** | 45.6 | 44.1 | 50.1 | **46.4** |
| LPB | 47.7 | 19.7 | 45.3 | **187.0** | 7.3 | 5.5 | 7.0 | **12.4** | 39.6 | 39.6 | 39.2 | **45.4** |
| LVT | 103.1 | 13.0 | 22.4 | **115.8** | 11.1 | 3.0 | 5.4 | **7.8** | 41.6 | 41.8 | 42.3 | **45.0** |
| LBF | 89.8 | 115.5 | 10.5 | **36.7** | 5.5 | 3.1 | 4.5 | **4.2** | 41.7 | 45.5 | 38.1 | **44.6** |
| LBH | 532.4 | 7.5 | 12.7 | **69.8** | 19.2 | 3.5 | 3.9 | **5.4** | 40.8 | 41.5 | 42.6 | **44.7** |
| LSD | 225.1 | 27.4 | 37.6 | **52.6** | 9.7 | 5.0 | 9.0 | **6.5** | 41.0 | 42.9 | 41.6 | **43.3** |
| LDN | 401.6 | 32.1 | 54.7 | **46.4** | 12.5 | 3.4 | 10.8 | **6.5** | 43.6 | 37.9 | 43.0 | **41.8** |
| LKL | 202.1 | 24.9 | 59.8 | **19.5** | 13.6 | 5.8 | 8.9 | **6.5** | 41.0 | 40.8 | 42.3 | **43.5** |
| TCS | 93.0 | 2.0 | 7.0 | **68.2** | 9.0 | 1.0 | 4.0 | **2.4** | 35.0 | 32.0 | 43.2 | **41.7** |
| TKO | 63.0 | 16.0 | 83.0 | **128.8** | 13.0 | 4.0 | 18.0 | **16.5** | 35.0 | 35.0 | 35.1 | **40.6** |
| TSM | 111.0 | 23.0 | 57.0 | **64.5** | 13.0 | 7.0 | 7.0 | **7.0** | 29.0 | 37.0 | 41.9 | **44.1** |
| TNP | 209.0 | 134.0 | 96.0 | **17.4** | 16.0 | 10.0 | 12.0 | **4.5** | 32.0 | 37.0 | 40.3 | **44.2** |
| TNK | 74.0 | 1,024.0 | 430.0 | **499.8** | 14.0 | 16.0 | 23.0 | **21.0** | 29.0 | 36.0 | 34.4 | **34.6** |
| TUN | 371.0 | 360.0 | 662.0 | **2,079.8** | 14.0 | 18.0 | 22.0 | **21.8** | 32.0 | 35.0 | 31.1 | **30.2** |
| TMU | 213.0 | 11.5 | 91.0 | **116.4** | 16.0 | 11.0 | 10.0 | **11.6** | 35.0 | 36.0 | 40.6 | **40.3** |
| TKC | 522.0 | 28.0 | 78.0 | **19.0** | 16.0 | 4.0 | 9.0 | **2.9** | 34.0 | 38.0 | 40.2 | **44.1** |
| CMR | | 373.0 | 65.2 | **397.0** | | 5.3 | 13.8 | **24.0** | | 40.4 | 36.4 | **34.8** |
| CKM | | 12.3 | 39.9 | **85.7** | | 6.2 | 9.2 | **16.0** | | 30.1 | 36.3 | **33.9** |
| CSS | | 13.0 | 61.5 | **332.0** | | 5.3 | 17.7 | **27.7** | | 37.6 | 39.7 | **34.7** |
| CSJ | | 10.4 | 61.8 | **136.0** | | 6.1 | 4.5 | **16.0** | | 39.4 | 34.2 | **35.0** |
| CUS | | 24.7 | 52.3 | **184.0** | | 8.9 | 10.4 | **21.6** | | 30.3 | 39.1 | **32.6** |
| CSP | | 37.6 | 211.0 | **158.0** | | 9.5 | 18.4 | **23.5** | | 35.4 | 42.5 | **34.8** |
| CKT | | 26.4 | 58.8 | **497.0** | | 5.3 | 10.4 | **16.7** | | 30.1 | 35.9 | **34.7** |
| CPT | | 16.5 | 46.8 | **50.8** | | 3.1 | 12.1 | **6.4** | | 34.2 | 34.3 | **46.9** |
| CCK | | 107.0 | 2,359.0 | **351.0** | | 9.2 | 19.7 | **22.7** | | 34.0 | 32.3 | **49.5** |
| CSK | | 39.8 | 17.1 | **61.5** | | 12.3 | 5.2 | **11.4** | | 33.2 | 36.6 | **50.8** |
| CPS | | 39.2 | 22.6 | **267.0** | | 6.8 | 4.6 | **21.2** | | 22.2 | 10.1 | **37.5** |
| CKL | | 124.0 | 28.2 | **635.0** | | 15.6 | 6.1 | **24.8** | | 29.9 | 37.9 | **33.6** |
| CSN | | 76.6 | 22.1 | **33.2** | | 11.5 | 8.0 | **9.3** | | 28.3 | 39.6 | **41.1** |
| CTU | | 52.0 | 34.1 | **173.0** | | 14.3 | 8.0 | **23.7** | | 40.8 | 45.2 | **35.3** |
| CPP | | 56.4 | 8.8 | **128.0** | | 13.3 | 3.5 | **10.1** | | 31.0 | 35.7 | **38.1** |
| CKK | | 84.5 | 2,114.0 | **416.0** | | 17.1 | 14.9 | **35.4** | | 32.1 | 43.5 | **48.0** |
| CNL | | 2.6 | 627.0 | **138.0** | | 1.9 | 17.6 | **8.5** | | 22.1 | 39.1 | **38.2** |
| VTP | 7.0 | 48.0 | 12.0 | **8.0** | 2.0 | 8.4 | 2.0 | **2.0** | 33.0 | 46.0 | 42.0 | **42.0** |

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 | 2011 | 2013 | 2015 | 2017 |
| VTT | 243.0 | 192.0 | 811.0 | **869.0** | 7.0 | 17.8 | 8.0 | **5.0** | 46.0 | 46.0 | 42.0 | **44.0** |
| VKB | 117.0 | 30.0 | 769.0 | **15.0** | 11.0 | 7.2 | 13.0 | **7.0** | 39.0 | 45.0 | 46.0 | **45.0** |
| VDP | 106.0 | 11.0 | 33.0 | **51.0** | 13.0 | 4.0 | 8.0 | **11.0** | 42.0 | 46.0 | 46.0 | **47.0** |
| VCL | 961.0 | 93.0 | 110.0 | **139.0** | 9.4 | 8.3 | 7.0 | **13.0** | 45.0 | 46.0 | 44.0 | **45.0** |
| VLX | 19.0 | 5.0 | 40.0 | **90.0** | 5.1 | 3.5 | 12.0 | **17.0** | 43.0 | 49.0 | 48.0 | **48.0** |
| VVL | 83.0 | 12.0 | 22.0 | **92.0** | 11.0 | 4.3 | 6.0 | **8.0** | 45.0 | 49.0 | 49.0 | **47.0** |
| VCT | 37.0 | 6.0 | 54.0 | **74.0** | 7.6 | 3.0 | 9.0 | **13.0** | 42.0 | 51.0 | 45.0 | **47.0** |

*(the yellow highlight indicates the sites not located on the mainstem.)*

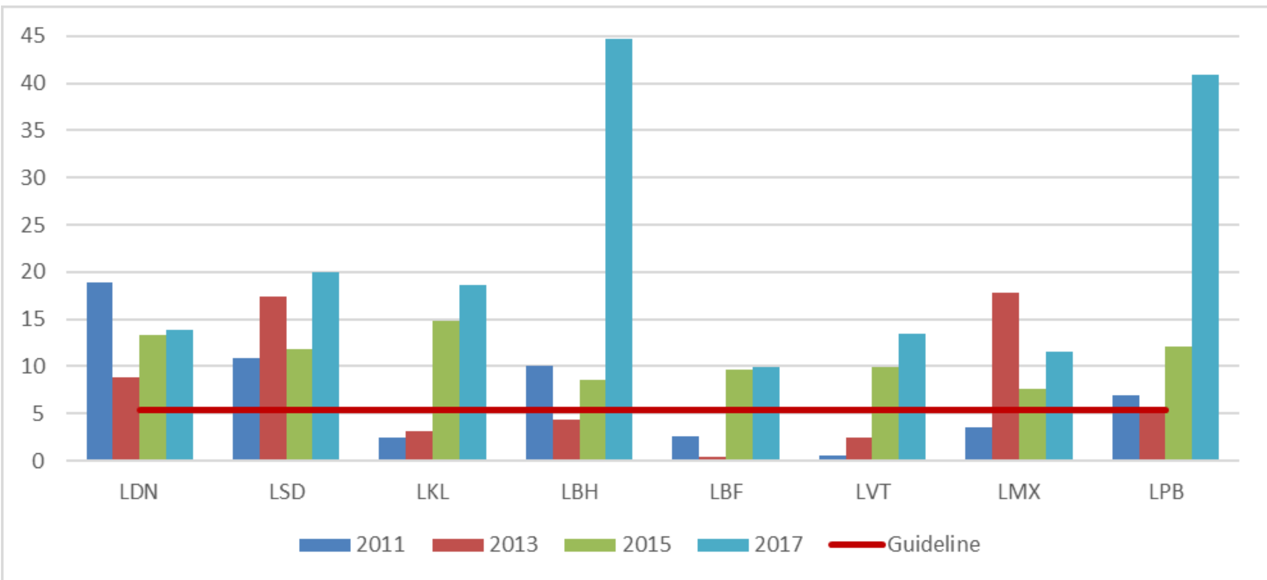
## 3.5. Benthic Macroinvertebrates

***Benthic Macroinvertebrate Abundance***

**Lao PDR**

In 2017, a total of 2,074 individual specimens of benthic macroinvertebrates were collected from eight sites and were separated in to 50 species (15 orders, 31 families and 38 genera). The order Insecta was dominating at all sites. The average abundance in Lao PDR ranged from 9.9 (LBF) to 44.8 (LBH) individuals per site with a mean of 21.6 ± 12.7 (as shown in ***Figure 3.42*** and ***Table 3.5***). All sites had higher abundance compared to 2015, which could be due to higher water levels and more favorable habitats and better sampling conditions, leading to better samples. Furthermore, all sites surpassed the minimum required benthic macroinvertebrate abundance to qualify as healthy ecosystem (> 5.4). A new species found at all sites, was present in high abundance with a total of 325 individuals in average, *Lumbricus* sp. This species belongs to family Lumbricidae and is most commonly found in Europe. It reacts on changes in soil nutrient availability. With the highest abundance present at LBH (83 individuals) of this species across the samples at this site it may well be that a rise in nutrients could have occurred in this site.

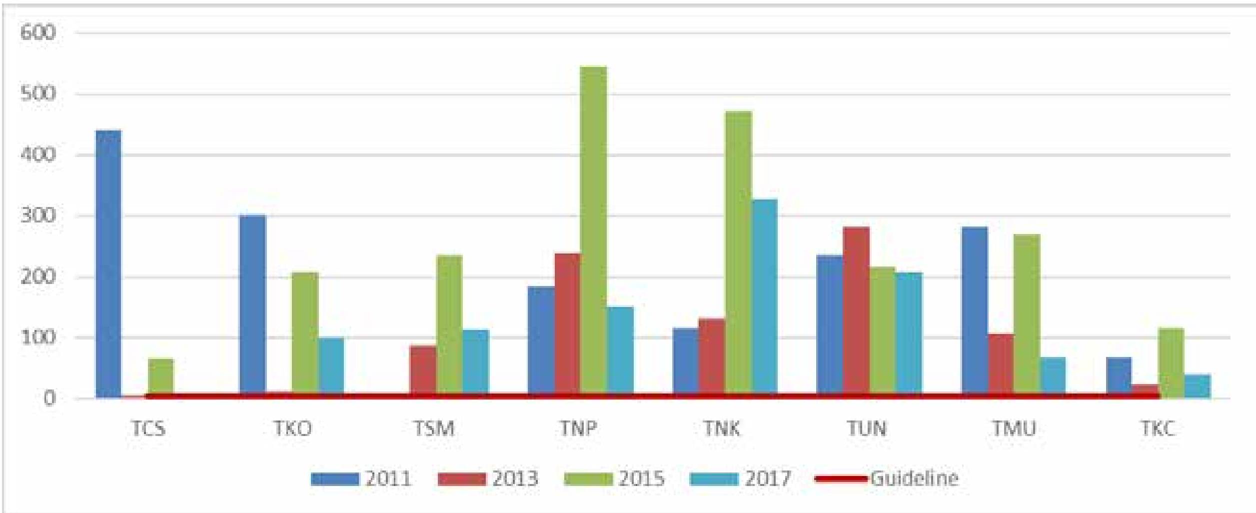
*Figure 3.42. Comparison of Benthic Macroinvertebrate Results - Average Abundance for Lao PDR in 2011, 2013, 2015 and 2017*



### Thailand

The 8 sites sampled in 2017, yielded a total of 69 different species of benthic macroinvertebrates out of the 3,023 individuals collected. The average abundance ranged from 1.0 to 326.7 individuals in the 2017 monitoring period per site (as shown in ***Figure 3.43*** and ***Table 3.5***). The highest abundance occurred at site TNK (326.7 individuals per site). This study site had a soft, varying and suitable substrate such as detritus, mud, sand and gravel and had a slow water current. The lowest abundance was found in TCS (1 individual among all samples collected at this site), which was considerably lower than the other sites. This was also the only site to not meet the guidelines for a healthy ecosystem due to the high flow velocity and an inappropriate substratum for macroinvertebrates, such as large cobbles and bedrock. Furthermore, TCS showed signs of high disturbance from navigation activities in addition to algae blooms at the water surface. *Melanoides* sp. and *Corbicula* sp. were the most abundant species occurring, which is similar to the last monitoring period in 2015. All sites show a decreased number of species compared to 2015, which could either be due to less favourable sampling conditions or due to a more unsuitable environment.

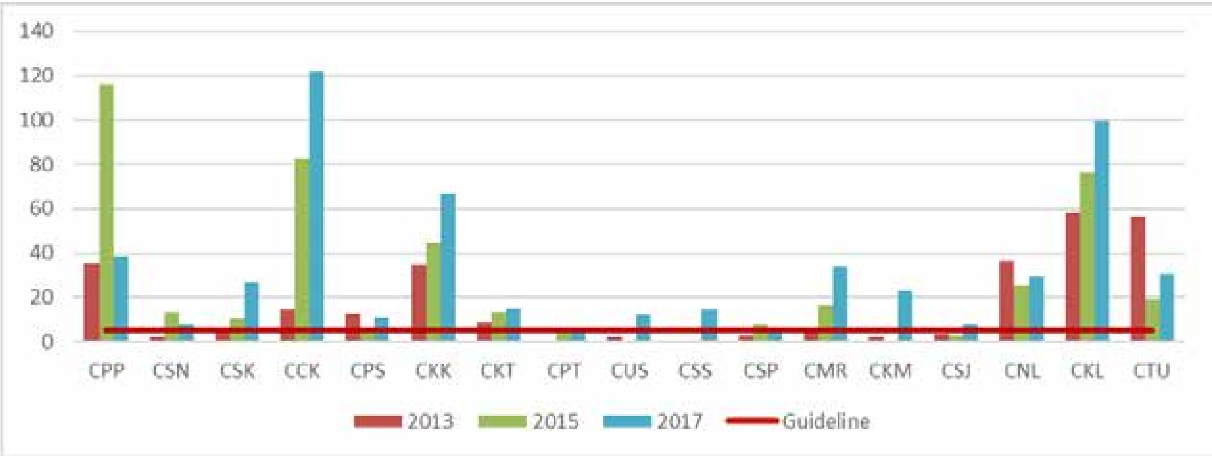
*Figure 3.43. Comparison of Benthic Macroinvertebrate Results - Average Abundance for Thailand in 2011, 2013, 2015 and 2017*




### Cambodia

Benthic macroinvertebrate abundance ranged from 4.0 to 122.2 individuals with a total average of 32.9 ± 33.7 per site (as shown in ***Figure 3.44*** and ***Table 3.5***). The highest abundance was found at CCK (Tonle Sap Lake, Chong Khnease, Siem Reap) with 122.2 individuals, followed by the site at Kampong Luong (CKL) with 99.6 individuals and CKK with 67.2 individuals, respectively. The remaining sites had an average abundance less than 30.0 individuals. Prek Te (CPT) had the lowest abundance of benthic macroinvertebrates with an average of 4.0 individuals per site collected on that site. CPT was also the only site not meeting the reference value for the healthy ecosystem's guideline of 5.4. The most dominant and abundant species was *Thiennemannimyia* sp. belonging to the order of Diptera with 535 individuals and being present at all sites, except CKL. As can be seen from the figure below, the abundance of benthic macroinvertebrates seem to have increased at most sampling sites in Cambodia. As for Thailand and Lao PDR, this may either be due to better conditions while sampling or due to a more favourable river environment for specific species, such as the above mentioned *Thiennemannimyia sp.*

*Figure 3.44. Comparison of Benthic Macroinvertebrate Results - Average Abundance for Cambodia in 2013, 2015 and 2017*

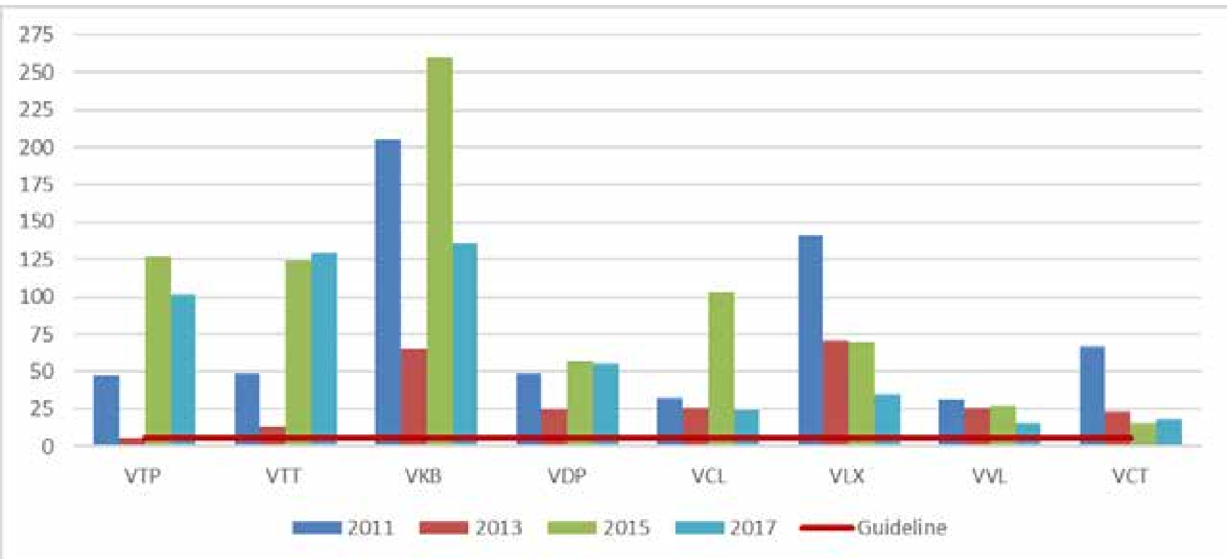



**Viet Nam**

In 2017, there were 75 species belonging to 38 families, 19 orders, 6 classes and 3 phyla. The average abundance at sites in 2017 had values in range of 16.0-136.0 individuals per site (as shown in ***Figure 3.45*** and ***Table 3.5***) with a mean of 64.3 ± 47.1. Site VKB had the highest abundance with 136.0 individuals while VVL had the lowest average abundance still meeting the threshold value for being considered as a healthy ecosystem.

The average abundance in 2017 was lower than 2015 at 6 of 8 sites, especially at site VKB where it was significantly lower (from 260 decrease to 136 individuals). The observations made while sampling indicated enhanced signs of erosion and sand dredging activities at that sites, which may have led to the decline of benthic macroinvertebrates at this site. The most abundant species found in 2017 were *Chironomus* sp., *Corbicula baudoni*, *Corbicula* sp., *Limnoperna siamensis*, *Sinomytilus harmandi*, and *Brachyura larv a.* Only two sites (VCT and VTT) saw an increase in abundance compared to the 2015 sampling. These results reflect decreasing numbers of individuals of some species such as at VKB where *Limnoperna siamensis* and *Sinomytilus harmandi* showed a reduced number of individuals in 2017. In 2015, *Limnodrilus hoffmeisteri* species where very abundant at VLX, while in 2017 this species was not found. In VCL the abundance of some species decreased considerably compared to 2015 monitoring (e.g. *Limnoperna siamensis*, *Sinomytilus harmandi, Corophium intermedium*, *Kamaka* sp.). Regardless, of the general decrease of individuals per site, all sites lay within the threshold of being classified as a healthy ecosystem.

*Figure 3.45. Comparison of Benthic Macroinvertebrate Results - Average Abundance for Viet Nam in 2011, 2013, 2015 and 2017*

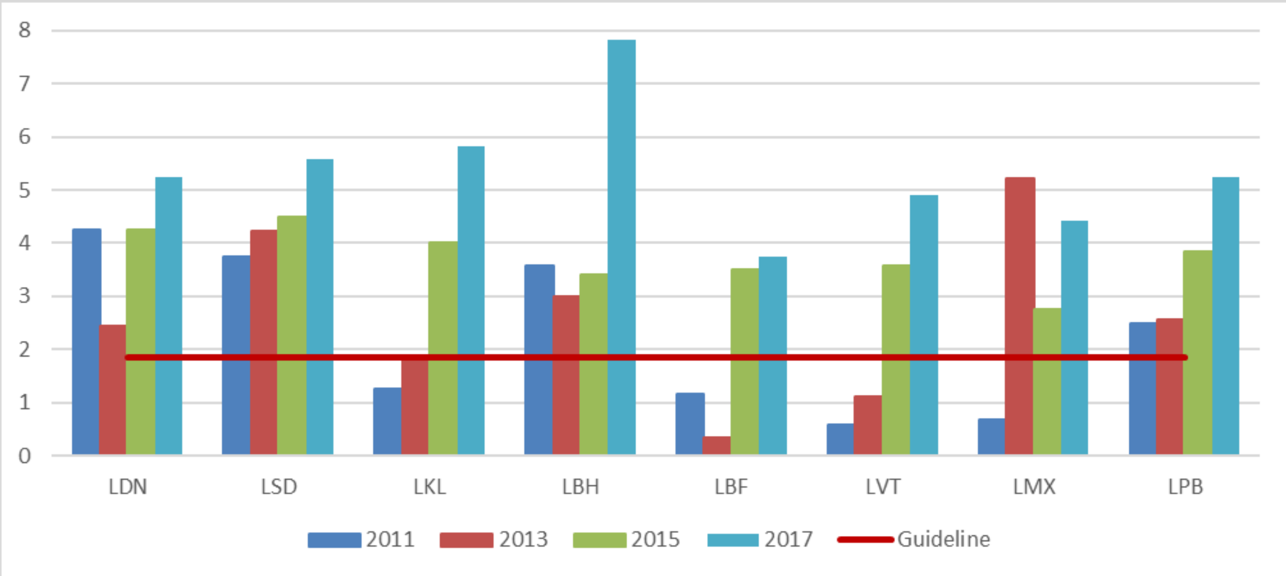


***Benthic Macroinvertebrate Average richness***

**Lao PDR**

Immature Diptera, Oligochaeta and Ephemeroptera were found at all sites, with high abundance of Chironomidae, Lumbricidae and Ephemeridae. As previously mentioned, a new species *Lumbricus* sp. was found. While *Kiefferulus* sp. was the most abundant species in 2017, *Lumbricus* sp. was present at all sites. As can be seen from ***Figure 3.46*** and ***Table 3.5***, the average richness was measured between 3.8-7.8 species per site (mean = 5.4 ± 1.1 species per site). The highest average richness was found at site LBH (Se Bang Hieng River, Songkhone, Savannakhet), whereas the lowest was measured at LBF (Se Bang Fai River, Se Bang Fai, Khammouan). In general, a slight increase in the species richness of benthic macroinvertebrates is observed compared to samples taken in 2015. This also reflects the predominant increase in abundance as discussed in the previous section. All sites met benthic macroinvertebrate richness levels to qualify as a healthy ecosystem (> 1.84 species per site) and providing a good food source for fish.

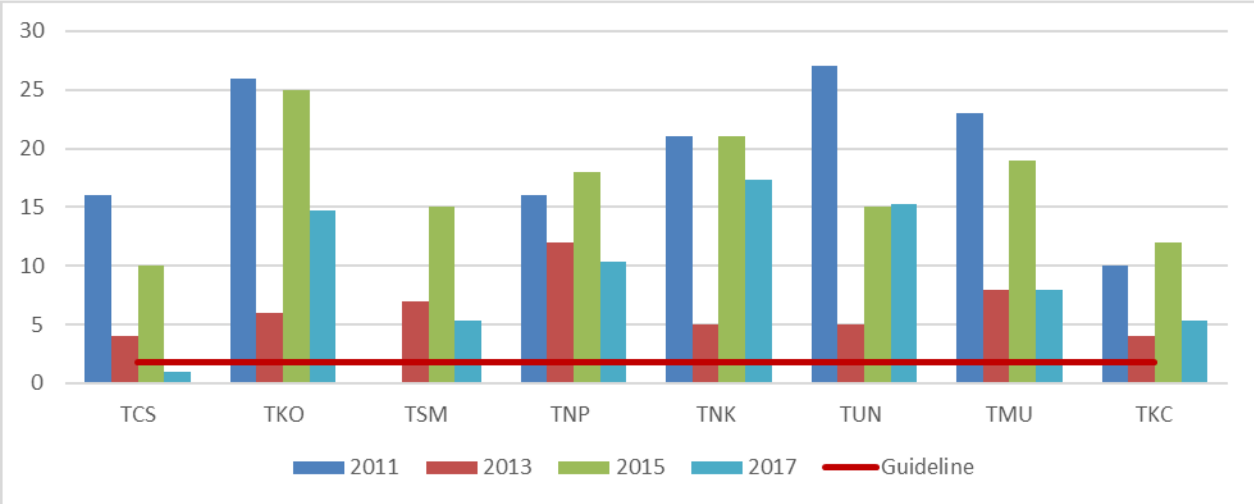
*Figure 3.46. Comparison of Benthic Macroinvertebrate Results - Average Richness for Lao PDR in 2011, 2013, 2015 and 2017*




**Thailand**

The average species richness for benthic macroinvertebrates in Thailand ranged from 1.0 to 17.3 species at the monitoring sites in Thailand (mean = 10.9 ± 5.4 species per site). *Melanoides* sp. and *Corbicula* sp. were the most dominant species, which is identical to the previous monitoring period (as shown in ***Figure 3.47*** and ***Table 3.5***). Chironomids and Oligochaetes families were also a common and distributed across all sample sites. The highest richness occurred at sites TNK (Nam Kham River, Na Kae, Mukdaharn) while TCS (Mekong River, Chiang San, Chiang Rai) did not reach the threshold value to be classified as a healthy ecosystem both for abundance and richness as only one species was present in low numbers. Already in previous monitoring years TCS had the lowest benthic macroinvertebrate species richness (2011, 2013 and 2015, respectively) among the monitored sites. On top of the high disturbance of human activities, the site has an inappropriate substrate such as sandy and cobble and a fast flowrate meaning benthic macroinvertebrates were unable to remain on the bottom surface. However, it is likely that navigation activities and also water quality play a dominant role. Monitoring of this site should be carried out in detail throughout the next monitoring periods.

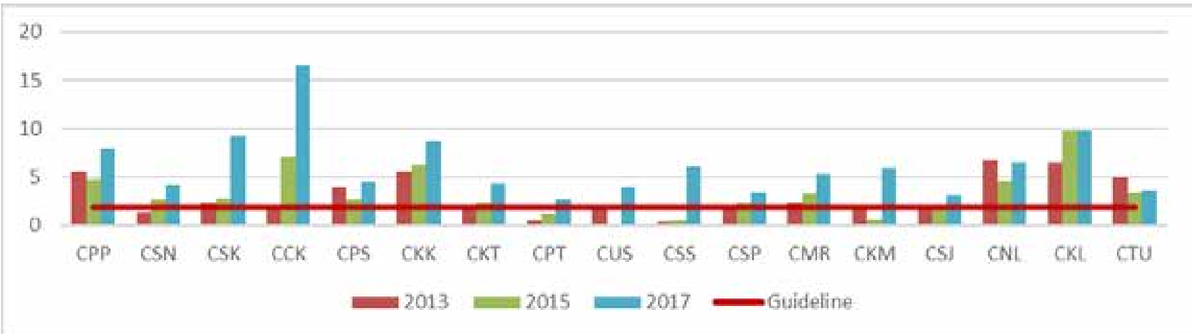
*Figure 3.47. Comparison of Benthic Macroinvertebrate Results - Average Richness for Thailand in 2011, 2013, 2015 and 2017*




**Cambodia**

In Cambodia the average richness ranged from 2.6 at site CPT to 16.6 individuals per site at CCK with a mean of 6.2 ± 3.5. All monitored sites surpassed the benthic macroinvertebrate richness level and met the guideline for a healthy ecosystem (as shown in ***Figure 3.48*** and ***Table 3.5***). Richness at CCK was markedly higher than the other sites, which coincides with the site having the highest abundance. Considering the location of this site being in Tonle Sap Lake, 1km from shore the diversity and abundance is not surprising since benthic macroinvertebrates are mostly immobile. At the other sites, the river environment may be unsuitable for an abundant variety of species. Better sampling conditions and methodology may also impact the results. Continuous monitoring is required to support the increasing trend.

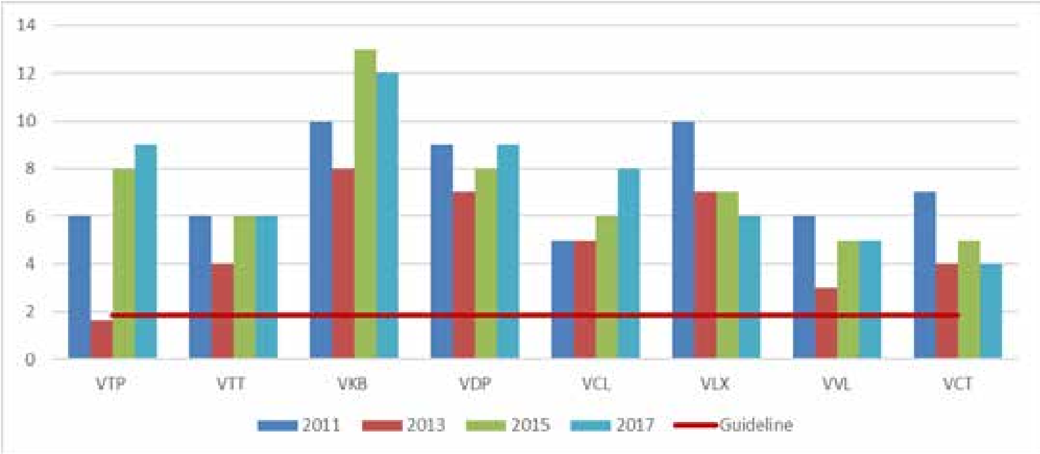
*Figure 3.48. Comparison of Benthic Macroinvertebrate Results - Average Richness for Cambodia in 2013, 2015 and 2017*




**Viet Nam**

***Figure 3.49*** and ***Table 3.5*** show the species richness values calculated for sites in 2017 from 4.0 – 12.0 species per site (mean = 7.4 ± 2.4 species per site). Richness was highest at VKB (12.0 species) and reached a minimum value at VCT (4.0 species). The explanation for the low diversity at VCT, could be due to the environmental conditions and the relative location of the site, being at the bottom of the Mekong Delta. All sites have richness values higher than the reference value for a healthy ecosystem for benthic macroinvertebrates. Compared with 2015, richness had increased at 3 sites (VDP, VTP and VCL), and decreased also at 3 sites (VCT, VLX and VKB). In general, richness decreased between 2008 – 2013 and increased between 2013 – 2017. The most diverse phylum was Mollusca (39 species), followed by Arthropoda with 26 species. The Annelida phylum had the lowest diversity with 10 species. From the 6 recorded classes, Gastropoda was most diverse with 21 species. Species such as *Chironomus* sp. (Insecta), *Corbicula baudoni*, *Corbicula* sp., *Limnoperna siamensis*, *Sinomytilus harmandi* (Bivalvia), *Brachyura larva* (Decapoda) appeared at all survey sites. Seven new species had established themselves, including 4 of Arthropoda and 3 species of Mollusca *(Macrobrachium mirabile*, *Sayamia triangularis*, *Melanotrichia* sp., *Styrulus* sp. belong to Arthropoda phylum and *Cipangopaludina lecithoides*, *Wattebledia crosseana*, *Paracrostoma* sp.).

*Figure 3.49. Comparison of Benthic Macroinvertebrate Results - Average Richness for Viet Nam in 2011, 2013, 2015 and 2017*

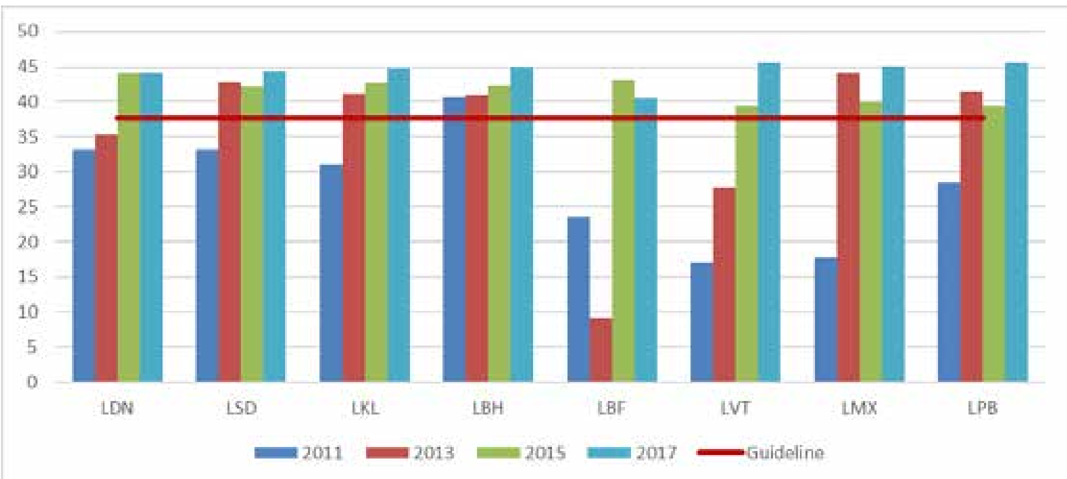



***Benthic Macroinvertebrate Average Tolerance Score Per Taxon (ATSPT)***

**Lao PDR**

ATSPT scores calculated for each of the sites across Lao PDR for benthic macroinvertebrates ranged from 44.1 - 45.5 (as shown in ***Figure 3.50*** and ***Table 3.5***) with a mean of 44.8 ± 0.5. The highest ATSPT was evaluated for LPB and LVT, while the lowest was calculated for LDN. LDN was also the only site showing almost the same ATSPT as in the previous monitoring period while all other sites either increased or decreased in the case of LBF compared to 2015. ATSPT scores are above that recommended for a healthy ecosystem status from the guidance level of < 37.7 at all sites across Lao PDR. The fact that predominantly an upward going trend is observed for the ATSPT and all sites' scores lie above the guideline, it is likely that the riverbed is increasingly disturbed by outside factors, such as sand dredging activities, waste disposal and possible sedimentation. It needs to be considered that the majority of benthic macroinvertebrates are unable to migrate and correspond to a good representative for the local river bed environment. The fact that an upward going trend of ATSPT can be observed suggests that this trend is likely to continue in the future. Focused monitoring should investigate these interpretations in order to get a better understanding of the river environment and the impacts induced by human activities.

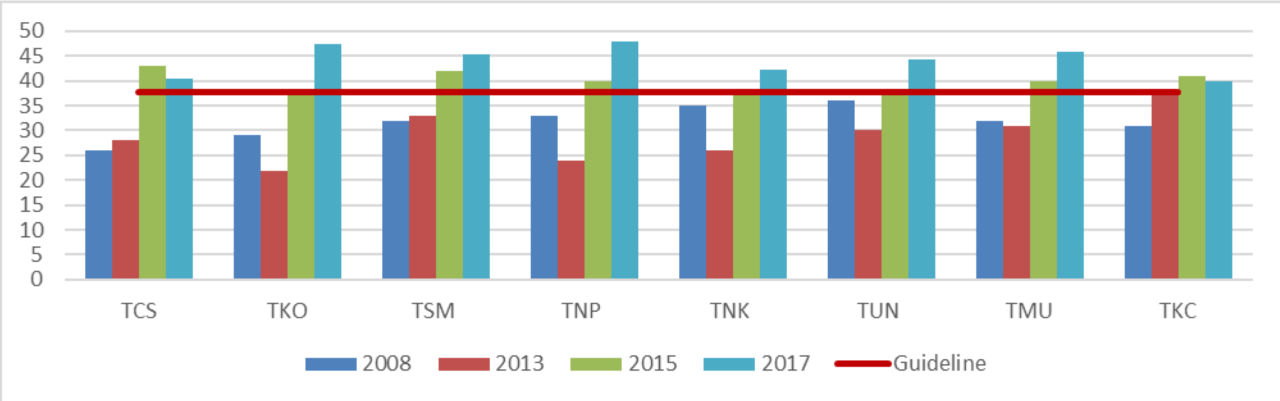
*Figure 3.50. Comparison of Benthic Macroinvertebrate Results - ATSPT for Lao PDR in 2011, 2013, 2015 and 2017*



### Thailand

All the ATSPT scores for benthic macroinvertebrates are above the threshold value for a healthy ecosystem (< 37.7) in Thailand, ranging from 40.4 at TCS to 48 at TNP (mean = 45.3 ± 2.7). TKO also had a particularly high ATSPT scores of 47.4 (as shown in ***Figure 3.51*** and ***Table 3.5***). It needs to be noted that TCS only had one individual species present, biasing the result of 40.4. It is the first monitoring period since the beginning that all sites lie above the reference value indicating a vast intensification of species being more tolerant to environmental changes. This trend follows the trend being observed in Lao PDR.

*Figure 3.51. Comparison of Benthic Macroinvertebrate Results - ATSPT for Thailand in 2008, 2013, 2015 and 2017*

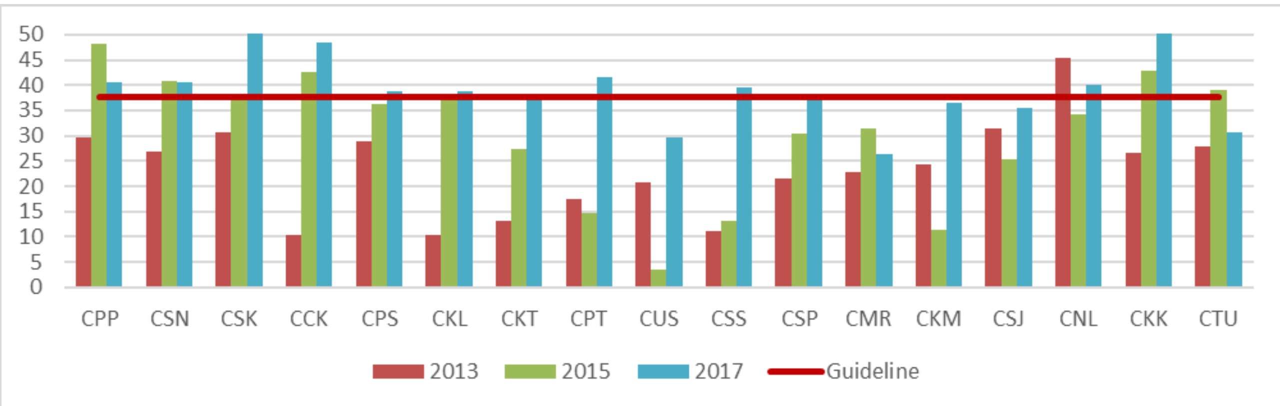



*(Note that due to missing data from 2011 the monitoring results from 2008 are shown)*

### Cambodia

The ATSPT scores for the Cambodian sites in 2017 ranged from 29.63 at CUS to 53.05 at CSK and are much higher than those taken in 2015 except in 2 sites, CMR and CTU (as shown in ***Figure 3.52*** and ***Table 3.5***). As with other biological indicators the sites CKK and CCK also show high ATSPT values (51.44 and 48.46) and an increasing disturbance trend over the last years. Detailed monitoring is necessary in order to take actions if necessary. The lowest score was found upstream in the tributary of the Sesan River (CUS). Most sites (12 out of 17) reached up to an ATSPT value being above the reference value for a healthy ecosystem. Lower ATSPT values were found in the northern part of Cambodia, particularly in the tributaries indicating a higher diversity and more less tolerant species being able to be present. In total only 5 sites fell below the threshold value of being classified as a healthy ecosystem. In general, it can be said that the upper tributaries are less impacted by human activities leading to lower ATSPT values.

*Figure 3.52. Comparison of Benthic Macroinvertebrate Results - ATSPT for Cambodia in 2013, 2015 and 2017*



**Viet Nam**

***Figure 3.53*** and ***Table 3.5*** show values of ATSPT at sites in 2017 ranging from 38 to 48. The highest ATSPT value was at VKB (48.0) and the lowest value at VTT (38.0) with an average of 48.6 ± 1.0. All sites had ATSPT scores that were higher than the guideline value. In comparison to 2015, ATSPT scores were higher at four sites (VLX, VTP, VKB and VCL); and lower at the other four sites (VDP, VTT, VCT and VVL). The ATSPT scores for the sites in Viet Nam have always been above the reference value indicating that more tolerant species towards environmental changes dominate. Since the number of species has decreased as mentioned in previous sections, this trend needs to be monitored with care as invasive species may lead to a loss of biodiversity.

*Figure 3.53. Comparison of Benthic Macroinvertebrate Results - ATSPT for Viet Nam in 2011, 2013, 2015 and 2017*

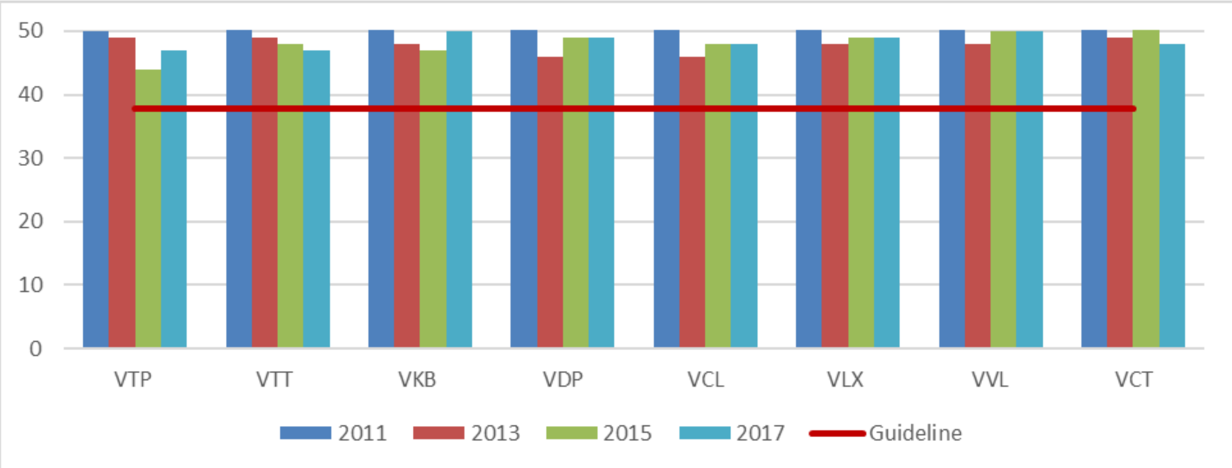



*Table 3.5. Comparison of Benthic Macroinvertebrates - Average Abundance, Average Richness and ATSPT scores for sites across the Lower Mekong Basin in 2011, 2013, 2015 and 2017*

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** |
| **LMX** | 3.5 | 17.8 | 7.7 | **11.5** | 0.7 | 5.2 | 2.8 | **4.4** | 17.7 | 44.1 | 40.0 | **45.2** |
| **LPB** | 6.9 | 5.0 | 12.1 | **40.9** | 2.5 | 2.6 | 3.8 | **5.3** | 28.4 | 41.4 | 39.4 | **45.5** |
| **LVT** | 0.6 | 2.4 | 9.9 | **13.4** | 0.6 | 1.1 | 3.6 | **4.9** | 17.1 | 44.1 | 40.0 | **45.5** |
| **LBF** | 2.6 | 0.4 | 9.7 | **9.9** | 1.2 | 0.3 | 3.5 | **3.8** | 23.5 | 9.2 | 43.2 | **44.5** |
| **LBH** | 10.1 | 4.3 | 8.5 | **44.8** | 3.6 | 3.0 | 3.4 | **7.8** | 40.6 | 41.0 | 42.6 | **44.8** |
| **LSD** | 10.8 | 17.4 | 11.8 | **19.9** | 3.8 | 4.2 | 4.5 | **5.6** | 33.1 | 42.8 | 42.1 | **44.4** |
| **LDN** | 18.8 | 8.8 | 13.3 | **13.8** | 4.3 | 2.4 | 4.3 | **5.3** | 33.2 | 35.3 | 44.0 | **44.1** |
| **LKL** | 2.4 | 3.1 | 14.8 | **18.6** | 1.3 | 1.9 | 4.0 | **5.8** | 31.0 | 41.1 | 42.6 | **44.8** |
| **TCS** | 441.0 | 6.0 | 65.0 | **1.0** | 16.0 | 4.0 | 10.0 | **1.0** | 26.0 | 28.0 | 43.0 | **40.4** |
| **TKO** | 302.0 | 12.0 | 208.0 | **100.0** | 26.0 | 6.0 | 25.0 | **14.7** | 29.0 | 22.0 | 37.0 | **47.4** |
| **TSM** | 0.0 | 88.0 | 235.0 | **114.0** | 0.0 | 7.0 | 15.0 | **5.3** | 32.0 | 33.0 | 42.0 | **45.3** |
| **TNP** | 184.0 | 240.0 | 545.0 | **151.0** | 16.0 | 12.0 | 18.0 | **10.3** | 33.0 | 24.0 | 40.0 | **48.0** |
| **TNK** | 115.0 | 132.0 | 471.0 | **327.0** | 21.0 | 5.0 | 21.0 | **17.3** | 35.0 | 26.0 | 38.0 | **42.3** |
| **TUN** | 235.0 | 281.0 | 215.0 | **208.0** | 27.0 | 5.0 | 15.0 | **15.3** | 36.0 | 30.0 | 38.0 | **44.2** |
| **TMU** | 282.0 | 108.0 | 269.0 | **67.3** | 23.0 | 8.0 | 19.0 | **8.0** | 32.0 | 31.0 | 40.0 | **45.9** |

| Site | Average Abundance | | | | Average Richness | | | | ATSPT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** | **2011** | **2013** | **2015** | **2017** |
| **TKC** | 68.0 | 23.0 | 115.0 | **39.6** | 10.0 | 4.0 | 12.0 | **5.3** | 31.0 | 37.0 | 41.0 | **40.0** |
| **CMR** | | 4.2 | 16.5 | **33.6** | | 2.3 | 3.3 | **5.3** | | 22.7 | 31.4 | **26.5** |
| **CKM** | | 2.4 | 0.7 | **22.8** | | 1.5 | 0.6 | **5.9** | | 24.3 | 11.4 | **36.5** |
| **CSS** | | 0.5 | 0.8 | **14.6** | | 0.3 | 0.5 | **6.0** | | 11.1 | 13.0 | **39.6** |
| **CSJ** | | 3.1 | 2.8 | **7.7** | | 1.7 | 1.9 | **3.2** | | 31.4 | 25.4 | **35.5** |
| **CUS** | | 2.2 | 0.2 | **12.2** | | 2.0 | 0.1 | **4.0** | | 20.7 | 3.5 | **29.6** |
| **CSP** | | 2.8 | 7.7 | **5.6** | | 2.2 | 2.3 | **3.4** | | 21.5 | 30.4 | **37.9** |
| **CKT** | | 8.7 | 13.0 | **15.2** | | 2.1 | 2.3 | **4.3** | | 13.2 | 27.3 | **38.3** |
| **CPT** | | 0.5 | 5.5 | **4.0** | | 0.4 | 1.2 | **2.6** | | 17.4 | 14.6 | **41.5** |
| **CCK** | | 14.6 | 82.6 | **122.2** | | 1.8 | 7.0 | **16.6** | | 10.4 | 42.7 | **48.5** |
| **CSK** | | 5.1 | 10.2 | **36.8** | | 2.3 | 2.8 | **9.2** | | 30.7 | 37.5 | **53.1** |
| **CPS** | | 12.8 | 4.3 | **11.1** | | 4.0 | 2.7 | **4.4** | | 28.9 | 36.3 | **38.7** |
| **CKL** | | 58.4 | 76.2 | **99.6** | | 6.5 | 9.8 | **9.8** | | 10.3 | 38.3 | **38.8** |
| **CSN** | | 22.3 | 13.0 | **7.7** | | 1.3 | 2.6 | **4.2** | | 27.0 | 40.8 | **40.7** |
| **CTU** | | 56.4 | 19.3 | **30.4** | | 5.0 | 3.3 | **3.7** | | 28.0 | 38.9 | **30.6** |
| **CPP** | | 35.6 | 116.1 | **38.8** | | 5.6 | 4.7 | **8.0** | | 29.7 | 48.1 | **40.6** |
| **CKK** | | 34.8 | 44.8 | **67.2** | | 5.6 | 6.3 | **8.7** | | 26.6 | 42.9 | **51.4** |
| **CNL** | | 36.6 | 25.8 | **29.3** | | 6.8 | 4.6 | **6.6** | | 45.5 | 34.1 | **40.0** |
| **VTP** | 47.0 | 6.0 | 127.0 | **101.0** | 6.0 | 1.6 | 8.0 | **9.0** | 50.0 | 49.0 | 44.0 | **47.0** |
| **VTT** | 49.0 | 13.0 | 124.0 | **129.0** | 6.0 | 4.0 | 6.0 | **6.0** | 54.0 | 49.0 | 48.0 | **47** |
| **VKB** | 205.0 | 65.0 | 260.0 | **136.0** | 10.0 | 8.0 | 13.0 | **12.0** | 55.0 | 48.0 | 47.0 | **50.0** |
| **VDP** | 49.0 | 25.0 | 57.0 | **55.0** | 9.0 | 7.0 | 8.0 | **9.0** | 56.0 | 46.0 | 49.0 | **49.0** |
| **VCL** | 32.0 | 26.0 | 103.0 | **24.0** | 5.0 | 5.0 | 6.0 | **8.0** | 56.0 | 46.0 | 48.0 | **48** |
| **VLX** | 141 | 71 | 70 | **35** | 10 | 7 | 7 | **6** | 56 | 48 | 49 | **49** |
| **VVL** | 31 | 26 | 27 | **16** | 6 | 3 | 5 | **5** | 56 | 48 | 50 | **50** |
| **VCT** | 67 | 23 | 16 | **18** | 7 | 4 | 5 | **4** | 55 | 49 | 51 | **48** |

*(Note – the cells shaded in pink correspond to the ATSPT values from 2008 for Thailand as due to the absence of those values, they are not shown here, the yellow highlight corresponds to sites that are not located on the Mekong mainstem)*

## 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) to assess the status of each site based on the scoring system described in *Section 3.5*. The site assessment and classification for 2017 is summarised in ***Table 3.6*** and ***Figure 3.54***, and the historical development since 2007 is summarised in ***Table 3.7.***

### *Lao PDR*

In Lao PDR, 4 out of 8 sites were rated class C and four sites were assessed as class B (LPB and LDN) (as shown in ***Table 3.6***). In comparison to 2015 monitoring, all sites remained at similar condition, except for LMX being classified as class B in 2017. It needs to be noted that all sites failed to meet the required ATSPT to be classified as a healthy system Monitoring should be carried out carefully and the most dominant species should be further studied and assessed.

### *Thailand*

The sites assessed in Thailand during 2017 show great signs of disturbance. No sites showed an improvement in ecological health but 7 out of 8 showed a decline. Two sites were classified as D indicating great disturbance and unhealthy living conditions for aquatic life (TCS and TKC). It needs to be noted that the mentioned sites are located on the mainstem of the Mekong River and have, furthermore, been impacted by navigation and fish farming, construction and river bank development, as well as activities associated with tourism. Three sites were classified as class C (TNP, TKO & TSM) and three sites were classified as B (TUN and TMU and TNK). Only site TNK at the Nam Kham River kept a consistent ecological health, although it needs to be mentioned that the ATSPT scores for all indicators failed to meet the healthy ecosystem's guideline. Finally, the condition of the mainstem at those sites is of concern but it needs to be noted that due to difficult sampling conditions, the results may be biased and more monitoring is required to make reliable predictions.

### *Cambodia*

In 2017, 6 out of 17 sites in Cambodia were assessed and classified as class A. CUS was the only site to lie within all threshold values to be classified as a healthy ecosystem. The site being located upstream from most human affected areas may have influenced this result. Four other sites (CKT, CKM, CSJ and CSP) that are located in the northern part of Cambodia have been classified as A, indicating a healthier river environment. The remaining 11 out of 17 sites were classified as class B (good) (CMR, CSS, CPT, CCK, CSK, CKL, CSN, CPP, CPS, CKL, CKK). CPP and CSK scored the lowest with only 7 out of 12 metrics being met. As for Lao PDR and Thailand, hardly any ATSPT scores fell within the guideline's threshold value. Furthermore, the results indicate that the Tonle Sap- Lake and River area shows greater signs of human disturbance and as a result more detailed monitoring should be undertaken at those sites.

### *Viet Nam*

Only VTP located in the Mekong River was given the classification of C (moderate), which is slightly different than the previous monitoring period. The two most northern sites in the Mekong River showed higher signs of disturbance through industrial and commercial activities in addition to sand dredging and leaking sewage into the river. Particularly VTP and VKB are of greater concern. All the other sites were in class B (good). As observed for the whole Lower Mekong Basin, in Viet Nam none of the biological indicators lay within the healthy ecosystem's guideline value for the ATSPT scores.

*Table 3.6. Environmental Assessment for all monitoring Sites of the Lower Mekong Basin 2017*

| Site code | Sampling dates | Benthic diatoms | | | Zooplankton | | | Littoral macroinvertebrates | | | Benthic macro-invertebrates | | | Meeting guideline | Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | | |
| LMX | 29/05/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ | | 7 | B |
| LPB | 31/05/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | B |
| LVT | 02/06/2017 | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | B |
| LBF | 19/05/2017 | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ | ✓ | | 6 | C |
| LBH | 24/05/2017 | | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ | | 6 | C |
| LSD | 23/05/2017 | | | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 6 | C |
| LKL | 21/05/2017 | | | | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | 5 | C |
| LDN | 22/05/2017 | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | 8 | B |
| TCS | 08/05/2017 | ✓ | ✓ | | | | | ✓ | | | | | | 3 | D |
| TKO | 09/05/2017 | ✓ | ✓ | | | | | ✓ | ✓ | | ✓ | ✓ | | 6 | C |
| TSM | 03/05/2017 | ✓ | ✓ | | | | | ✓ | ✓ | | ✓ | ✓ | | 6 | C |
| TNP | 02/05/2017 | ✓ | ✓ | | | | | | | | ✓ | ✓ | | 4 | C |
| TNK | 04/05/2017 | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | B |
| TUN | 06/05/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | 9 | B |
| TMU | 05/05/2017 | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | B |
| TKC | 05/05/2017 | | ✓ | | | | | | | | ✓ | ✓ | | 3 | D |
| CMR | 30/03/2017 | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | 8 | B |
| CKM | 31/03/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | 10 | A |
| CUS | 03/04/2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 12 | A |
| CSS | 02/04/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | 9 | B |
| CSP | 04/04/2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | 10 | A |
| CSJ | 01/04/2017 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | 10 | A |
| CKT | 29/03/2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | 10 | A |
| CPT | 28/03/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | 8 | B |
| CCK | 07/04/2017 | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | | 8 | B |
| CKL | 09/04/2017 | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | 8 | B |
| CSN | 05/04/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | 8 | B |
| CSK | 06/04/2017 | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | B |
| CTU | 22/04/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | 10 | A |
| CPP | 24/04/2017 | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | B |
| CPS | 08/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | B |

| Site code | Sampling dates | Benthic diatoms | | | Zooplankton | | | Littoral macroin-vertebrates | | | Benthic macro-invertebrates | | | Meeting guideline | Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | Abundance | Richness | ATSPT | | |
| **CNL** | 21/04/2017 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | 9 | **B** |
| **CKK** | 20/04/2017 | | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 7 | **B** |
| **VTP** | 12/04/2017 | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ | ✓ | | 6 | **C** |
| **VTT** | 13/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ | | 7 | **B** |
| **VKB** | 11/04/2017 | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | ✓ | ✓ | | 7 | **B** |
| **VDP** | 10/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | **B** |
| **VCL** | 14/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | **B** |
| **VLX** | 09/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | **B** |
| **VVL** | 07/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | **B** |
| **VCT** | 08/04/2017 | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | | 8 | **B** |

*(The sites highlighted in yellow are not located on the mainstem).*

*Figure 3.54. Ecological Health Status of the River 2017*

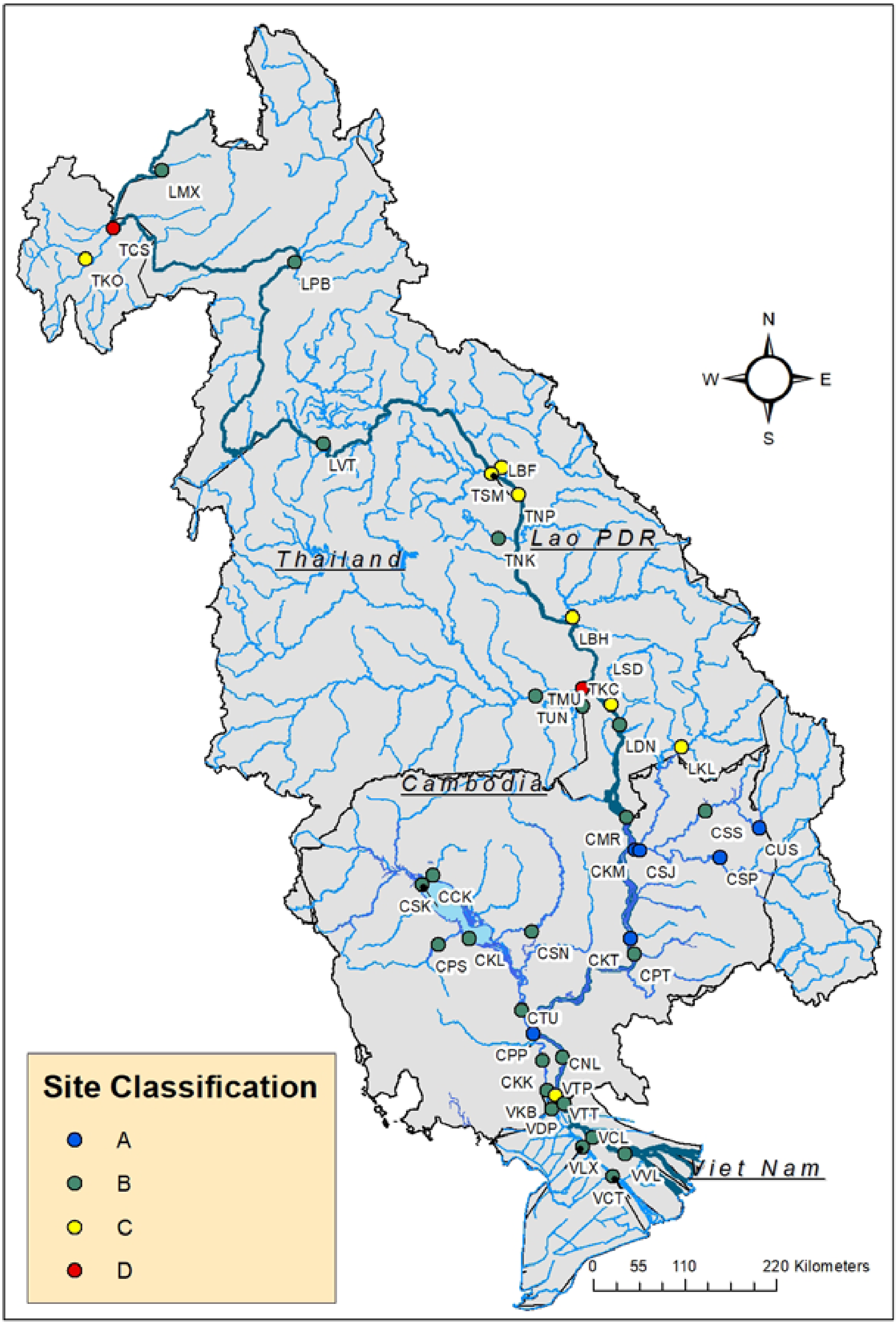


*Table 3.7. Site Assessment between 2007 and 2017*

| Site code | Location | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 |
| **Lao PDR** | | | | | | | |
| **LMX** | Mekong River, Ban Xiengkok, Luangnamtha | | D Abnormal | D Abnormal | C | C | B |
| **LPB** | Mekong River, Done Chor, Luang Prabang | | B | A | C | B | B |
| **LVT** | Mekong River, Ban Huayhome, Vientiane | B | C | C | D Abnormal | B | B |
| **LBF** | Se Bang Fai River, Se Bang Fai, Khammouan | B | B | C | D Abnormal | C | C |
| **LBH** | Se Bang Hieng River, Songkhone, Savannakhet | A | C | B | D Abnormal | C | C |
| **LSD** | Sedone River, Ban Hae, Pakse | B | B | B | D Abnormal | C | C |
| **LKL** | Se Kong River, Ban Somsanouk, Attapeu | B | C | C | D Abnormal | C | C |
| **LDN** | Mekong River, Done Ngiew , Champasak | A | B | A | D Abnormal | B | B |
| **Thailand** | | | | | | | |
| **TCS** | Mekong River, Chiang San, Chiang Rai | | B | B | B | B | D Abnormal |
| **TKO** | Kok River, Chiang Rai City | | A | B | B | B | C |
| **TSM** | Songkram and Mekong River junction, Nakorn Phanom | C | A | C | B | A | C |
| **TNP** | Mekong River, Nakorn Phanom City | | C | B | A | B | C |
| **TNK** | Nam Kham River, Na Kae, Mukdaharn | C | B | B | A | B | B |
| **TUN** | Mun River, Ubon Rachathani City | | A | A | A | A | B |
| **TMU** | Mun River, Kong Chiam, Ubon Rachathani | | B | C | A | A | B |
| **TKC** | Mun and Mekong River junction, Ubon Rachathani | | A | C | B | A | D Abnormal |
| **Cambodia** | | | | | | | |
| **CMR** | Mekong River, Ramsar Site, Stung Treng | B | B | A | B | B | B |
| **CKM** | Se Kong River, Kbal Koh, Stung Treng | B | A | B | C | B | A |
| **CUS** | Se San River, Dey It, Rattanakiri | B | A | C | B | B | A |
| **CSS** | Se San River, Veunsai, Rattanakiri | | | B | C | C | B |
| **CSP** | Srepok River, Phik, Rattanakiri | A | B | A | B | A | A |
| **CSJ** | Se San River, Downstream of Srepok River junction, Stung Treng | A | A | A | C | B | A |
| **CKT** | Mekong River, Kampi Pool, Kratie | | A | A | B | B | A |
| **CPT** | Prek Te River, Preh Kanlong, Kratie | | | C | D Abnormal | B | B |
| **CCK** | Tonle Sap Lake, Chong Khnease, Siem Reap | | | B | B | B | B |

| Site code | Location | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2007 | 2008 | 2011 | 2013 | 2015 | 2017 |
| **CSN** | Stoeng Sangke River, Battambang | | | B | C | B | B |
| **CSK** | Stung Sen River, Kampong Thom | | B | C | B | B | B |
| **CTU** | Tonle Sap River, Peek Kdam Ferry, Kandal | | | B | B | B | B |
| **CPP** | Tonle Sap River, Phnom Penh Port | | | B | C | B | A |
| **CPS** | Pursat River, Damnak Ampil, Pursat | | | B | B | A | B |
| **CKL** | Tonle Sap Lake, Kampong Luong, Pursat | | | B | B | B | B |
| **CNL** | Mekong River, Nak Loeung, Prey Veng | | | B | C | A | B |
| **CKK** | Bassac River, Koh Khel, Kandal | | C | B | B | A | B |
| **Viet Nam** | | | | | | | |
| **VTP** | Mekong River, Thuong Phuoc, Dong Thap | | C | B | C | C | C |
| **VTT** | Mekong River, Thuong Thoi, Dong Thap | | C | B | C | B | B |
| **VKB** | Bassac River, Khanh Binh, An Giang | | B | B | B | B | B |
| **VDP** | Bassac River, Da Phuoc, An Giang | | C | B | C | B | B |
| **VCL** | Mekong River, Cao Lanh, Dong Thap | | C | B | B | B | B |
| **VLX** | Bassac River, Long Xuyen, An Giang | | B | C | C | B | B |
| **VVL** | Mekong River, My Thuan, Vinh Long | | C | C | C | B | B |
| **VCT** | Bassac River, Phu An, Can Tho | | B | B | C | B | B |

# 4. Regional Summary and Conclusion

The main objective were to (i) describe the biological indicator groups sampled during 2017; (ii) use this information to derive biological indicators for the sites examined in 2017; and (iii) use biometric indicators to evaluate these sites to establish the Ecological Health of the Lower Mekong Basin (LMB). Physical variables were also assessed measuring the pH, electrical conductivity, DO content, in addition to visibility (Secchi Depth) and the general width and depth of the river. After sampling, sites were evaluated based on average abundance, average richness and Average Tolerance Score Per Taxon (ATSPT) scores per site for benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. Based on the MRC guidelines for these indicators, sites were allocated into classes representing classes A (excellent), B (good), C (moderate) and D (poor) ecological health.

Ten sites across the LMB did not meet the recommended guideline levels of benthic diatom abundance of >136.2 individuals per site, representative of a healthy ecosystem. This included three sites in Lao PDR (LSD, LBH and LKL), three in Thailand (TNK, TMU, TKC) and 4 sites from Cambodia (CSJ, CKL, CSK, CPP). Diatom richness was lower than the guidelines set out with the reference sites (> 6.5) at four of the sample sites including 3 sites in Lao PDR (LVT, LKL and LSD) and one site in Cambodia (CKL at Kampoung Luong). Thailand and Viet Nam sites all met the threshold diatom richness levels. ATSPT scores for benthic diatoms were universally high across the basin, particularly in Viet Nam with only 6 sites across the basin meeting ATSPT guideline scores all lying in the tributaries of the Mekong in Cambodia. However, as mentioned in the Assessment Report from 2015, a continuous rise in ATSPT scores is observed. It remains complex and difficult to distinguish between natural and anthropogenic effects. However, overall dominant species seem to dominate across the monitoring sites with an increasing rate. The most abundant species across the sites were *Nitzschia* sp., *Cymbella turgidula, Cocconius placentula*. The first time since 2011, it *Eunotia* sp. was present at the sites in Lao PDR. Overall, a decrease in total abundance of all diatoms collected across the 41 monitoring sites was observed being only 11,033 individuals in 2017 compared to 22,555 individuals in 2015.

In Lao PDR, all sites except for LMX and LPB the two most northern sites of the Mekong, showed a decrease in individuals of zooplankton. Five sites in Thailand (TNP, TCS, TKO, TSM and TKC) and one site in Cambodia (CMR) failed to meet the guideline level of zooplankton abundance to signify a healthy ecosystem of > 9.8 species per sample. Three sites in Thailand (TCS, TKO, TNP) were absent of zooplankton and therefore also did not meet requirements for a healthy ecosystem in terms of richness and ATSPT score. It was noticed that all these sites were located on the mainstem of the Mekong River, which was also observed at the mainstem sites in Cambodia containing lower numbers of zooplankton (CMR, CKT, CNL). The fact of fast flowing current may have biased the sampling results. LDN had the highest zooplankton richness and abundance in Lao PDR, indicative of a healthy ecosystem. In total, 8 sites failed to reach the zooplankton richness guidelines including 5 in Thailand (TNP, TSM, TKC, TCS and TKO) and three in Cambodia (CMR, CKK and CCK). Overall, 27 sites exceeded the guideline values for ATSPT of < 41.8, including all sites from Lao PDR and all sites from Thailand: Considering that the three sites TCS, TSM and TNP were absent of zooplankton, they were not meeting the threshold value for a healthy ecosystem. Three sites in Cambodia (CPS, CPP and CSK) in addition to all 8 sites in Viet Nam also exceeded the ATSPT threshold value. It was noticed that the ATSPT scores in Viet Nam were predominantly higher than in the other countries. The distribution was almost certainly affected by high flowrates during the sample period, as well as temperature, DO, altitude, pH and EC. Finally, in Viet Nam, it was noticed that at site VKB an extremely high number of Family Volvocaceae was present at that site, which is common for places with an excess of nutrients and can lead to large algae blooms. Care should be taken over the next monitoring periods to monitor the reoccurrence and area covered. In total, the number of zooplankton showed an increase from only being 8,824 in average to 19,045 individuals in 2017. However, it is noted that approximately 12,000 correspond to the already mentioned *Volvox aureus* species in Viet Nam. Hence, it can be said that, in reality, the overall abundance may have dropped.

Eight sites did not meet criteria for healthy ecosystem for littoral macroinvertebrate abundance of which three are in Lao PDR (LBF, LDN and LKL), two in Thailand (TKC, TNP) one in Cambodia (CSN) and two in Viet Nam (VKB and VTP). Sites LBF, TNP, TKC and VTP also had lower littoral macroinvertebrate richness than guideline levels, as well as a further 4 sites (LMX, LBH, TCS and VTT). ATSPT scores were universally high across the LMB with all sites in Lao PDR and Viet Nam exceeding the guideline and only TUN and CUS meeting the criteria in Thailand and Cambodia. Species *Baetis* sp. and *Nigrobaetis* sp. were dominating in Lao PDR. The first occurrence of *Kiefferulus* sp. since 2011 was also identified. Backed up by literature in Cambodia results indicate that a higher of DO may lead to a higher proportion of littoral macroinvertebrates. In Viet Nam the critically endangered species *Pachydropbia* sp. was no longer present in 2017. It will be important to monitor carefully during the next assessment periods to confirm the actual disappearance of the species. In the end, several disturbances occurred at most monitoring sites which have the potential to impact littoral macroinvertebrate communities, including human settlements and associated domestic waste, sand pumping, fishing and fish farming and bank erosion. Habitat suitability and streamflow velocity also played an important part in littoral macroinvertebrate distribution. As for the previous biological indicator the total number of individuals collected in 2017 has declined, although only by a small amount from 9,474 individuals in 2015 to 8,993 in 2017. Considering that littoral macroinvertebrates are more respondent towards long-term changes, this may only be a natural variation.

In Thailand, only site TCS failed to meet guidelines to qualify as healthy ecosystem for benthic macroinvertebrate abundance and richness. In Cambodia site CPT in Cambodia was the only other site that did not meet threshold value for average abundance. This could be due to inappropriate substrate for benthic macroinvertebrate which require a soft substrate such as mud. However, tolerance scores were universally high across sample sites. In Lao PDR, a species, previously not found, was discovered at a majority of sites: *Lumbricus* sp. As in 2015, the most dominant species found in Thailand were *Melanoides* sp. and *Corbicula* sp., while in Cambodia it was *Thiennemannimyia* sp. with a high number biasing some of the results. In Viet Nam, on the other hand, there was a large variation and change compared to the previous monitoring years. *Chironomus* sp. (Insecta), *Corbicula baudoni*, *Corbicula* sp., *Limnoperna siamensis*, *Sinomytilus harmandi* (Bivalvia), *Brachyura larva* (Decapoda) were the most abundant and additional 7 species were found. The overall abundance also decreased for the benthic macroinvertebrate biological indicator in 2017 from 3,434 individuals in 2015 to 2,253 individuals collected in 2017.

In conclusion, the 2017 Ecological Health monitoring revealed that 25 out of the 41 sites were found to have good ecological health (class B). Six sites were rated class A, meaning that they had excellent ecological health. Most of those were located in the tributaries of Cambodia (CSP CKM, CSJ, CSP, CKT and CPP). Sites TCS and TKC were the only ones that were found to have poor ecological quality according to the MRC guidelines (class D). It is noted that zooplankton was not present at TKC, which prevented the calculation of an ATSPT score for this site. However, since none were present this could be an indication for an unsuitable living environment. The remaining 8 sites had moderate ecological health (class C). As already commented in 2015, the overall condition of the river is stable, however, predominantly the ATSPT scores keep increasing, which indicates higher disturbance at the individual sites. There are particular sites that scored the highest ATSPT for all indicators. Particularly, sites, CSK, CCK in the northern part of the Tonle Sap, in addition to TCS and TKC in Thailand and VDP in Viet Nam experience great disturbances. Most of those sites, have seen an increase of SDS as well, confirming the increase in disturbance. Careful monitoring should be carried out at all sites accessing the most abundant species such as the mentioned species in the previous section, which seem to dominate the sites.

# 5. Recommendation

The ecological health monitoring programme in the Lower Mekong Basin has been an ongoing routine programme providing baseline data for future decision making in regional natural resource management. Detailed and careful sampling is essential to capture the overall ecological health status of the Mekong River and its major tributaries. With increasing outside pressures from human disturbance and climate change, may it be natural or anthropogenic, this programme will become even more important in the future.

| Recommendation | Current State | Reason | Example |
|---|---|---|---|
| **Revisit sampling results from previous monitoring results (site descriptions and photos) prior to site visit.**<br><br>- Make good field descriptions, noting changes from previous monitoring results<br>- Take photographs from the same spots to record changes | Assessing and analysing the latest report it was found that site descriptions were simply repeated across the countries and no detailed descriptions were provided, allowing for comparison between the physical conditions of the individual sites. | - Detection of immediate changes are easier detectable and recorded<br>- Reporting of changes will be easier trackable.<br>- Pre-knowledge will flag particular patterns and species to look out for.<br>- Identify trends and spatial patterns over time. | *The species Volvox aureus biased the abundance result of zooplankton across the whole LMB in 2017 due to the large amount present at one site.*<br><br>*This should be reassessed in 2019.*<br><br>*The importance of individual species should be a focus of the next monitoring cycles since individual species favor different conditions and reflect the overall conditions of the occupying water bodies.* |
| **Enhance usage of technology and investigate spatial patterns and connectivity across sites**<br><br>- Diversify methodologies<br>- Utilise other forms of data collection (remote sensing) | The Mekong River and Tonle Sap Lake are connected through a great water body. Everything is interconnected. Currently, each of the 41 sites is treated as an individual site, which is not connected to any others. | - Identification of possible point pollution sources<br>- The use of remote sensing techniques would allow to cover a larger scale and identify possible sources of further pollution<br>- Collected and consistent data allow interconnectivity between spatial and temporal trends | *Sites CSK and CCK in Cambodia have shown increased ATSPT for almost all biological indicators throughout the last monitoring periods, are spatially closely connected and should be assessed on whether there is a source of disturbance affecting both sites.* |
| **The timing of sample collection should be kept consistent between the monitoring periods to eliminate high levels of fluctuation in the river system**<br><br>- The field work needs to be undertaken in the same month by every country<br>- Reporting structure should be consistent across countries. | In 2017, the monitoring period was spread across at least three months (March-June), which may or may not have biased the result. On the other hand, in 2015 monitoring occurred during March and April | - No temporal trends can be obtained and proven with accurate results<br>- Field conditions are too variable<br>- The further in to the wet season we go the more dangerous sampling becomes. | *In 2017, Lao PDR conducted the field work by the end of May and beginning of June, which is also the start to the wet season. Being close to the elevated terrain, rainy periods are becoming more dominant around this time. As noted in the report, sampling conditions became harder and various flooding had occurred already.* |

| Recommendation | Current State | Reason | Example |
|---|---|---|---|
| **A regional and uniform database/structure for EHM results to allow easier storage, comparison and transfer of data.**<br><br>- Development of a regional standard for reporting EHM results<br>- Development of regional database with national plug-in. | A regional sampling technology exist without a direct reporting structure. Every MC is reporting in individualistic way using different technologies. Everything is done manually. | - It would be more efficient to develop a regional reporting guideline to allow easier comparison and limit the probability of error<br>- Automating the calculations of the biometric indicators will make reporting more efficient and allow more time for interpretation and analysis<br>- Could potentially allow the expansion of the monitoring programme, adding more sites or revisit of sites, if necessary.<br>- Keeping the goal of decentralisation in mind, the more efficient data structure would support this strategy. | *Every MC is submitting the raw data and national reports to the MRC Secretariat after the completion of each monitoring period. Every national report has a different design and monitoring details vary between each country. Furthermore, the raw data and calculation of biometric indicators are not following the same format, making cross-control and comparison a complex and time-consuming process.* |
| **Investigation of possible drivers leading to enhanced values of SDS and higher numbers of individual species.**<br><br>- Application of DPSIR Model to investigate: drivers pressures impacts and possible response mitigation measures. | The average tolerance scores per taxon continues to increase. Considering that the Mekong and Bassac rivers, in addition to the Tonle Sap are great in size, it is of great concern that these values show this increase since these water bodies are the accumulation of all the water originating from further upstream, the surrounding mountain belts and agricultural run-off. | - To find solutions for the individual sites showing high ATSPT, it is necessary to identify the drivers and direct impacts to the surrounding ecosystem in order to define precise mitigation measures.<br>- To propose changes, solutions and activities should be proposed along with the description of the current situation to drive changes. | *Due to the missing links between drivers and solutions, no clear roadmap has yet been identified for solving local sources of pollution and how to mitigate for the regional change of ecosystems and biodiversity.*<br><br>*More than 80,000,000 people are dependent on the Mekong River and its tributaries, making the monitoring and management of the river system so important.* |

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# 7. Annex 1 – Images of fieldwork activities in 2017

**Field work: Zooplankton Collection**

*Field work: Littoral Macroinvertebrates Collection*

*Field work: Benthic Macroinvertebrates Collection*

# 8. Annex 2 – Images of specimen collected in 2017

**Zooplankton images collected in 2017**

*Brachionus urceolaris*

*Ceriodaphnia rigaudii*

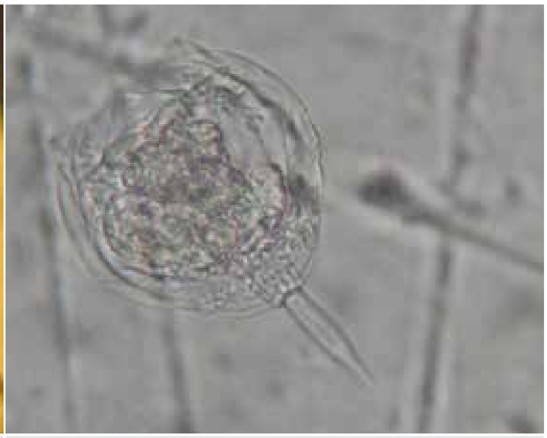
*Keratella lenzi*

*Lecane arcula*

*Testudinella patina*

*Lecane curvicornis*

*Leydigia acanthocercoides*



*Lecane closterocerca*

*Bosminopsis deitersi*

*Platyias quadricornis*


*Keratella coclearearis*

*Brachionus falcatus*

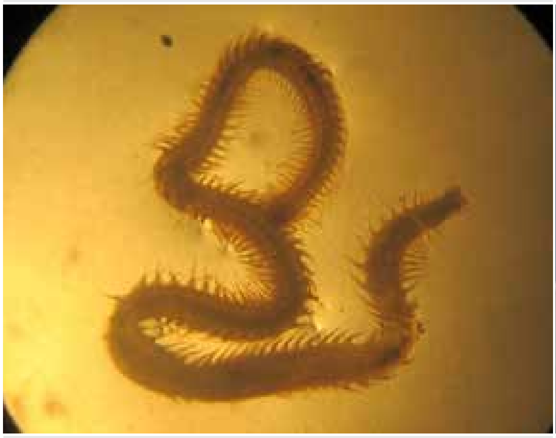
## Littoral Macroinvertebrates images collected in 2017

*Clea helena*

*Hyriopsis bialata*

*Pomacea canaliculata*

*Limnoperna siamensis*



*Namalycastis longicirris*

*Pilsbryoconcha exilis*

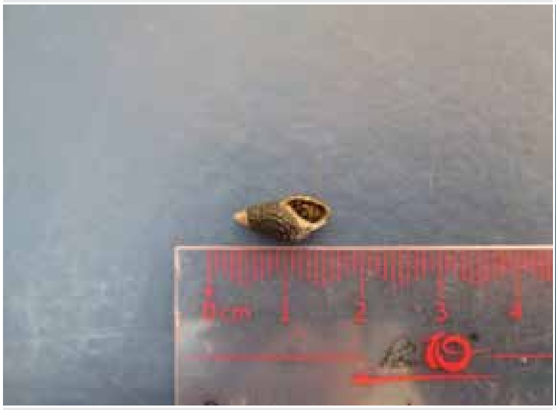
*Limnodrilus grandisetosus*

*Branchiura sowerbyi*

**Benthic Macroinvertebrates Images collected in 2017**

*Scabies crispata*

*Physunio micropterus*

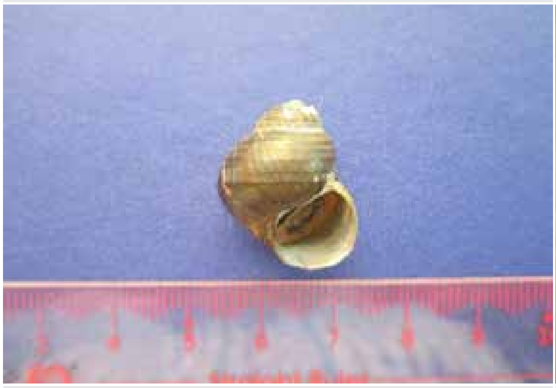


*Tarebia granifera*

*Sinomytilus harmandi*


*Corbicola moreletiana*


*Novaculina siamensis*



*Filopaludina (F.) sumatrensis*

*Watteblediacrosseana*

*Thiara scabra*

*Melanoides tuberculatus*

*Caradina sp. (scalebar 3 mm)*

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