STATE of KNOWLEDGE

Monitoring the Health of the Greater Mekong's Rivers

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Why monitor river ecology?

We monitor rivers for many reasons. Most obviously, river hydrology is monitored so that we know how much water there is and how much of this is available for our use. But the health of these river ecosystems is also important for the societies that depend on them. A 'healthy' river ecosystem generally means 'good' water quality, adequate water volumes, thriving biota and diverse habitats, all coming together as a functional whole. By monitoring river ecosystems, we can also see how they change and track how these changes might have repercussions for people. Thinking about river 'health' is useful because it is a metaphor that people understand, allowing them to envision a 'sick' or 'healthy' river ecosystem. Globally, this approach has much support, and is well respected in the United Nations system (see Box 1 for an example). For these reasons, the organisations and water departments who manage rivers will nearly always include some form of ecosystem health monitoring.

Biological monitoring (or biomonitoring) analyses how specific organisms in or close to a river respond when conditions change, e.g. how a water snail reacts when pollution enters its ecosystem. Biomonitoring has become a global standard for monitoring freshwater ecosystems, managing water quality and determining the amount of water needed to maintain a river's environment.

Biomonitoring of water ecosystems can involve many different organisms, including fish, aquatic vegetation, macroinvertebrates and micro-organisms. In river monitoring programs, most attention has been given to macroinvertebrates living on or close to the bottom of the river. In developing countries, focussing on these animals is the most common type of biomonitoring (Resh, 2007).

Box 1: Biomonitoring and the Sustainable Development Goals (SDGs)

The SDGs were adopted by the United Nations General Assembly in 2015. There are 193 countries in the General Assembly, including all Greater Mekong countries. Target 6.6 of the SDGs states; *"By 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes,"* which has a single Indicator, *"Change in the extent of water-related ecosystems over time."*

2017 was the first year that data was collected for this indicator and the data will form the baseline for future monitoring in order to detect trends. The indicator has five sub-indicators that measure the spatial extent of these ecosystems, the quantity of water contained within them, and its quality. The indicator also proposes that countries begin monitoring the health of ecosystems, which they will be required to report on starting in 2020. This gives UN member countries time to build their biomonitoring abilities so they can report on ecosystem health.

Evidence of UN support for biomonitoring is indicated by two recent publications on the subject, firstly a "Framework for Freshwater Ecosystems Management" (UN Environment, 2017) that includes details on how biomonitoring can be included in water resources management, and secondly the "UN World Water Development Report" (2018) on nature-based solutions, which may utilise biomonitoring for implementation.

Conclusion: *Monitoring how water-based animals respond to changes in their environment is a widely-accepted tool for understanding the health of a river. By analysing these responses, information can be gained on how a river is changing, if it has becoming polluted, or if its hydrology is changing. The scientific methods for carrying out this kind of work are well established and widely used.*

What are aquatic macroinvertebrates and how are they used for biomonitoring?

'Aquatic macro-invertebrates' are small animals without a backbone (for example, insects, crabs, leeches and snails) that can be seen with the naked eye, and which live in water. They are very important to aquatic ecosystems because they are near the bottom of the food chain. Some eat rotting material including masses of bacteria, as well as live vegetation or algae, while others feed on other invertebrates, amphibians and even small fish.

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By eating and processing most of the organic matter that passes through a river, these invertebrates help to 'recycle' the nutrients in the ecosystem, and in the process, help break up and remove pollutants. Aquatic invertebrates are also sensitive to both the quantity and quality of the water in the river and can die if there is a change in condition. In addition, they are relatively easy to catch, and a laboratory is not necessarily needed to analyse them. Combined, these characteristics make them excellent 'bio-indicators,' that can show the health of their river ecosystem.

Some invertebrates will spend their entire lives living in the water, while others will only live in the water as juveniles, moving onto land when they become adults. Aquatic macro-invertebrates are a large and diverse group. The common English names of the 15 main groups are given in Box 2.

Box 2: Main groups of aquatic macroinvertebrates

Temporary residents:	Permanent residents:
Mayflies	Aquatic Beetles
Stoneflies	True Bugs
Caddisflies	Shrimps, Prawns and Crabs
Dobsonflies and Alderflies	Flatworms
Dragonflies and Damselflies	Snails and Limpets
Aquatic Caterpillars and Moths	Mussels and Clams
Sewage flies	Aquatic Worms
	Leeches

Bio-monitoring focuses on the macroinvertebrates living in a particular area of a river at a particular time. In all natural rivers, there will be a variety of species present that have a different tolerance to different types of pollution. For example, one species might be very sensitive to reduced amounts of oxygen in the water, while another is sensitive to an increase in a particular type of pollution. By looking at how a community of macro-invertebrates responds to these changes, we can see how an ecosystem is coping with this change. In Figure 1, for example, we see a selection of macro-invertebrates from a healthy river on the left, which shows much diversity and the presence of some sensitive species. On the right, there is less diversity, indicating that the river is unhealthy.

Figure 1: Example of aquatic invertebrates from a healthy stream (top), and an unhealthy one (bottom). Note difference in the number and types of species between the two streams, which forms the basis of biomonitoring techniques. (C. Dickens)

Macro-invertebrates occur in all rivers across the world, with different types living in different parts of the river, reflecting how a river's environment changes as it crosses landscapes, altitudes and climates. Focusing on macro-invertebrates as a way of understanding a river's environment and the ways in which it is changing can therefore be very location specific.

Once the macroinvertebrates have been caught, they are usually identified quickly (before they die) at or close to where they were caught. This exercise will normally focus on:

- Species richness: number of invertebrate groups per sample.
- Abundance: number of individual organisms per sample.
- A measure of sensitivity for each invertebrate group present (sensitivity to changes in water quality or other factors).

In most scoring calculations, the sensitivity scores of all of the organisms from one site are added up, and divided by the species richness. This index value is then used to gauge overall river health. These scores may then be used to classify stretches of the river (a 'reach'), and thus to represent its overall ecological condition.

The great diversity of macro-invertebrates can make interpreting biomonitoring complicated. A difficulty with biomonitoring is that while a scientist may observe that a change in a community of macro-invertebrates, linking this to an upstream cause can be challenging.

Figure 2: Collecting samples from an irrigation canal using a kick or dip net

Biomonitoring scoring systems are generally designed for a particular part of the world and are not cannot necessarily be used in other places where the sensitivity of the macroinvertebrates may be different. Scoring systems are also particular to the ecosystems where they are effective; thus a system designed for flowing rivers will not work in a wetland, and vice versa, while the results from a mountain stream will need to be interpreted differently to the results from a lowland floodplain river (using the natural reference condition as the fixed point).

Conclusion: *Biomonitoring is a highly effective way of evaluating the health of a river. Even by focussing just on macroinvertebrates, which can be seen with the naked eye, biomonitoring can tell us what is happening in a river's ecosystem. This information can tell us if there are changes to water levels and hydrology, to the amount of nutrients, whether or not there are toxins or pollutants present in the system and other information essential to water and river managers.*

Who can perform biomonitoring?

Because macroinvertebrates are so easy to catch, they can be used for biomonitoring purposes by almost anyone, using sophisticated systems for specialists and simpler systems for citizens. These simplified but accurate and verified methods (e.g. Graham *et al*, 2004) have been developed to make use of simpler sample collection methods with less complex ways to identify the invertebrates.

Well established groups of school children and citizens collect invertebrates and report the results to governments in the South African through a programme called miniSASS[1] and in Australia through Streamwatch[2] and Waterwatch[3]. In Figure 3, a simple miniSASS citizen science results sheet is shown, while Figure 4 shows children in Africa implementing the miniSASS method.

Conclusion: *The methods used for biomonitoring can be sophisticated, producing highly accurate results, but can also be simplified for communities to use. In countries where budgets for biomonitoring are low, using community-based biomonitoring systems can effectively and cheaply tell us about a river's health.*

Ecological category (Condition)	River Category	
	Sandy Type	Rocky Type
NATURAL CONDITION (Unchanged/untouched – Blue)	> 6.9	> 7.2
GOOD CONDITION (Few modifications – Green)	5.9 to 6.8	6.2 to 7.2
FAIR CONDITION (Some modifications – Orange)	5.4 to 5.8	5.7 to 6.1
POOR CONDITION (Lots of modifications – Red)	4.8 to 5.3	5.3 to 5.6
VERY POOR CONDITION (Critically modified – Purple)	< 4.8	< 5.3

Figure 3: Figure 3 River classification example from miniSASS (Graham

Figure 4: Children using miniSASS to determine the state of a river in South Africa (Mark Graham, miniSASS)

1 - www.minisass.org
2 - http://australianmuseum.net.au/what-is-streamwatch
3 - www.vic.waterwatch.org.au/

Where has biomonitoring been used?

Biomonitoring of aquatic macro-invertebrates has been used all over the world as a key input to river health assessments.

South Africa

The South African River Eco-status Monitoring Programme (REMP)[4] uses biomonitoring of aquatic invertebrates (along with fish and vegetation) to identify trends in river condition and to support water resources management. Invertebrate assessments use the South African Scoring System (SASS) (Dickens and Graham, 2002), a detailed analysis generally conducted by experts. It has been widely applied to measure the biological affects of a range of pollutants (Ollis *et al*., 2006), and as an input to setting river health targets and resource objectives (Dickens *et al*. 2014). The simplified 'miniSASS' version was described above (Graham *et al*., 2004).

Australia

In Australia, aquatic invertebrate biomonitoring is undertaken by both experts and communities. The National River Health Program developed and implemented the AusRIVAS[5]rapid bioassessment method as a national approach for river health assessment. AusRIVAS compares observed macroinvertebrate groups with computer-based models that aim to predict which macro-invertebrate communities should occur at a site in the absence of any environmental stress. In this way, a number of indices to summarise river conditions are derived (Chessman, 2003). The Sustainable Rivers Audit of the Murray-Darling Basin applied this approach in a comprehensive assessment of river health in Australia's southeast (SRA2, 2012).

Europe

At the end of 2000, the EU Water Framework Directive (WFD) was published and entered into force. This directive aimed to achieve good water status for all EU countries by 2015. All member states were required to design and implement appropriate monitoring programmes, with an emphasis on biological monitoring to classify water bodies. This program was based on specified indicator parameters to estimate values for the quality of biological elements. Biomonitoring of aquatic macroinvertebrates was used as a way to confirm monitoring that used non-biological indicators. The science of biological monitoring has advanced a great deal under the WFD, with a sustained effort to streamline methods across countries, and to ensure high standards are applied. Hering *et al*. (2010) provide a useful review of this process.

USA

In the USA, the National Rivers and Streams Assessment (NRSA)[6] uses both fish and bottom-dwelling macroinvertebrates as bio-indicators. All states monitor bottom-dwelling macroinvertebrates except Hawaii, where a programme is under development; two thirds of the states monitor fish and one-third monitor algae (Carter *et al*., 2006). Two comprehensive NRSAs have been completed by the US Environmental Protection Agency and partners, one in 2008-09 and the other in 2013-14.

Conclusion: *Aquatic biomonitoring programmes are common around the world in both developed and developing countries where their usefulness has been well demonstrated. These biomonitoring programmes are often associated with water quality and stream-flow monitoring programmes so that an overall understanding can be gathered, not only of the response of the biota, but also the changes in water quantity and quality that may be the cause of degradation.*

What river biomonitoring occurs in the Greater Mekong Region?

A number of biomonitoring programmes exist in the Mekong region and in neighbouring East Asian countries (cf. Morse *et al*., 2007).

Mekong River Commission (MRC)

A progressive plan to develop biomonitoring in the Mekong has been under way since 2003 and continues to the present. It was established for the lower Mekong and its major tributaries, and comprises a thorough investigation of the methods best suited to the region, as well as successive surveys and reports. All of the biomonitoring in this project was undertaken by experts and not by communities.

The organisms selected for the programme included:

- Diatoms (a type of micro-organism) mostly confined to rocks.
- Macroinvertebrates from the river bank.
- Macroinvertebrates from the centre channel bottom sediments.
- Zooplankton from the main water middle of the river.

Note that despite the importance of fish, they were not included due to the high cost of collection.

Three indices are used to describe the biota:

- Abundance.
- Average richness.
- Average Tolerance Score Per Taxon/group (ATSPT) – a score of tolerance to habitat disturbance.

In 2008, the biomonitoring programme was transferred from the MRC to the MRC Member Countries where each of the national teams, with MRC's support, performed all of these processes at 8–17 sites in each country. These initial surveys, together with the information collected in 2008, produced a large body of information (109 sampling events, 60 sites) on the Mekong River and its tributaries. This routine bio-monitoring complements the hydrology, climate and water quality monitoring systems already established by the MRC. The data supports the governments' understanding and sustainable management of the Mekong river system.

4 - http://www.dwa.gov.za/IWQS/rhp/default.aspx
5 - https://ausrivas.ewater.org.au/index.php/home
6 - https://www.epa.gov/national-aquatic-resource-surveys/nrsa

The latest comprehensive survey of the Mekong River (MRC, 2014) assessed 41 sites. These were classed into four groups according to ecological status. Seven were in Class A ('excellent ecological health'), 22 in Class B ('Good'), 11 in Class C ('Moderate') and 1 in Class D ('Poor'). The ecological quality in the mainstream sites varied between class A and D without any clear pattern. Changes in ecological health over time (2005 to 2011) were found at many locations, where one-third of the monitoring sites show degradation, one-third show improved scores and another third show stable scores. Further analysis showed that degradation was quite severe in some cases, with some sites dropping by as much as two classes.

Biomonitoring in Lao PDR

Beginning in 2010, with funding support from the McConnell Foundation, The Asia Foundation (TAF) has been implementing a Water Quality Monitoring programme in Vientiane and Bolikhamxay provinces. Viable river systems are critical to the wellbeing of the citizens of Lao PDR and to the country's national development, yet a number of growing pressures threaten the quality of the country's river resources and the livelihoods that depend on them. As such, monitoring is regarded as essential. The project was among the first in the country to focus on engaging citizens in the process of water quality monitoring.

The biomonitoring techniques that TAF used in Lao PDR were adapted from a TAF Mongolia biomonitoring programme. The tolerance values for each macroinvertebrate group were determined by experts from the National University of Laos (NUoL).

In May 2013 (dry season), a biomonitoring project using macro-invertebrates was piloted on the Seut and Tong Rivers in Vientiane Province. In May 2014, an additional eight rivers across Vientiane and Bolikhamxay provinces were added to the study. The addition of these new sites increased the number of sampling locations from 12 to 21 across 10 different waterways, with sampling taking place at the test and control sites that are known to be unimpacted. The project is being implemented with the Natural Resources and Environment Institute (NREI) under the Ministry of Natural Resources and Environment (MoNRE) and consultants from Fishbio Laos.

Village volunteers were trained how to biomonitor macro-invertebrates; in turn, the volunteers then trained teachers from the schools in the focus villages. The village volunteers and teachers then conducted the sampling programme with their students. Results from the field programme were presented to the wider community in each village and used to develop village water management and action plans. Some of the activities proposed in the action plans included designing, procuring, and installing signs/posters with 'clean river' messages; revising village regulations regarding waste management; adopting school recycling programmes; banning illegal fishing techniques; and promoting decreased use of agricultural chemicals.

Results from the biomonitoring programme were also added to NREI's Data Management System, and MoNRE planned to make the results available to the public on their website.

In October 2016, TAF launched a Community-based Water Resources Management project in Xe Bang Fai District in Khammoune Province, with MoNRE's Department of Water Resources (DWR). TAF and their partners include training on biomonitoring in schools and in wetland and fisheries village committees as part of this new initiative. The organisms sampled will expand to include both macro-invertebrates and fish.

In a separate initiative, a small non-specialist team from the DWR and International Finance Corporation (IFC) carried out invertebrate sampling at about 10 different locations in the Nam Ou river in Northern Lao PDR as input to a river basin profile for the Nam Ou. The surveys were carried out in January and February 2016, and involved detailed discussions on the uses of the river and its resources in a number of selected villages, together with water quality sampling, habitat surveys and biomonitoring. The team used a (slightly modified) miniSASS scoring method (Graham *et al*, 2004) and identification keys.

In general, the system worked well in that the upper reaches, including near the source of the Nam Ou, scored as 'rocky type, natural condition', while reaches lower down the river scored 'good condition (largely natural, few modifications)', although most were 'fair condition (moderately modified)'. The sites where 'poor conditions' were recorded were those that were either downstream of urban areas, receiving domestic and industrial waste waters, or those where the flows had been modified due to hydropower.

One of the Nam Ou sites, located about 5 km upstream from the confluence with the Mekong, was near a site that had been used by the MRC as a reference site for their own bio-monitoring work in 2004 and 2005. In these years, it had scored as a natural, unmodified site. Since that time, there have been large changes due to dam construction and flow variation. The macroinvertebrates from the river banks in 2016 indicated that the habitat condition was now 'fair: moderately modified'.

Myanmar Healthy Rivers Initiative

The Myanmar Healthy Rivers Initiative (MHRI) aimed to develop and test approaches that would allow communities to monitor the status of the river ecosystem services they valued, and provide evidence for integrated water resource planning. MHRI evaluated the potential for communities to use stream bank-based biomonitoring techniques in the lower Irrawaddy and Salween Rivers. The project was confined to the lower sand dominated reaches of these rivers and did not include sites to be found higher up in steeper parts of the basin.

Exploratory field collection was undertaken in October 2015 (wet season) and February 2016 (dry season) at a number of sites along the main river channels. A range of close-to-shore habitats in the mainstream were sampled, including vegetation and sand/mud habitats, using a sampling effort based on but significantly greater than required by the SASS method. Very few macroinvertebrates were found during these surveys, so that biotic index scores could not be calculated. The lack of invertebrates could be attributed to the nature of these floodplain rivers, which in the lower reaches have high sediment loads and widely fluctuating flows, with very unstable river beds. Vegetated, rocky and stony sites were difficult to find, but even when present, these were also almost devoid of invertebrates.

The surveys did not include deep sampling of river beds in deep waters, as this would have required specialised equipment and is inappropriate for monitoring by local communities. Results from the Mekong suggest that sampling beds in deep waters may be more successful than sampling in shallower waters along the river's edge (MRC, 2005 – 2014).

Preliminary surveys thus suggested that a stream bank-based biomonitoring programme is not appropriate for the mainstream of the Irrawaddy and Salween Rivers in their lower reaches where the rivers are dominated by sand. Sampling in small streams and irrigation canals was, however, much more promising, and there is an opportunity to develop a biomonitoring programme in the upper reaches of the rivers in Myanmar, where gradients are steeper and there are more rocky beds in which invertebrates are common.

Given how uncommon macroinvertebrates are in these waters, fish are likely the most promising indicators for monitoring. The possibility of using fisheries data (or ideally records collected directly from fishers) to develop an index of fish health has yet to be investigated. The latter approach using fisher catch records could help to reduce the costs of such an approach by reducing the need for fish sample collection which can be very expensive.

Songkran Catchment, Thailand

In 2016, the Asian Institute of Technology (AIT) initiated a community-driven river health monitoring programme in the Songkran catchment, Thailand. In close consultation with communities and the district administration, a framework for community-scale river health assessment was established. A key component of this framework emphasized the engagement of citizens in biomonitoring activities to inform river health status. A feasibility study for biomonitoring was carried out in October 2016. The catchment received an unusual amount of rainfall in that month, which made it difficult to access a few areas. Nevertheless, it was still possible to identify good close-shore sampling sites on the river itself as well as in surrounding wetlands. These sites had not only a good number of macroinvertebrates, but also a fairly rich variety. Among the species found, mayflies and caddish flies were in abundance. Both these species have a low tolerance for disturbance. Given that the Songkran River is still relatively healthy, the presence of these specimens was expected. The index developed by TAF (described earlier) was used for the feasibility study. The scores for all the sites suggested that the health of the River Songkran was "Fair-Good."

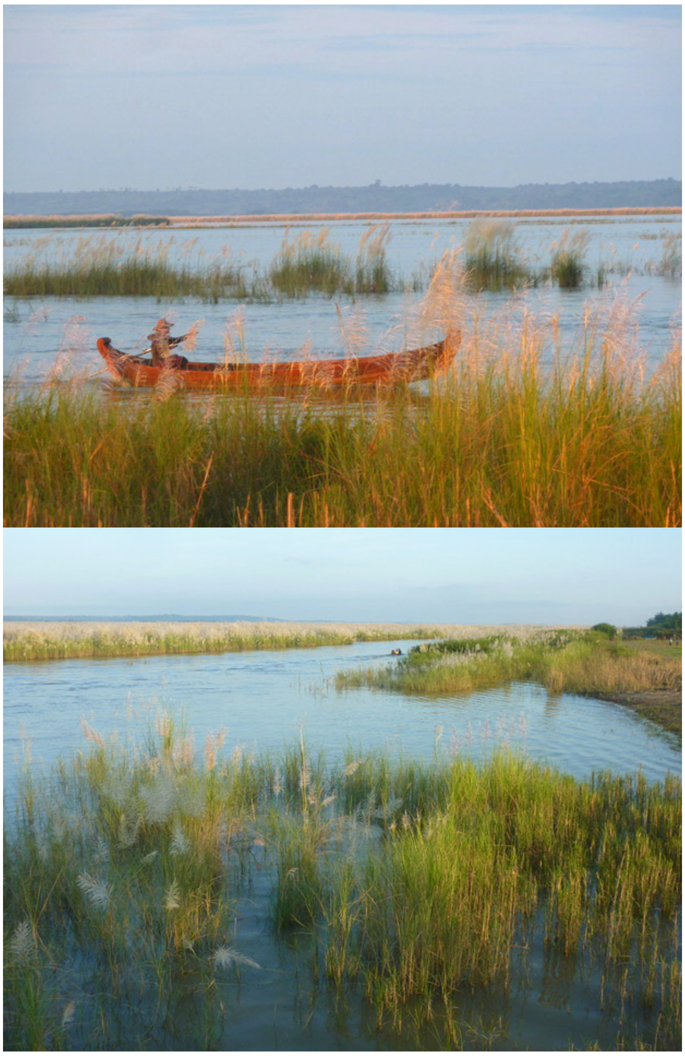

Figure 5: The Irrawaddy upstream of Mandalay showing apparently ideal vegetation habitat for invertebrates in October 2015

Despite this initial success in biomonitoring, some fine-tuning is required before the biomonitoring programme can start on a regular basis. First, it will be important to carry out the survey once again in the dry season (March/April). This is when the flow depth is at its lowest and the water is cloudy with sediment. If adequate specimens are not found, there could be a need to make changes to the established monitoring sites. Second, a close examination of the river health index will be required to ensure that it is able to capture site-specific characteristics. Third, pristine sites will have to be identified to enable comparisons with the monitoring sites. This will be particularly useful when the case for up-scaling to other catchments becomes strong.

Ping River, Thailand

Experts undertook a study on the Ping River in Thailand, near Chiang Mai city during the 2010 dry season (Itayama *et al.*, 2015). A number of different indices were used, including

Figure 6: School children sampling for macroinvertebrates along the Songkhran River, Thailand (credit: V. Shinde).

those from the MRC but also others similar to SASS. The limitation with the MRC index in Thailand was that there was no data on the sensitivity scores for the invertebrates. Hence, this part of the index was not calculated.

Indices based on the composition of the macroinvertebrate and the deep-water diatom communities were the most sensitive. Stretches of river in closer to Chiang Mai city showed evidence of increased disturbances within these communities. Diatoms were also found to be very sensitive to different types of pollution. Results of this study are useful for future water pollution control efforts around Chiang Mai.

Conclusion: *the use of macroinvertebrates as an indicator of river health probably does not work well when sampling from large rivers with muddy or sandy beds, with large water level fluctuations or high loads of sediment. Macroinvertebrates are best found in streams flowing over rocky beds. The season in which monitoring takes place is also very important, as fluctuations in the composition and abundance of macroinvertebrates can affect results. Because invertebrates in different parts of the world differ, it is important to provide region-specific scoring based on the sensitivity of locally occurring invertebrates. It is important to stress that biomonitoring projects using invertebrates will not be successful or reliable if the scoring systems behind them are not robust. Properly implemented biomonitoring can work very well alongside physical and chemical monitoring of river systems. Care needs to be taken, however, to select sites that will yield good invertebrate communities. Incorporating biological indicators into government monitoring procedure can be very useful and can lead to better management decisions being made. At a community level, invertebrate biomonitoring provides an ideal opportunity for citizen science.*

What is the future of biomonitoring in the rivers of the Greater Mekong region?

Biomonitoring in the region is still relatively new and under-developed. If biomonitoring is to advance, then a variety of issues will need to be considered:

- Should there be a standard key and index used in all biomonitoring programmes in the Mekong Region? If so should a new one be developed and at what scale? If not, should a standard regional validation method be introduced?
- How should biomonitoring be framed for community-based projects? Is it possible to introduce it in schools? Are there other social or economic factors that need to be considered in developing countries?
- How can other organisms such as fish and diatoms be included in a biomonitoring programme? How valuable would a coordinated fish monitoring project be across the region and is the idea feasible?
- How should reference sites be developed? What should be done if appropriate reference sites do not exist? Should we consider using predictive modelling to assess river condition as an alternative?

Conclusion: *Undoubtedly, there is great enthusiasm and potential for biomonitoring in the Mekong region. There is also great technical and scientific merit to including biological indicators when assessing the health of rivers and streams. Biomonitoring is an excellent way to raise the awareness of local communities to the importance of river health, and to empower them to play an active part in water resource management. Understanding and monitoring water quality is essential to prevent increasing pollution, protect aquatic life and human health, and ultimately to help achieve sustainable development in the Mekong Region. This will become increasingly important as the Sustainable Development Goals (SDGs) take a hold, as SDG Indicator 6.6.1. is designed to protect and restore ecosystem health.*

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What is the State of Knowledge (SOK) Series?

The SOK series evaluate the state of knowledge on subjects related to the management and development of rivers in the Greater Mekong Region. Publications in the series are issued by the CGIAR Research Program on Water, Land and Ecosystems – Greater Mekong. The papers draw on both regional and international experience. Papers seek to gauge what is known about a specific subject and where there are gaps in our knowledge and understanding. All SOK papers are reviewed by experts in the field.

State of knowledge:

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