Biomonitoring of Singapore's Freshwater Ecosystems

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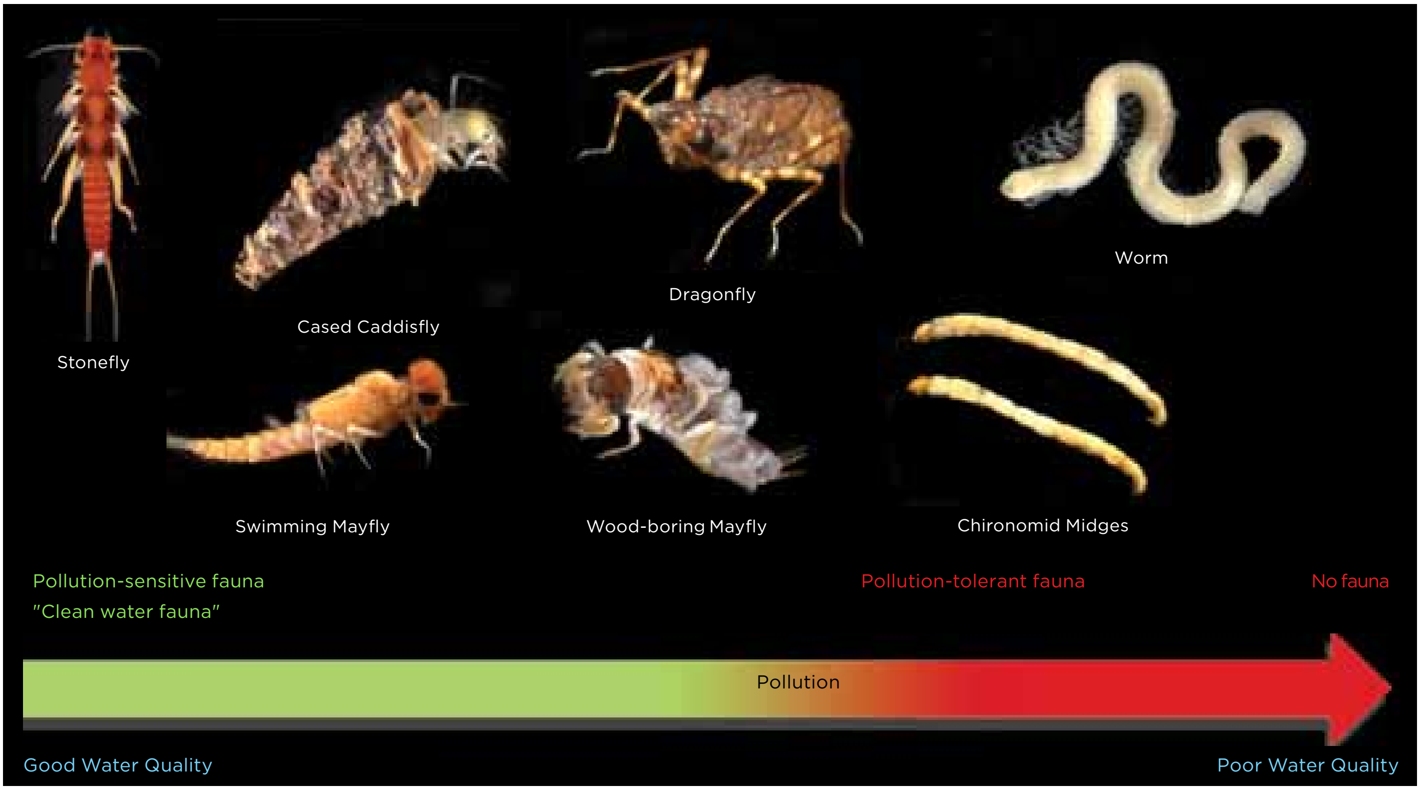
Freshwater Biomonitoring

"Biological monitoring" or "biomonitoring" is the use of animals and plants to detect change, often due to pollution, in the environment. The monitoring of biological communities offers a means of holistic environmental appraisal to detect impairment, because these integrate the physical and chemical aspects of their immediate environment over time. Traditionally, freshwater monitoring programmes undertook routine or "surveillance" monitoring of key pollutants of concern primarily for drinking water quality. Over the last 50 years, the monitoring of freshwater quality has evolved from simple chemical analysis of water samples through to the use of a multitude of chemical, physical, and biological metrics developed to comprehensively indicate the condition of water bodies. As our understanding of these systems developed along with the problems associated with algal blooms caused by excessive plant nutrients to freshwater systems from either agricultural or domestic sources, these nutrients and other factors associated with the biological health of freshwater systems were also monitored. The use of biological indicators in monitoring marks a conceptual transition from single parameter assessments towards an evaluation of ecologically relevant change.

In the freshwater environment, fish algae and benthic invertebrates are effective "bioindicators" of pollution or disturbance because they demonstrate differential sensitivities to pollution. In the case of freshwater algae, some species are of particular concern with regard to toxic algal blooms, so they are often monitored as a water quality concern of their own right as well as indicators of enrichment, particularly in lake systems. While the use of particular indicator taxa may be a valuable aspect of biomonitoring, whole community responses offer a more holistic representation of environmental conditions. However, because community level information is complex and requires expert interpretation, biotic indices are often developed as compound metrics of condition for ease of interpretation and communication to stakeholders.

Benthic invertebrates are the most commonly used communities in the assessment of the health of lotic freshwater systems worldwide and are being increasingly adopted for standing waters (Rosenberg and Resh 1993). Their communities comprise insect larvae, snails, shrimps, and worms that live predominantly in the sediments at the bottom of lakes and streams. Some worms and midge larvae are able to tolerate relatively polluted waters, whereas others, such as mayflies and stoneflies, are sensitive to pollution (Fig. 1). The presence and/or abundance of these animals may be weighted by their respective sensitivities to pollution so as to calculate biotic indices of water quality and ecological health. Because the presence of different invertebrates in the sediments



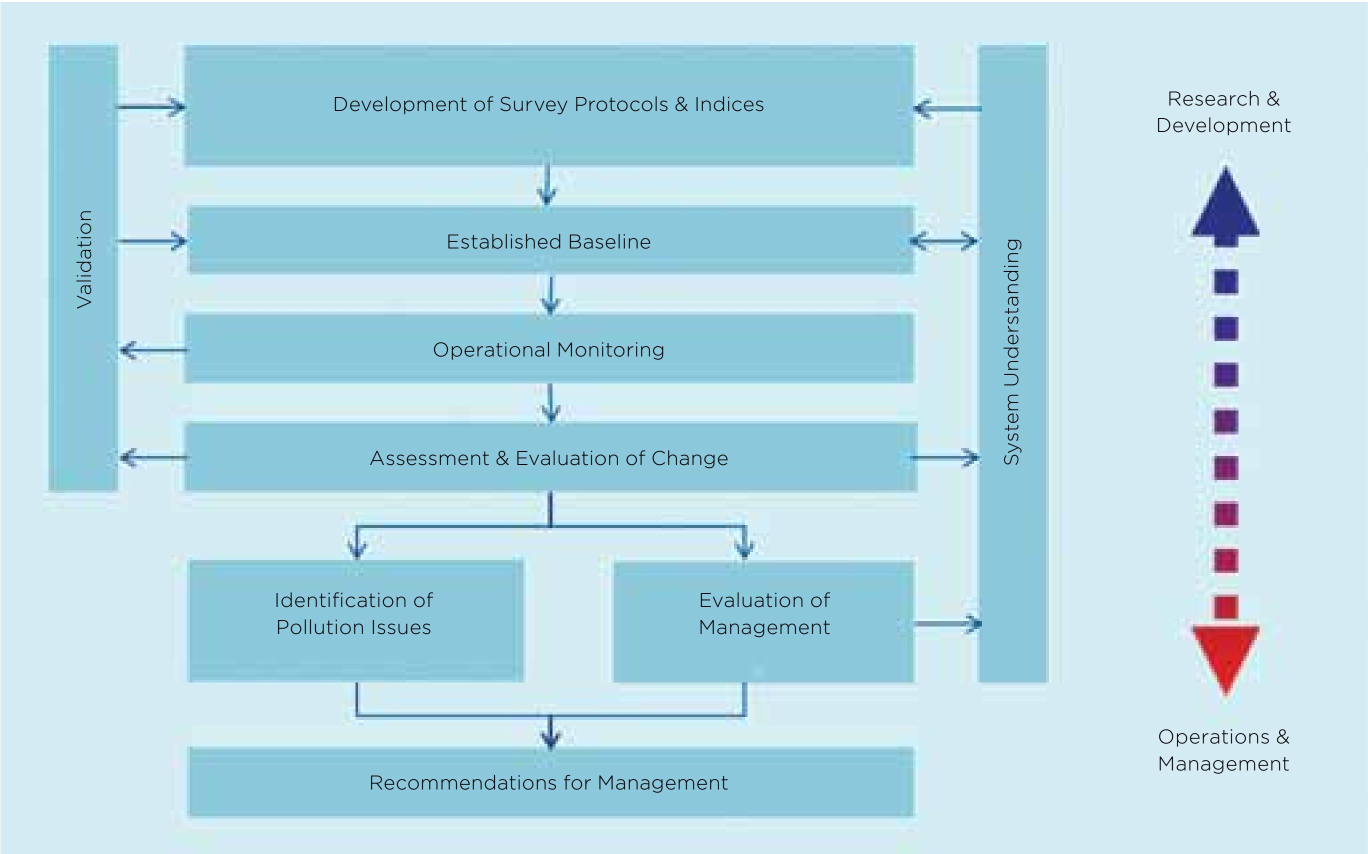
1 Invertebrates as Indicators of Pollution

is indicative of the conditions of the freshwater system throughout their aquatic life spans, the use of these indices of ecological conditions in a comprehensive monitoring programme effectively complements periodic chemical point-sampling, which may miss sporadic pollution events.

While freshwater biomonitoring has a long history in Europe and North America, it is only more recently being adopted in Southeast Asia. In many Asian countries, monitoring of freshwater quality is primarily undertaken via traditional physiochemical and microbial measurements, with biomonitoring routinely applied only in Japan, Korea and Singapore (Morse et al. 2007). Researchers in Malaysia, Thailand, and Vietnam have adapted bioindicators of stream water quality from European indices, such as the UK's Biological Monitoring Working Party index, but these have not yet been implemented in monitoring programmes.

The adoption of biotic indices developed for temperate countries provides a valuable shortcut to establishing indices, as long as modifications are made to include local taxa. However, this approach may misinterpret the sensitivities of resident invertebrates without local validation of faunal associations with environmental parameters. A more robust but more data-intensive and costly means of establishing local biotic indices is to build them on the association between local water quality and invertebrate communities. This not only ensures that the indices are locally relevant but also establishes local capability and understanding of freshwater systems, which are important for the testing of the indices and their operational use within the relevant country. In all cases, biotic indices and sampling methods must be standardised, quantitative, and repeatable to ensure comparability over time and among sampling stations.

1. Photographs taken in fulfillment of collaborative research projects with NUS, PUB, and University of Canterbury, New Zealand (Photos: Stephen Moore; Diagram by the authors).



2 Biomonitoring Programmes and Application

In Singapore

Singapore-specific biotic indices for reservoir water quality and stream health using benthic macroinvertebrates were developed in collaboration between local and international universities and Public Utilities Board, Singapore (PUB). The Benthic Quality Index-Singapore (BQI_{SING} index) of tropical reservoir water quality was developed by the National University of Singapore (NUS) (Clews et al. 2009; Loke et al. 2010). Concurrently, the University of Canterbury, New Zealand, developed the SingScore index of waterway health in Singapore (Blakely and Harding 2010). Both indices were created using a weighted average approach to determine the sensitivity of the invertebrate families to pollution, based on invertebrate and water quality data collected during an intensive field investigation.

Two separate indices were developed, one for each of the two primary freshwater habitats in Singapore: first, reservoirs representing standing waters, and second, running waters that comprise natural streams within the protected Nature Reserves and concrete drainage canals within residential, commercial, and industrial areas. These two types of water bodies not only support different biological communities due to their very different retentions of water and associated chemicals but are also ecologically susceptible to different types of pollution. In the reservoirs, the input of plant nutrients, such as nitrate and phosphate, are of principal concern with respect to the growth of potentially toxic algae. Conversely, in the streams, the constant flushing of water usually mitigates against the accumulation of planktonic algal populations but concentrations of heavy metals and other chemicals derived from urban and industrial runoff have a greater potential to impair their health. Thus, the BQI_{SING} index of reservoir water quality was therefore designed to assess nutrient enrichment in Singapore's reservoirs and the SingScore index was created to assess urban pollution, based principally on heavy metal contamination.

The methods applied to collect invertebrates from these two habitats also differ, again due to their hydrologic characteristics. In running waters, standard methods applied internationally were adopted, namely "sweep" and "surber" sampling. The sweep sampling procedure involves kicking the stream substrata to disturb and release invertebrates into a net held downstream. Sweep samples are collected from a wide range of microhabitats (for example, leaf packs, cobbles, pools, log jams, and stream margins) over a two-minute period within a ten-metre-stream-reach delimiting each site. Surber sampling works similarly to sweep sampling except that in this case the hands are used to disturb a fixed area of the stream bed to release invertebrates into a net. Invertebrates collected during an initial survey of 47 streams were used to derive the SingScore index.

Methods for the collection of invertebrates from lentic systems, especially hard-edged ones, are less well established. Artificial substrate samplers, consisting of coconut brushes combined with split palm fronds, were identified as the most effective method of sampling these tropical urban reservoirs in Singapore (Loke

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et al. 2010). These samplers were placed in 15 reservoirs and two quarry lakes and the communities that colonised them were retrieved after one month in order to calculate the BQI_{SING} index.

Validation of the biotic indices developed is important to ensure that they are consistently representative of the water quality and ecological health. Even in fully operational programmes, it is important to continue to use the wealth of data collected as feedback for our understanding of the system and modify the monitoring protocol if necessary (Fig. 2). For example, seasonal and extreme events may be captured, improving the data coverage for deriving the underlying models of faunal-response to environmental conditions.

Biotic indices calculated on the communities retrieved by these methods are now being tested and validated in under the Long-term Bio-index Project undertaken by the Freshwater Section of the Ecological Monitoring Informatics and Dynamics (EMID) group at the Tropical Marine Science Institute (TMSI), NUS, with support and funding from PUB. The EMID group specialises in the ecological monitoring and assessment of aquatic systems while the Catchment and Waterways department of PUB is responsible for the management of Singapore's "raw" waters.

Initially the validation phase targeted five reservoirs and multiple sites on three waterways. This has now been supplemented with operational data following the expansion of the programme to include all of Singapore's reservoirs and an additional 14 waterways from October 2011. The results of the first three years of biomonitoring will be used to identify the appropriate sampling times and frequencies required for a country-wide freshwater biomonitoring programme.

Whilst freshwater ecology research in temperate regions is very well established, the effects of the monsoon, extreme events, and climate change on freshwater ecosystems in the tropics are less well known. This work further supports research to better understand tropical freshwater systems in highly urbanised environments (Fig. 2).

2. (Diagram by the authors).

Applications

In Singapore, the operational use of biotic indices in a national biomonitoring programme to detect pollution began in October 2011. This programme now serves as additional surveillance monitoring to complement the water quality and algal sampling which are routinely conducted by PUB. Tracking changes in environmental and water quality is especially important in water bodies used for recreation, for drinking water or as reserves to conserve local biodiversity, more so if they are likely to be impacted by surrounding anthropogenic activities, such as deforestation, industry, urban development, and agriculture. A decline in the animals known to be sensitive to a specific pollutant combined with water analysis can provide clear evidence of how a particular activity may be adversely affecting the water quality. Such information can then contribute towards management decisions for the development of pollution control measures and best management practices, and also provide a means to test the effectiveness of these strategies in mitigating and minimising pollution.

Biomonitoring is also used in Singapore and elsewhere as a component of investigative monitoring to further identify the causes of pollution and in environmental impact assessment (Metcalfe-Smith 1996). Environmental impact assessment often refers to an evaluation of potentially adverse impacts on the environment, such as a new construction or development. While biomonitoring can be and is used as a means of assessing changes following activities that may disturb ecosystems, it is also used to evaluate management strategies designed to improve water quality or ecosystem health.

In Singapore, the Active, Beautiful and Clean (ABC) Waters Programme aims to improve flood control and water quality and to enhance biodiversity through in-stream, riparian, and wetland design features within the predominantly urban landscape of Singapore (PUB 2011). Further, to the specific objectives of the ABC Waters Programme, Singapore's pioneering role in the international Cities Biodiversity Index (CBI) also requires that we support our local biodiversity by providing for and conserving habitats within the urban jungle (CBD 2009). The biomonitoring and ecological appraisal of these initiatives can gauge their effectiveness and inform future enterprises. The progress of efforts to restore the health of waterbodies can be tracked against reference sites where no management has been undertaken. For example, shifts in the composition of the macroinvertebrate community, from one dominated by pollution-tolerant taxa to one with a greater variety of organisms sensitive to perturbations at the managed site, in the absence of change at the reference site, would indicate improved ecological quality.

One example of the application of biomonitoring in Singapore is the appraisal of the Kallang River @ Bishan-Ang Mo Kio Park ABC Waters project. A three-kilometre stretch of Kallang River that flows through Bishan Park was restored from a concrete canal into a naturalised meandering river that flows through the park, adding aesthetic value as well as providing a greater capacity for stormwater treatment and drainage (Fig. 3). With the return of vegetated banks and varied in-stream habitats, the restoration of the Kallang River should create habitats for aquatic life, increase the aquatic biodiversity, and improve ecological functioning (such as nutrient uptake and cycling) within the former concrete canal.

Before construction works began, biomonitoring commenced in the Kallang River to serve as a baseline of the local macroinvertebrate community, habitat, and water quality. Ecological changes are currently being tracked in the park as well as at two reference locations: one urban drain and one natural stream. This will allow for the robust, scientific evaluation of the effectiveness of the ABC Waters Programme in meeting its targeted objectives. If effective, we would expect to see a departure from the conditions in the urban drain and a move towards the more natural, healthy stream.

Routine assessment through biomonitoring in combination with dedicated evaluation of rehabilitation projects continues to improve our understanding of local freshwater ecosystems (Fig. 2). This will further elucidate system requirements for effective habitat creation and rehabilitation to meet management goals, such as reduced pollutant loads and enhanced biodiversity in Singapore.

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3. The Kallang River @ Ang Mo Kio-Bishan Park, Singapore, following rehabilitation under the Active, Beautiful and Clean Waters Programme (Photo: Adam Quek).

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