Biomonitoring using aquatic macroinvertebrates as a tool for building capacity in the field of freshwater ecology and conservation in Meghalaya, India

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Abstract

This paper describes a stream biomonitoring program that builds capacity in undergraduate college students in the field of freshwater ecology and conservation. The program involves sampling of aquatic macroinvertebrates and hydrological parameters in streams of Meghalaya. Several colleges from Shillong initiated short-term, one-year and long-term biomonitoring of streams in East Khasi Hills and Ri-Bhoi districts. Nine stream locations were sampled once in months of October-December in 2014 allowing a snapshot of physical and biotic conditions which enabled the students to examine spatial trends in stream parameters and aquatic biota. A year-long sampling study from 2014-2015 provided a seasonal view of stream parameters at Lwai (clean) and Umkaliar (moderately polluted) streams. Results from both sampling schemes suggest that turbidity was a major factor influencing the richness of pollution sensitive taxa. Dissolved Oxygen values were lower in polluted stream and also had a seasonal trend. After an initial training in the field, the sampling was conducted by college students with supervision from their lecturers. Data obtained on macroinvertebrates adds to the sparse information available on stream ecosystems in the biodiversity-rich northeast Indian region.

Acknowledgements

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Introduction

Northeastern India is a region blessed with plentiful rainfall, streams and rivers, and is also internationally known as a biodiversity hotspot. However, changing land use, growing water demands and pollution are altering water quality and quantity, and with that the ecosystems themselves. There is not much specific information on freshwater aquatic ecosystems in the Northeast as well as how these ecosystems are linked/maintained with water flow and quality, and how in turn they maintain water quality. Here we present the data from biomonitoring of Meghalayan streams from sampling conducted by undergraduate students and their supervising faculty from colleges of Shillong, Meghalaya. Biomonitoring of Meghalayan streams was conducted as a tool to develop capacity of college students in the field of freshwater ecology and conservation and to initiate monitoring of hydrological parameters and aquatic biodiversity.

Aquatic macroinvertebrate assemblages comprise primarily of insect larvae that have terrestrial adult life forms, insects whose adult life-history stages such as beetles and true bugs are also aquatic, and include arthropods such as crustaceans, and organisms from other phyla such as mollusks (gastropods, bivalves), and annelids (oligochaete, hirudinea; Allan 1995, Meritt et al. 2008). Macroinvertebrate assemblages show a strong correlation with variables of water quality and stream geomorphology (Resh et al. 1995, Lamouroux et al. 2004).

Biomonitoring of freshwater ecosystems using aquatic macroinvertebrate abundance and diversity is a widely used tool to assess the health of aquatic ecosystems and to determine policy intervention with regards developing and enforcing regulation for water quality (Bonada et al. 2006, Kennedy et al. 2009). Benthic macroinvertebrates are an important part of the food chain, especially for fish and other predators. Macroinvertebrates occupy different trophic levels in a food chain due to diverse feeding habits; many feed on algae and bacteria some eat leaves and other organic matter, some are filter-feeders and quite a few predatory. Because of their abundance and intermediate position in the aquatic food chain, benthic macroinvertebrates play a critical role in the natural flow of energy and nutrients (Resh et al. 1995). Biological stream monitoring is based on the fact that different species react to pollution in different ways. Pollution-sensitive organisms such as mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) are more susceptible to the physical or chemical changes associated with pollution and siltation in a stream than other organisms. Pollution sensitive organisms act as indicators of the absence of pollutants. Pollution-tolerant organisms such as midges and worms are less susceptible to changes in physical and chemical parameters in a stream and their presence is an indirect measure of pollution. When a stream becomes polluted, pollution-sensitive organisms decrease in number or disappear; pollution-tolerant organisms increase in variety and number. Thus the maintenance of macroinvertebrate biodiversity is a critical test of whether the water use regime is sustainable (Dudgeon et al. 2004).

Biomonitoring also adds the possibility of encountering new species that are not known to science and can enhance the understanding of life history traits of macroinvertebrates. As a consequence of all these benefits, biomonitoring is being mainstreamed into policy regulations for managing water quality in streams and rivers.

Documentation of stream and river conditions using aquatic macroinvertebrate is an appropriate tool to develop capacity in the field of freshwater ecosystem science and conservation (Goulden 2009), especially in region rich in springs, streams, and aquatic biodiversity such as in Meghalaya. However, it has never been put in practice before, this pioneer hands-on experience brings students in close contact with the ecosystem, while periodic monitoring develops an appreciation for the links between a diverse ecosystem and the physico-chemical parameters of water quality and flow that maintain life. Biomonitoring of streams and rivers enables students to relate river parameters such as water depth and discharge to day to day availability of water and also with extreme events such as flooding and drought. By correlating the diversity and abundances of freshwater taxa with water quality and quantity the baseline information on streams and rivers can be obtained; rivers harboring healthy and diverse ecosystems would be considered reference sites as benchmark for restoration. Thus biomonitoring enhances the understanding of rivers as living parts of the landscape, which needs ecologically-guided maintenance and protection, and not just as a natural resource to be harvested. In this paper we summarize results from biomonitoring projects that have been undertaken since 2014 by different colleges in Meghalaya.

Study Site and Methods

Meghalaya is a Northeastern state in India with annual rainfall averaging to 1150 cm; it is an extremely wet place, with the world's highest rainfall occurring at Cherrapunjee-Mawsynram (Basumatary et al. 2013), but with increasing water shortages in the dry season. Topographically Meghalaya is a plateau peaking at the altitude of 1964 m. The catchment divide is oriented in an east-west direction bisecting the state so that the north facing slopes drain into Brahmaputra river, while the southern slopes drain into Bangladesh to join the Barak-Meghna river system.

The majority of the streams were sampled in and around the greater Shillong area in the East Khasi hills district (25º32´10´´ N to 25º36´20′′ N latitude and 91º51´30′′ to 91º51´30′′ E longitude). Two streams, Umkaliar (in Shillong, polluted) and Lwai (22 km from Shillong, unpolluted) were chosen for a year-round study. Drinking water from the Lwai stream is supplied to nearby villages. Other streams were sampled once or bi-yearly during the monsoonal rains (May to September in Meghalaya) and or in the winter (December-February). The Rymben river (a fast flowing stream with pools and riffles very close to the border with Bangladesh) in East Khasi Hills District was also sampled near Lapalang Village. In Ri-Bhoi district, two streams were sampled near Umsning Village (25º44´1.2′′ N latitude and 91º51´35′′ E longitude). Figure 1 shows the locations in Meghalaya where stream biomonitoring was conducted by different groups of students representing six colleges of Shillong. Table 1 list the sampling conducted by different groups as part of the biomonitoring effort initiated in 2014. At each stream site, plants of the riparian vegetation were collected and when possible identified to species level (Table 2).

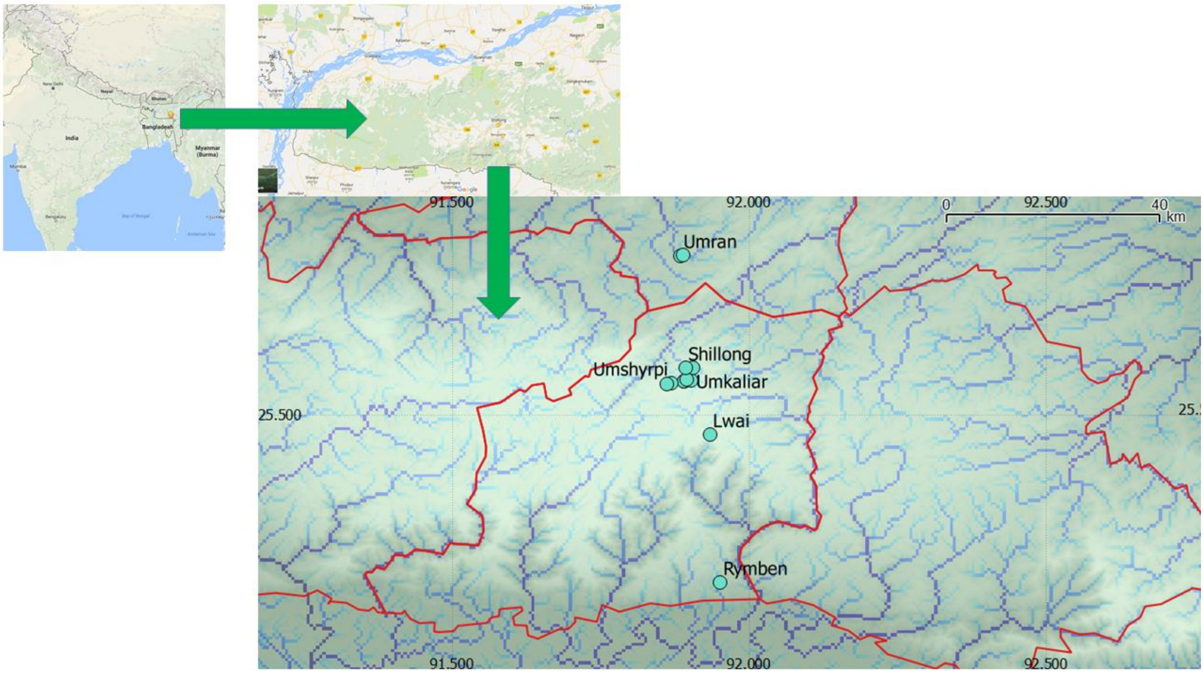
Table 1. Stream biomonitoring conducted by students from different colleges in Meghalaya. *For these streams two distinct lower order streams from their catchment network were chosen for sampling.

Stream/river	Location	Sampling regime	Sampling performed	Parameters sampled	Hydrological variables
Lwai	25°27'59.1"N 91°56'04.5"E	Monthly	Sep 2014-2015	Macroinvertebrates Dissolved Oxygen (DO), turbidity, nitrates, TDS	None
Lawjynriew	25°33'30.1"N 91°54'08.2"E	One-time	Oct 2014	Macroinvertebrates DO, turbidity	Discharge
Malki	25°33'21.3"N 91°53'27.4"E	One-time	Oct 2014	Macroinvertebrates DO, turbidity	Discharge
Mawshubuit	25°33'21.8"N 91°53'27.4"E	One-time	Oct 2014	Macroinvertebrates DO, turbidity	Discharge
Rymben	25°11'34.8"N 91°57'29"E	One-time	Nov 2015	Macroinvertebrates, DO, turbidity	Discharge
Umran* (2nd and 4th order streams)	25°33'21.8"N 91°53'27"E	One-time	August 2014	Macroinvertebrates DO, turbidity	Discharge
Umkaliar	25°34'44.4"N 91°54'24.4"E	Monthly	Sep 2014-2015	Macroinvertebrates DO, turbidity, nitrates, TDS	None
Umshyrpi*, 1st order 3rd order streams	25°33'11.9"N 91°52'09.8"E 25°33'07.9"N 91°51'42.6"E	Bi-yearly	Oct-Dec 2014	Macroinvertebrates, DO, Turbidity, pH	Discharge
Wahdienglieng	25°33'34.4"N 91°53'42.2"E	One-time	Oct 2014 Jan 2015	Macroinvertebrates DO, turbidity, pH	None

Table 2. Riparian vegetation bordering the sampled streams.

Stream	Vegetation
Lwai	Riparian vegetation included understorey tree of *Litsea spp*., and shrubs belonging to genera *Ardisia*, *Psychotria*, *Pittosporum*, and tree fern *Cyathea gigantea*
Lawjynriew	Riparian zone was dominated by shrubs-*Mahonia pycnophylla*, *Daphne papyraceae*, *Polygala arillata*, *Camellia caduca*, *Rubus* spp., and herbs belonging to families Balsaminaceae and Asteraceae
Malki	Riparian plants were shrubs- *Mahonia pycnophylla*, *Daphne papyraceae*, *Polygala arillata*, *Camellia caduca*, *Rubus* spp., and herbs belonging to families Balsaminaceae and Asteraceae
Mawshubuit	*Mahonia pycnophylla*, *Daphne papyraceae*, *Polygala arillata*, *Camellia caduca*, *Rubus* spp., and herbs belonging to families Balsaminaceae and Asteraceae
Rymben	The riparian vegetation consists of steep slopes lining the perennial river which has mid-sized trees of *Syzygium* spp., *Tetrameles nudiflora* and shrubs such as *Dracaena elliptica*, *Leea edgeworthia*, while plantations of *Areca catechu* mixed with species of *Artocarpu*s, *Cinnamomum* and *Bauhinia* occur on gentle slopes.
Umran* (2^{nd} and 4^{th} order streams)	In the first order stream the riparian vegetation consisted of Ardisia spp., Dracaena elliptica, Leea edgeworthia, Phlogacanthus sp., and other species belonging to the family Acanthaceae, Rubiaceae, Balsaminaceae and Asteraceae. The third order stream dominated by dense grassy vegetation including broom grass *Thysanolaena maxima* and woody taxa such as *Syzygium* and *Leea*
Umkaliar	Trees belonging to *Litsea* spp., and shrubs belonging to genera *Ardisia*, *Psychotria*, *Pittosporum*, and tree fern Cyatheae
Umshyrpi*, 1^{st} orderv 3^{rd} order streams	1^{st} order stream had the shrubs *Lasianthus hookerii*, *Ardisia sp*. and herbs such as *Costus* sp. The bank of 3^{rd} order stream was impacted by human activities. It had tress of Syzygium sp., and *Melocanna* bamboo clumps and other grass taxa.
Wahdienglieng	Trees of *Syzygium* sp., *Litsea* sp. *Ficus* sp., grass taxa and human settlements

Figure 1. Map of India showing the location of Meghalaya. Stud y sites represented by blue circles in East Khasi Hills District and Ri-Bhoi districts in Meghalaya, of which some are labeled.



Biomonitoring using benthic macroinvertebrates

Macroinvertebrates were collected from shallow riffle habitats in streams that students could access. Three stream reaches that were 50 m apart were chosen for sampling per stream site. Macroinvertebrates were collected by flushing organisms from under the rocks, floor of the channel and debris and were collected in net held just below or downstream of the sample area. Wood, stones and debris collected from the net was sorted for macroinvertebrates and the samples preserved (in 70% ethyl alcohol). Pools are the other main type of physical stream habitats but do not contain the abundance and diversity of macroinvertebrate fauna found in riffles (however, being deeper and having calmer water, pools constitute the preferred habitat for the larger stream fish such as trout and mahseer). This collection contains aquatic invertebrates in proportion to their relative abundance within the riffle sample areas. Samples were identified up to the order level and in some cases up to the family level.

To assess the stream conditions a scoring process was used to derive metric value that relies on macroinvertebrate abundance and diversity data (Sharpe et al. 2002). Streams grossly polluted have scores ranging from 0-2, moderately polluted streams range from 3-9, and clean streams have value of 10. The index value is obtained by allocating a higher score to the species richness of pollution sensitive taxa belonging to the insect orders Ephemeroptera (mayflies), Plectoptera (stoneflies) and Trichoptera (caddisflies, excluding the net spinning caddisfly), a lower score to richness of taxa belonging to insect orders Odonata, Megaloptera, some

Coleopterans, and crustacean orders, Isoptera and Amphipoda, while the pollution tolerant taxa are not scored at all. Pollution tolerant taxa are Dipteran (true flies) larvae, adult aquatic Coleopterans (beetles), Mollusca order Gastropoda (snails) and aquatic earthworms, Oligochaeta, and Hemipterans, surface film insects.

Biotic Index was calculated as
Biotic Index = 2(n Class I) + (n Class II)
where n = number of taxa (species richness per category of taxa)

Pollution sensitive taxa belong to Class I while moderately sensitive taxa belong to class III, while pollution tolerant taxa which belong to Class III are not considered in the calculation of Biotic Index. Samples were identified using a pictorial field (Subramaniam and Sivaramakrishnan 2007) to key the taxa up to the family level when possible.

Hydrological, physical and chemical parameters

Concurrent measurement of river discharge, dissolved oxygen, pH, temperature and turbidity were made. To measure stream discharge, flow rate was obtained using the float or mechanical current meter (General Oceanics 2030R, Miami, USA) and multiplied by stream cross sectional area (average channel depth * channel width). Dissolved oxygen was either measured using a hand held portable dissolved oxygen meter (Milwaukee MW600, Milwaukee Instruments, North Carolina, USA).

Turbidity measurements were made with a turbidity tube (Meyer & Shawn 2006). The turbidity tube uses the correlation between visibility and turbidity to approximate a turbidity level. A marker is placed at the bottom of the turbidity tube until it can no longer be seen from above due to the murkiness of the water. This height from which the marker can no longer be seen correlates to a known turbidity value which is reported in Nephelometric Turbidity Units (NTU). Cloudier the water is higher is the turbidity value.

Results

1. Year-long study: Trends from Umkaliar and Lwai streams

Water Quality

The year-long sampling data from Umkaliar and Lwai streams showed seasonal trends in temperature, and dissolved oxygen. Dissolve oxygen values rise as the water temperature lowers with the onset of winter. This trend is sharper in the polluted Umkaliar stream (average of 5.7 ± 0.92 mg L^{-1} Figure 2 upper panel) as compared to Lwai stream as the dissolved oxygen values in the summer were higher at Lwai than Umkaliar, with the mean value of 7.6 ± 0.42 mg L^{-1}.

A set of paired t-tests were used to compare the differences between the two streams among paired values of dissolved oxygen, temperature, and turbidity taken at each sampling event. Temperature in Lwai stream was marginally higher than Umkaliar stream across the entire year (t = 2.1, df = 11, P = 0.05, with mean of 16.8 ^{0}C at Lwai and 15.4 ^{0}C at Umkaliar; Figure 2a). The temperature difference could be due to the higher altitude and temperate climate of Umkaliar stream as compared to Lwai stream that is in sub-tropical habitat.

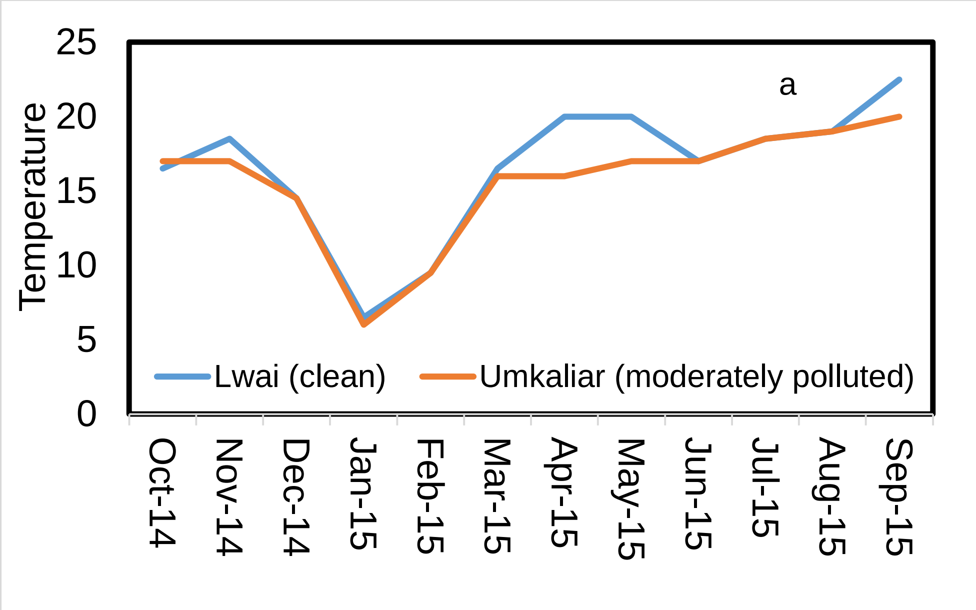
Dissolved oxygen at each monthly sampling event was significantly higher in Lwai compared to Umkaliar stream (t = 4.46, df = 11, $P < 0.001$, with mean of 7.6 mg L^{-1} at Lwai and 5.7 mg L^{-} at Umkaliar; Figure 2b).

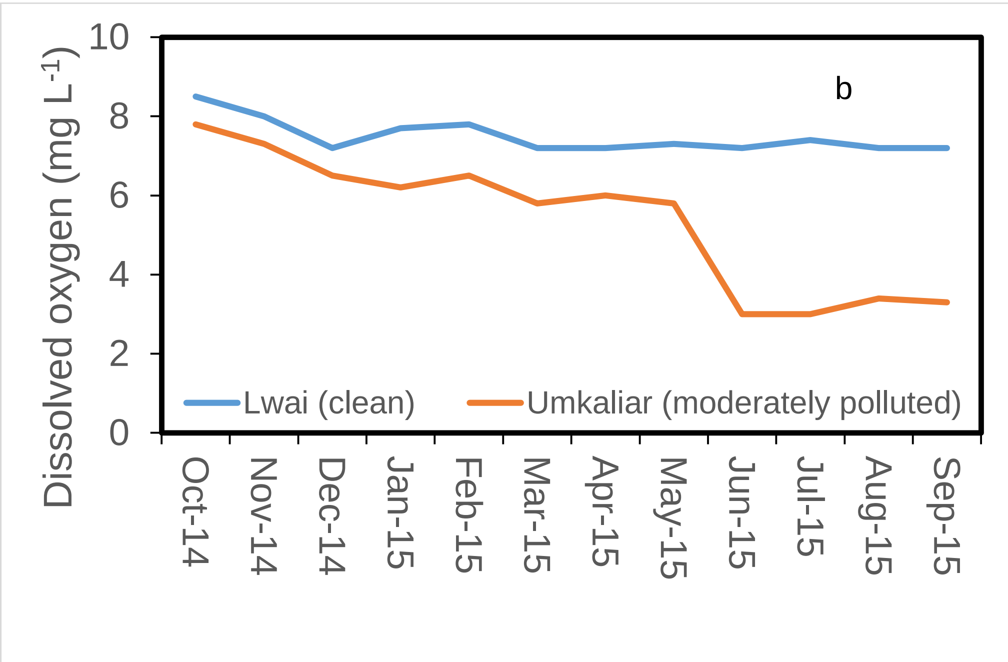
Paired t-test between turbidity values at two streams within a sampling event was significantly higher in Umkaliar stream than Lwai strean (t = 4.89, df = 11, $P < 0.001$, with mean of 15.5 NTU at Lwai and 22.6 NTU at Umkaliar; Figure 2c). Since biotic index is a derived variable we did not perform a paired t-test.

Variation in dissolved oxygen ($P < 0.01$, $r^2 = 0.21$) was significantly explained by temperature. ($P < 0.01$, $r^2 = 0.35$; Figure 3 upper panel). Turbidity had a strong effect on dissolved oxygen as well and explained significant variation in DO values ($P < 0.01$, $r^2 = 0.36$; Figure 3 lower panel).

Biotic index

Lwai stream had greater biotic index with an average of 14.6 ± 0.8 (mean ± SE; Figure 2d) which is an indication of clean streams compared to Umkaliar stream where the average biotic index score was 8 ± 1.4 indicating that Umkaliar is moderately polluted stream. Lwai harbors greater diversity of pollution sensitive taxa. Leech, mosquito larvae, midge larvae, snails, and mayflies were frequently encountered in Umkalair streams as compared to Lwai stream where caddisflies, stoneflies, mayflies, adult water beetles, water scorpions and snails were commonly found (Table 2). No strong seasonal trend in biotic index was observed in Lwai or Umkaliar streams.


a
Temperature
25
20
15
10
5
0
Lwai (clean)
Umkaliar (moderately polluted)
Oct-14
Nov-14
Dec-14
Jan-15
Feb-15
Mar-15
Apr-15
May-15
Jun-15
Jul-15
Aug-15
Sep-15


b
Dissolved oxygen (mg L-1)
10
8
6
4
2
0
Lwai (clean)
Umkaliar (moderately polluted)
Oct-14
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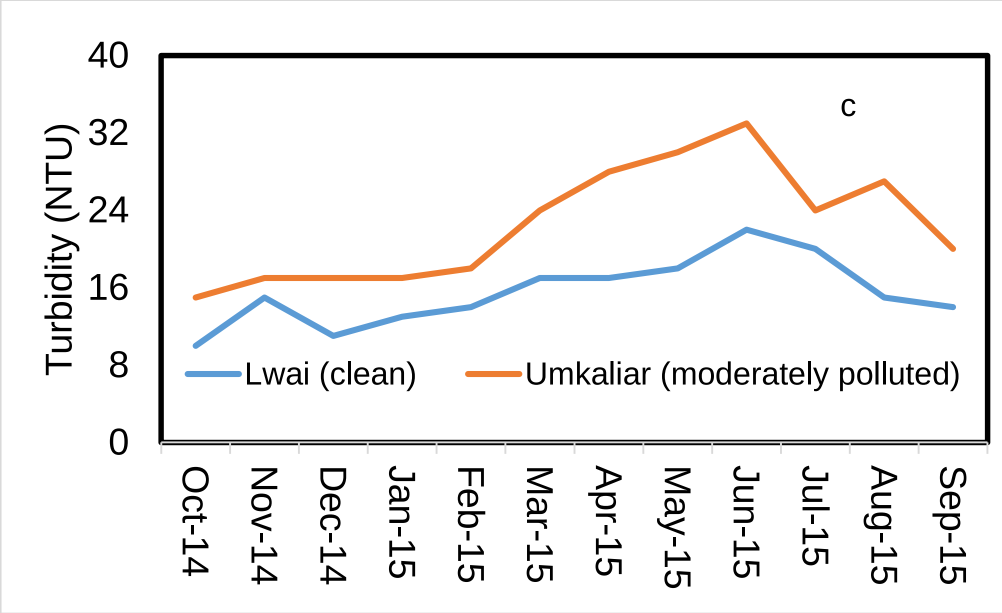
Jul-15
Aug-15
Sep-15



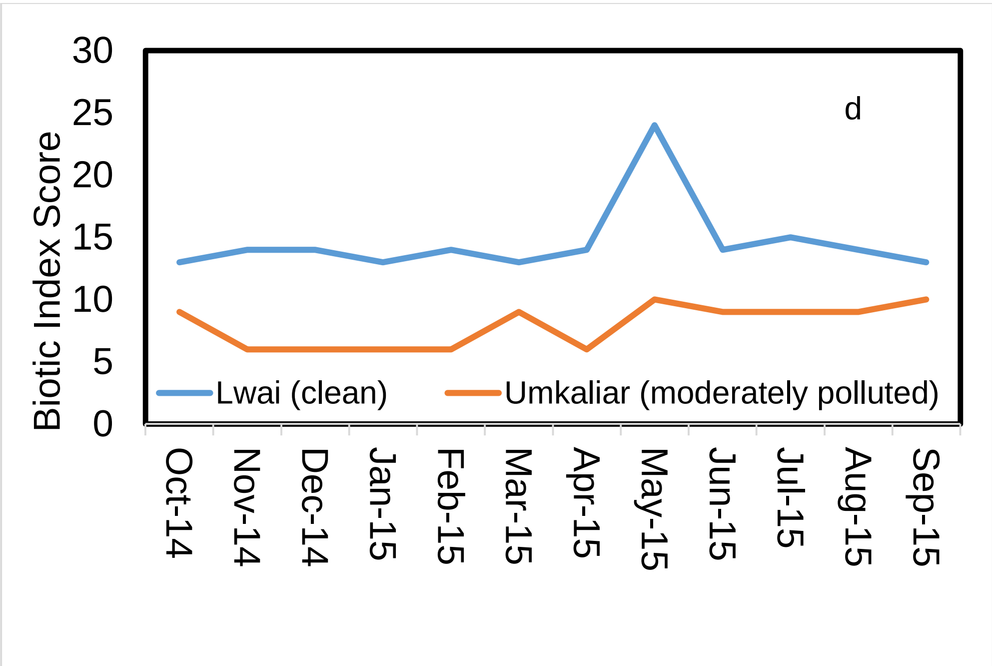


Figure 2: a. Temperature variation across months, Lwai stream was marginally warmer than Umkaliar stream. b. Trend in dissolve oxygen at Lwai and Umkaliar streams over a sampling period of one year, DO at Lwai was significantly higher than Umkaliar. The trend in relation to temperature is sharper for polluted stream compared to clean Lwai stream. c. Turbidity was significantly higher in Umkaliar than Lwai stream. d. Biotic index scores based on sampling of macroinvertebrates from the riffle sections of the streams. Biotic index values obtained at Lwai, indicate that the stream is fairly clean.

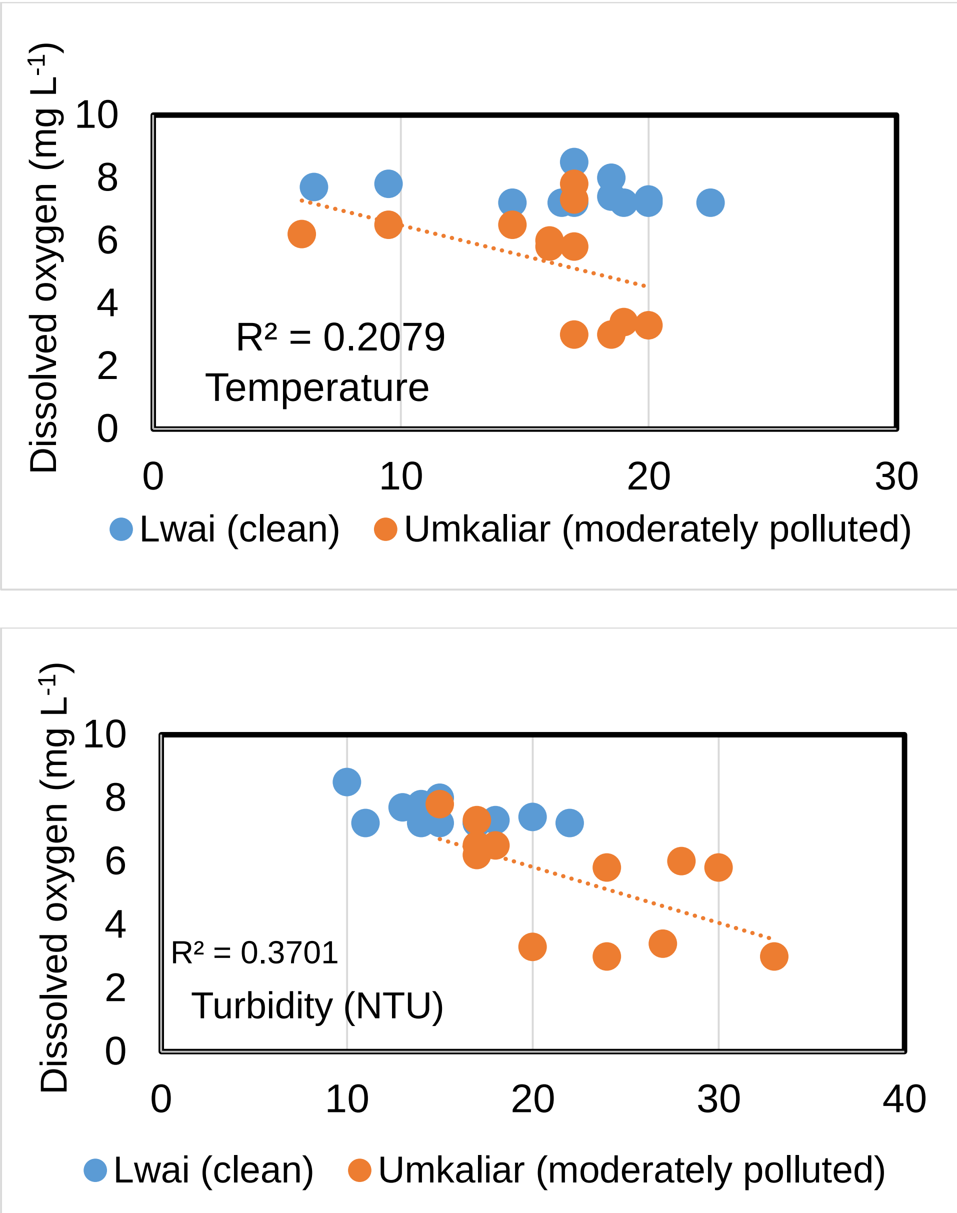


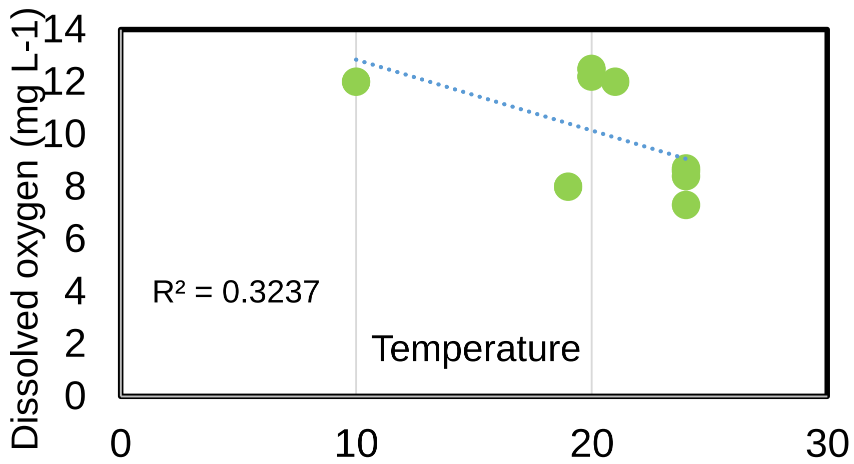
Figure 3. Upper panel shows that the temperature was a significantly important variable in determining DO in moderately polluted stream, while in Lwai stream DO stayed stable across the year. Lower panel also depicts that turbidity explains a significant trend in DO values in moderately polluted stream, while in Lwai stream the pattern is non-significant.

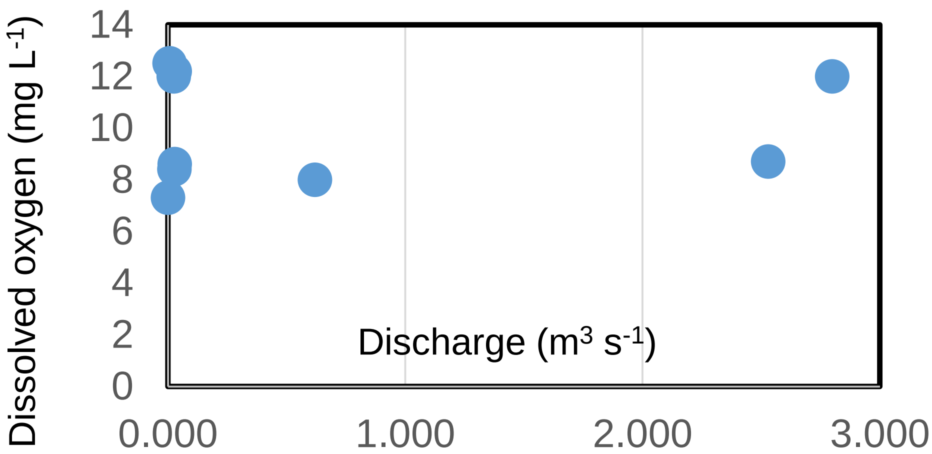
2. Patterns from spatially segregated sampling data

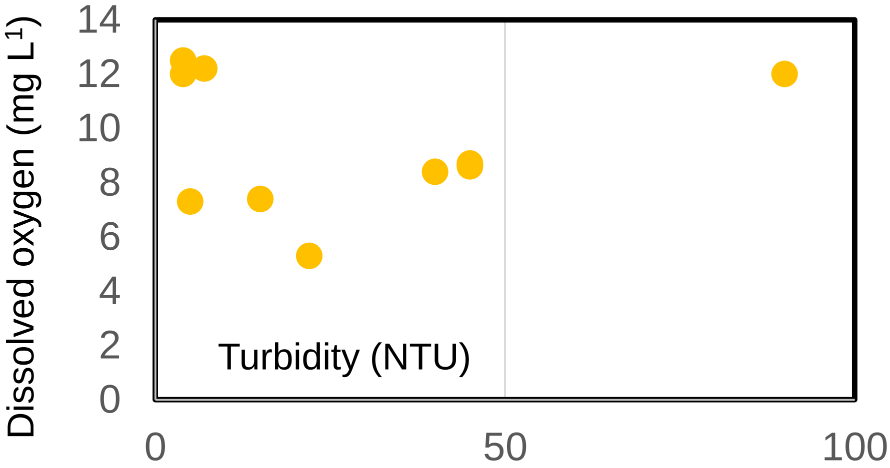
A dataset from 8 streams sampled once or bi-yearly were pooled to examine if there were any emergent trends in biotic index, turbidity, temperature and discharge along the continuum of pollution. Multiple sections but separated by at least 2 km and belonging to different stream orders of Umshyrpi and Umran river network were sampled. Patterns in dissolved oxygen were significantly explained by temperature ($P < 0.001$, $r^2 = 0.37$; Figure 4 upper panel) cooler waters had greater capacity to hold dissolved oxygen compared to warmer waters. Stream discharge varied among sites as a factor of channel width and stream morphology with most 1st and 2nd order streams showing lower and comparable discharge values while the larger 3rd and 4th order stream with higher discharge values. No significant relationship was observed between discharge and dissolved oxygen concentration (Figure 4 middle panel). Turbidity did not influence dissolved oxygen concentration (Figure 4 lower panel). Turbidity can be caused by high rates of sedimentation or dumping of solid wastes in the rivers which lowers the visibility and amount of DO in the streams. However larger streams with high discharge and mixing of water could lead to increase in DO concentrations, alleviating the impact of high turbidity.

Table 2 summarize the taxonomic groups (insect orders) observed at different stream locations. Biotic Index values across sites were significantly influenced by turbidity indicating that streams with pollution tolerant taxa tend to have murky waters based on the streams sampled here ($P < 0.001$, $r^2 = 0.38$; Figure 5). Biotic index value was not influenced by dissolved oxygen value, as polluted streams can have comparable or higher concentrations of DO than the less polluted streams if the streams have greater discharge and mixing of water, both factors leading to high DO concentrations.

Figure 4. Spatial variation in relationship between DO and the variables- temperature, turbidity, and discharge Upper panel depicts a significant relationship between temperature and DO across the entire spectrum of streams sampled in Shillong; the lower the temperature the greater was DO in the streams. Middle panel shows that discharge can be categorized as low values within 1st and 2nd order streams, intermediate value for 3rd order stream and highest for 4th order stream. Lower panel depicts the values of DO across a range of turbidity among the sampled streams.


Dissolved oxygen (mg L-1)
14
12
10
8
6
4
2
0
R² = 0.3237
Temperature
0
10
20
30


Dissolved oxygen (mg L-1)
14
12
10
8
6
4
2
0
Discharge (m3 s-1)
0.000
1.000
2.000
3.000


Dissolved oxygen (mg L-1)
14
12
10
8
6
4
2
0
Turbidity (NTU)
0
50
100

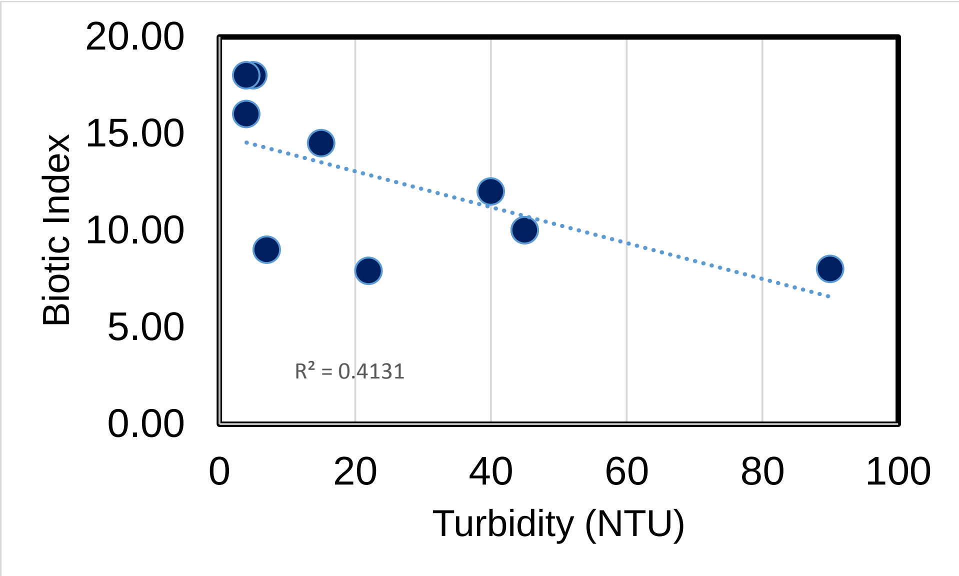


Figure 5. Turbidity explained a significant variation in biotic index values across the streams.

Table 2. Common macroinvertebrates sampled from the riffle section of streams in Meghalaya

Stream/river	Location	Sampling regime	Macroinvertebrates
Lwai	East Khasi Hills	Monthly, Sep 2014-2015	Caddisflies, stoneflies, mayflies, adult water beetles, water scorpion, mosquito larvae, snails
Lawjynriew	East Khasi Hills	One-time, Oct-2014	Caddisflies, stoneflies, mayflies, hellgrammite, dragonfly, water scorpion, midge larvae
Malki	East Khasi Hills	One-time, Oct-2014	Caddisflies, stoneflies, mayflies, dragonfly, adult water beetles, water scorpion
Mawshubuit	East Khasi Hills	One-time, Oct-2014	Caddisflies, stoneflies, mayflies, midge larvae, mosquito larvae
Umran 2nd order	Ri-Bhoi	One-time, July-14, Jan-14	Caddisflies, stoneflies, mayflies, dragonfly, adult water beetles, water scorpion, crabs
Umran 4th order	Ri-Bhoi	One-time, July-14, Jan-14	Caddisflies, mayflies, adult water beetles, aquatic earthworms
Umkaliar	East Khasi Hills	Monthly, Sep 2014-2015	Leech, mosquito larvae, midge larvae, snails, mayflies
Umshyrpi 1st order	East Khasi Hills	Once Oct-14	Caddisflies, stoneflies, mayflies, amphipod, adult water beetles, aquatic earthworms, snails
Umshyrpi 3rd order	East Khasi Hills	Once Oct-14	Adult water beetles, blackfly and midge larvae, aquatic worms, snails
Wahdienglieng	East Khasi Hills	Bi-yearly, Oct-14, Jan-15	Blackflies, caddisflies, mayflies, midge larvae,

Discussion

The biomonitoring initiative in Meghalaya was setup with a dual aim. Firstly, to infuse curiosity and to introduce students to scientific method of asking and answering questions in stream ecology and conservation of water resources. Secondly to document macroinvertebrate diversity in conjunction with hydrological and physico-chemical parameters of streams so that a metric for streams in Meghalaya can be established, which could be used state-wide. Biological measures provide the integrative measure of stream health as opposed to snapshots of stream conditions as obtained by physicochemical parameters (Karr 1999).

While stream biomonitoring with benthic macroinvertebrates is a tool for guiding policy on setting effluent limits and water quality standards (Kennedy et al. 2009), capacity building in freshwater ecology is a novel application of biomonitoring. Several colleges from Shillong, Meghalaya, participated in designing the studies, collecting and analyzing data, the results of which were presented in international conferences (Saha 2016) and college seminars. A rapid turnover of students in an undergraduate college allowed us to train several groups of students over three years, but posed logistical challenge to maintaining long-term studies.

Our dataset on documenting spatial variation in stream parameters across Meghalaya allowed us to assess the range of water quality parameters across sites such as turbidity and DO and correlate it with the composition of macroinvertebrate assemblages. Turbidity had a strong negative effect on macroinvertebrate assemblages as exhibited by decline in the biotic index score value with increase in turbidity. Turbidity in rivers and streams of Meghalaya results as the dust and soil erodes from farming, limestone mining, cement factory effluents, and roadbuilding (Lamare and Singh 2016). As silt covers rocks and thereby removes habitat for the aquatic larvae sheltering underneath rocks from the swift flowing currents (Feio et al. 2015). In streams of Meghalaya the Simuliidae (Dipterans, true flies) abundance of sensitive species was depressed near mining areas (Rabha et al. 2013); while some species of blacflies densely occurred in areas impacted by anthropogenic activities.

We observed temporal trends in temperature, and differences in turbidity and DO between clean Lwai and polluted Umkaliar streams that were reflected in distinct macroinvertebrate assemblages observed at each of the streams respectively. However some results were clear and true irrespective of temporal variation. Lwai streams with non-turbid clear water and high DO levels supported pollution sensitive macroinvertebrates such as stoneflies and mayflies (sensu Rosenberg and Resh 1993, Lamoureaux et al. 2004), while pollution tolerant taxa such as midge larvae and mosquito larvae were common in Umkaliar stream. The high turbidity and low DO concentration in Umkaliar stream was correlated with biotic index scores associated with moderately polluted streams (Sharpe et al. 2006, Feio et al. 2015). Our data did not exhibit a strong seasonal variation in macroinvertebrate abundances, but the patterns in adult emergence and life-history traits, are known to influence the abundances of macroinvertebrates in monsoonal streams (Mesa 2012).

The summer temperatures were almost four times higher than mid-day winter temperature. Dissolved oxygen showed a decline in summer months especially in polluted stream while showed stable values in Lwai stream. Turbidity was significantly higher during all sampling events in polluted Umkaliar stream compared to Lwai stream. Cooler water temperatures support greater DO concentration than warmer temperatures (Michaud 1991, Wetzel 2001), as observed in Umkaliar stream. The relationship between temperature and DO was not significant in Lwai stream perhaps because discharge (not measured here) is very high in summer monsoonal months, compensating for the effect of temperature. Turbidity is known to limit the ability of oxygen to freely dissolve in water (Hem 1985, Anderson 2005, Bayram et al. 2014, Smith 2015) is much lower in Lwai compared to Umkaliar stream which might have influence DO values. It is also likely that Biological Oxygen Demand in Lwai is lower than in Umkaliar stream due to greater pollution and intense anthropogenic use of Umkaliar stream. Biological Oxygen Demand depresses oxygen availability in waters as the processes involving decomposition and chemical reactions of organic matter tend to consume oxygen (Wetzel 2001).

Most of the Meghalayan streams sampled here had relatively high DO values, besides the Umkaliar river where the DO values were as low as 3 mg L^{-1} during the peak rainy season. The ability of fish to survive in low oxygen environments depends upon the extent of exposure, the level and constancy of dissolved oxygen and other environmental conditions, as well as on the species, its health, and life stage (Birtwell1989), which we do not have data on yet, but are working towards making our datasets stronger and comprehensive. Lack of adequate wastewater treatment and sewage treatment leads to untreated water and sewage dumped in the water bodies and cause an increase in BOD in the streams and rivers that flow through Shillong and other urban areas of Meghalaya.

While several studies have looked at diversity and abundance of macroinvertebrates as a biomonitoring tool in Indian streams and rivers (for example, Martin et al. 2000, Shah and Shah 2013), few studies exist in the Indian Northeast (but see Meghalaya Pollution Control Board 2016). While we have interesting datasets on biotic and abiotic parameters of Meghalayan streams we are confronted by multiple challenges. Figure 6 provides a glance at some results from our work. Similar to volunteer monitoring organizations that fail to get adequate technical support due to lack of quality equipment (funding related) or inability of ground staff to troubleshoot technical problems (dearth of time, funding and experience), that hinder their ability to defend and interpret data on the quality of streams and lakes they monitor (Latimore and Steen 2014), our biomonitoring efforts face similar issues. Data collection efforts were interrupted due to equipment breakdown, lack of time among students and their supervising lecturers, and due to other higher priority activities such as semester and term exams. Amidst of these challenges, the colleges in Meghalaya have come forward and recognized that capacity building in the field of freshwater ecology opens up several novel horizons for college students and increases the ability of students and college staff to work for improving water quality in the region. Training in use of open source software and monitoring equipment, introduction to GIS, and data collection and analysis are some tools that are acquired by students working on biomonitoring projects. These tools increase employability of students in other sectors as well. Meghalaya's biomonitoring program now enters 3rd year of sampling with the hope that some of the older studies will be revived as newer studies are established.

In conclusion

Ultimately, clean adequate water and aquatic resources (such as fisheries) are necessary for all. Given the increasingly negative human impacts on aquatic ecosystems and their catchments, it is important for society to have a better understanding of the links between ecosystems and water resources, as well as know how to monitor their local streams, thereby acting as sentinels for noticing adverse changes. Monitoring, knowing what is the current status is the first step towards management of ecosystems and water resources that necessitates cooperation between all stakeholders involved, from local communities to the government, organizations and educational institutions. With that in mind, giving the current generation the tools and the perspectives is a way to foster a collective conservation mindset. The protection and wise management of natural resources requires our united effort, more than ever in recent history given the ongoing degradation and the looming uncertainty of climate change upon water resources.

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Figure 6. Some specimens of macroinvertebrate larvae, top row, left to right- Water scorpion of *Ranatra* sp. (Family Nepidae, Order- Hemiptera), Mayfly larva of Family Heptageniidae, (Order- Ephemeroptera), damsel fly larva of Family Coenagrionidae (Order Odonata). 2nd row from top, left to right: Caddisfly larvae of Family Polycentropodidae (Order Trichoptera), Rove beetle of Family Staphylinidae (Order Coleoptera) not strictly aquatic but hunt along margins of water bodies), Caddisfly larva of Family Rhyacophilidae (Order Trichoptera) and Crab (Crustacea) of Genus *Liotelphusa*, Ffamily Gecarcinucidae. 3rd row from top, left to right are: Amphipod (Order Amphipoda, Subphylum Crustacea), Caddisfly larva of Family Stenopsychidae, (Order Trichoptera), Dragonfly larva of Family Corduliidae (Order Odonata). 4th row from top, Stonefly larva of Order Plecoptera. Last row from top students working in the 2nd and 4th order streams of Umran river near Umsning village;