Freshwater Zoobenthic Species: Role in Biomonitoring and Ecological Processes- A Review

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Abstract

Water resources especially lotic ecosystems drain diverse landscapes with their peculiar climatic regime, making them extremely diverse in terms of establishment of complex network of benthic communities, one such component are benthic macroinvertebrates or zoobenthos which are integral components of freshwater systems. They are represented by insects, molluscs, crustaceans, annelids and nematodes. Physical environment determines the patterns in the distribution and abundance of species over broad scales, while the relative importance of biotic factors (e.g. competition and predation) is thought to be greater thereby determinant of species diversity. Ecologists have recognized their utility in biological monitoring, the benthic community is dependent on its surrounding, and therefore it serves as an indicator that reflects the overall condition of the ecosystem. Thus, their use as bio-monitoring agents (unlike chemical data) depicts long-term environmental stresses as they have a broad spectrum of taxa-specific responses to varying levels of pollution. This paper highlights the importance of benthic invertebrate community in aquatic food web thereby making them one of the key organisms being used in biological monitoring studies.

INTRODUCTION

Aquatic ecosystem provides a wide range of ecosystem services [22,28] also serving as a source for different resources (e.g. water, fish) and sink for dumping many anthropogenic wastes (industrial, domestic wastes and agricultural runoff). These systems be it lentic or lotic exhibit a great variety of biological- and genetic diversity, the invertebrates are one of the major biological components of the aquatic ecosystems [41]. This community is represented by insects, molluscs, crustaceans, annelids and nematodes. The greatest diversity in form and habit is exhibited by the insects [34]. Although less than 3% of all insect species have aquatic stage [16], but in some freshwater biotopes, insects may comprise over 95% of total individuals or species of macroinvertebrates. The distribution of aquatic macroinvertebrate species and communities is controlled by a variety of environmental factors such as habitat characteristics [47], sediment size [57], water quality [25], sediment quality [12], contaminants [48], and by biological factors such as competition and predation [36]. On the basis of behaviour invertebrates are classified as nekton (actively swimming organisms that are able to move about at will through water), neuston (organisms which rest or swim on the surface of water), and benthos (organisms which remain attached to the bottom substrates or sediments).

The benthic macro-invertebrates or benthos are the animals inhabiting the sediment or living on or in other available bottom substrate of fresh water, estuarine and marine ecosystem [6]. Naumann [43], further classified zoobenthos on the basis of size into Microbenthos (less than 500 µm), Mesobenthos (500 -1000 µm) and Macrobenthos (greater than 1000 µm). Also, these bottom dwelling organisms are retained by mesh sizes of 200-500 µm [53]. During all or part of their life cycles, these organisms may construct attached cases (e.g. Limnephilus sp.); roam freely over rocks and other substrates (e.g. Rhycophila sp.); or burrow freely in substrates (e.g. Palingenia sp.). Benthic organisms accelerate nutrient transfer to overlying open waters of lakes [14], as well as to adjacent riparian zones of streams [15,64]. They influence sediment and bottom-water chemistry [4], alter sediment organic content [35] and structure [51], and serve as major prey species for crustaceans and fish [61]. Benthic macroinvertebrates constitute an extremely diverse assemblage both at taxonomic and ecological levels.

Biomonitoring using zoobenthic invertebrate species

The aquatic ecosystems are under constant threat due to multiple local and global impacts [21,46,56], prominent being habitat degradation vis-a-vis fragmentation [49], nutrient enrichment and sediment settling from agricultural activities [2]. In light of the increasing anthropogenic pressures on the environment there ascended a need of continuous monitoring of the changing ecosystem dynamics.
Macroinvertebrates are diagnostic of the health of the aquatic ecosystems, the composition and density of the benthic macroinvertebrates reflects the habitat condition as different taxa prefer a unique set of water qualities. That is why they are being used as indicators i.e. organisms that become dominant under specific set of environmental conditions [34]. Hellawell [25], revealed that benthic macroinvertebrates were one of the organism groups most often recommended for assessing water quality due to the sensitivity of benthic invertebrates to different impacts [26], a single sample of benthic macroinvertebrates can replace several repeated chemical and physical measurements [19]. Besides, a critical part of food web benthic macroinvertebrates are common inhabitants of lakes and streams where they are important in moving energy through food webs, thereby, reflect habitat degradation which is quite difficult to be done via the traditional water assessment methods. They are easy to sample and identify, different taxa show varying degrees of sensitivity to pollution and other impacts [8]. Their sedentary mode of life i.e. length of life cycles and relatively constant presence in one location make the analysis of community structure, a strong tool to detect the development of human pressures over long periods [25,1], they are varying sensitivity to the pollution [18], finally this method is cost-effective, qualitative sampling and sample analyses is possible using simple, inexpensive equipment, also the taxonomy of macrozoobenthos is well known, and there are many keys available for identification [53]. For example, Oligochaetes are used in Ecological risk assessment (EcoRA), as the whole taxon of it has been considered to be ‘pollution tolerant’ [13]. It was found that certain species of aquatic oligochaetes (e.g. Tubifex tubifex and Limnodrilus hoffmeisteri) were abundant in organically polluted waters because of lack of competition and an abundant food supply coupled with their tolerance capacity to reduced oxygen conditions. Thus, the use of macro-invertebrates for valuations of water quality arose from the aggravated problem of water pollution and its related effects on human health and safety, the world scenario has reached to an extent that the access to safe freshwater is now regarded as a Universal Human Right [59]. Approximately there are more than 50 different approaches for bio-monitoring using macro-invertebrates [65,23]. Unlike chemical data, which provides water quality information at a discrete point in time, the biological organisms such as benthic macroinvertebrates are long-term indicators of environmental stressors. In addition, macroinvertebrates are more effective than chemical methods for detecting non-point source pollution due to the range of taxa-specific responses among invertebrates to environmental stressors and their long-term response to these factors. Hence, all these factors make them a prime runners as agents of biomonitoring.

Role of invertebrates in complex and dynamic ecological processes

The variable ecological roles of freshwater benthic species influence the freshwater ecosystems. Some benthic species are important for determining how organic matter is processed in freshwater ecosystems [45]. The changes in distributions and abundances of one species can result in disproportionate and unexpected responses by other species as they attempt to compensate functionally for changes in the associated species [24,42]. Vannote et al. [60] postulated in their River Continuum Concept that systems with highly stable physical structure tend to have low biological diversity, while systems with lower stability tend to have higher diversities. Each organism prefers a particular optimal temperature, so a greater variation in temperature would allow more organisms to attain their optimal metabolic activity at some time during the day [52]. A positive relation between high species richness and large fast flowing breeding sites, with dense canopy cover and cool temperature was observed.

Many factors play a role in shaping the distribution and abundance of benthic species [5]. Abiotic factors are often regarded to determine patterns in the dispersal and richness of species over broad scales, while the relative importance of biotic factors (e.g. competition and predation) is thought to be greater over more indigenous scales [32]. In general, it’s suggested that the diversity and abundance of benthos increase with substrate stability and the presence of organic detritus [3]. Other substrate features which appear to play a role in the mean particle size of mineral substrates, the variety of sizes, and surface texture.

Many statistical methods are used for determining the variation in benthic community structure in terms of changes in the absolute abundances of different genera relative to one another. For instance, Michael et al., [39] used redundancy analysis (RDA) and canonical correspondence analysis (CCA), to assess the relationships among physico-chemical characteristics and macroinvertebrate assemblages at stream sites in Southern Rockies (Colorado). The RDA was correlated with dissolved cadmium, sediment zinc, and total suspended solids (indicating mining effects), water temperature, mean substrate embeddedness, mean canopy density at the banks and a riparian human disturbance index (reported grazing by livestock).

The benthic invertebrates distribution exhibit habitat preferences even in the same ecosystem as Toshihito [58], investigated the species composition and distributional patterns among nymphs of 5 Baetid genera in Yura stream (Japan). Based on the longitudinal distribution patterns and with regard to habitat preference, Alainites and Labiobaetis were restricted to riffle-vegetated zone species, whereas Baetis and Nigrobaetis contained both riffle species and ubiquitous species. The external conditions be it natural or anthropogenic has a profound impact on the diversity and density of living organisms. Bruce et al., [11] showcased the seasonal variations in invertebrate assemblages on six Florida headwater streams. Two of the streams were reclaimed following phosphate mining (~6 yr prior to the study), two received runoff from mined lands, and two were disturbed by agriculture and/or residential developments. The physico-chemical and biological characteristics of the reclaimed streams differed markedly from those of the non-reclaimed streams; principal differences between the streams were in current velocity, percent organic matter, conductivity, alkalinity and taxonomic composition. Besides it was also observed that drought appeared to have a larger influence on invertebrates than the type of land use.

The density of particular invertebrate is also dependent on the frequency of habitat disturbance; Jose et al., [31] studied

the univoltine winter life history of *Epeorus torrentium* and its secondary production was observed, which was consistent with the unpredictable environment where they dwelled. A higher density, biomass and production was observed at the headwater site than at the downstream sites, but the annual production/biomass ratios followed the opposite spatial trend. Joakim et al., [30] carried the comparison of 84 macroinvertebrate single metrics so as to calculate and test them for their ability of detecting organic pollution of streams. Jacobson [27], studied macroinvertebrate–stone relationship in equatorial streams and observed that the physical characteristics of stone microhabitats such as water depth, current velocity, horizontal position, embeddedness and size (surface area) all to varying degree influenced spatial distribution of invertebrates density and richness. It was also concluded depth has negative effect and current velocity has a positive effect on the density and number of families of macrobenthos. The study of the River Ganga ecosystem from Varanasi to Farakka conducted by Roy [54], indicated the gradual decline in diversity, abundance, population size and distribution of benthic biota due to habitat alteration and fragmentation by development activities, indiscriminate fishing, pollution, and introduction of exotic species. Besides the other factors affecting biodiversity were massive deforestation, over-grazing, siltation and eutrophication which pose a great threat to the river basin as a whole.

Marcel et al., [38] carried out an experimental study to investigate the role of leaf litter as a major basal resource to stream ecosystems. They concluded that the input of leaf litter strongly influences macroinvertebrate assemblage structure. The study also suggested that snails have an important role in decomposer food webs, facilitating or directly contributing to leaf breakdown. Braccia and Voshell [10] studied the relationship between benthic macroinvertebrate assemblages and cattle density in streams that represented a gradient of cattle grazing intensity. Regression analysis revealed a highly significant and strong macroinvertebrate metric response to cattle density during most sampling periods. Banerjee and Banerjee studied the physico-chemical parameters and distribution of macrobenthic forms in the river Ganga, in three polluted areas in the upper stretches of the river. It was reported that the allochthonous materials carried by river varied greatly in both composition and nature, which in turn influenced the variability of organic matter in the estuary that had influence on the distribution of macrozoobenthos. Jin and Ward [29], studied life history and secondary production of a caddisfly scraper, *Glossosomanigrion* in two Alabama streams. It exhibited trivoltine life histories, which was attributed to the higher water temperature regimes, also the majority of its secondary production (>80%) was contributed by the consumption of algae. Barber-James et al., [7] worked on global diversity of Mayflies (*Ephemeroptera, Insecta*) in freshwater. They reported that the exact global *Ephemeroptera* fauna is represented by over 3,000 described species of 42 families and more than 400 genera.

Luana et al., [33] assessed the effect of hydrological variations on macrobenthic communities of Mediterranean stream. Results suggest that flow peaks and substratum instability remarkably affect population abundance and composition of macroinvertebrate assemblages. Early colonizers (organisms with high dispersal and drifting tendency) dominate during hydrological perturbation and post-perturbation phases.

Ezekiel et al., [20] during their study on the benthic macroinvertebrates of Sombreiro river that is connected to other rivers via creeks in the coastal areas of the Niger Delta that makes the mouth of the river with a brackish and tidal environment, found that the distribution pattern of macroinvertebrates showed a striking longitudinal zonation and significant seasonal variation occurred between the mean values of wet season and the dry season. The dry season had higher value than the wet season.

A relation between the organic debris in the habitat, the abundance of individuals and the decrease in the diversity value of the macroinvertebrate association was observed by Oscar [44], when he compared the results obtained by processing a series of data (based on the seasonal variations of macroinvertebrates from the Ravella stream) according to several diversity indices (Simpson, Berger-Parker, Margalef, McIntosh, Shannon) and one similarity index (Jaccard) with those obtained from two biotic indices (Trent River Biotic Index and Extended Biotic Index). Thomas et al., [55] developed a multimetric index to detect river deterioration caused by human impacts in the Hindu Kush-Himalayan region. The application of multimetric indices was inexpensive and provided accurate information about many stressor types especially impacts of pollution were detected by benthic macroinvertebrates at a fraction of cost and technical expertise than via conventional methods.

Macroinvertebrates play fundamental roles in stream ecosystems, being consumers at intermediate trophic levels and thus serving as channels by which bottom-up and top-down forces are transmitted [62,63]. The relative abundances of the different species having variable feeding habits are main characteristics of macroinvertebrate communities with important implications at ecosystem level [50], thereby directly impact community structure w.r.t. ecosystem functioning. Different feeding groups of benthic macroinvertebrates include collector / gatherer, collector / filterer, scrapper, shredder and predator. The functional composition of macroinvertebrate communities referred to as functional feeding groups (FFGs), has important implications for ecosystem functioning [40]. However this concept is highly debateable due to high plasticity among benthic species for the utilization of food resources [17], still the classification of macroinvertebrates on the basis of their feeding habit is highly useful to describe communities functionally, especially to compare stream sites of different size, riparian vegetation, physico-chemical characteristics, etc. The variation of the different FFGs at different spatial scales can be explained by their mode of search for their food resources, together with the environmental variability [9,37]. Hence, benthic macroinvertebrates form an integral part of freshwater systems playing a vital role maintaining its ecosystem services. They serve as an efficient, cost-effective agent in biomonitoring studies, thereby depicting the effect of anthropogenic pressures on our water resources much better than via conventional chemical methods.
CONCLUSION

The benthic macroinvertebrates are a lucrative option for biomonitoring due to their sedentary and cumulative response to pollution, their responses aid to assess changes in the ecosystem which are generally due to changes as a result of anthropogenic pressures. They provide essential ecosystem services by accelerating detrital decomposition thus increasing the transfer of nutrients to the overlaying water column. The chemically bound nutrients are released by their feeding and metabolic activities, and burrowing into sediments. Zoobenthos are an indispensable part of the complex aquatic food web, they not only serve as prey to fish species and other vertebrate consumers but are also predators that regulate the density and distribution of their prey. Hence, any change in the patterns of zoobenthic density and diversity reflect human and natural influences in form of habitat and environmental degradation. However, the entire community is to be considered as a unit of study to assess the health of any ecosystem, inferences on the basis of particular species can be misleading since various factors interplay and are interdependent to bring out the change in the entire ecosystem.

REFERENCES

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