IJESRT: 14(2), February, 2025 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

A REVIEW ON MOLLUSCAN DIVERSITY IN FRESHWATER HABITATS: IMPLICATIONS FOR CONSERVATION AND AQUATIC HEALTH

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DOI: 10.5281/zenodo.14892480

ABSTRACT
Mollusks play a crucial role in riverine ecosystems, contributing to nutrient cycling, sediment stabilization, and providing food sources for various wildlife. This review examines the diversity of molluscan species in riverine habitats, highlighting their ecological importance, distribution patterns, and the factors influencing their populations. Riverine environments are home to a variety of mollusks, including gastropods, bivalves, and freshwater mussels, each of which serves vital functions in ecosystem health. However, these species face increasing threats from habitat degradation, pollution, invasive species, and climate change. The loss of molluscan diversity can have cascading effects on river health, impairing water quality and disrupting food webs. This review explores the implications of declining molluscan populations for conservation strategies, emphasizing the need for habitat restoration, pollution control, and effective monitoring programs. Additionally, the review discusses the use of mollusks as bioindicators for assessing the ecological status of river systems. Protecting molluscan diversity is essential not only for maintaining healthy aquatic ecosystems but also for supporting sustainable riverine resources. Ultimately, integrating molluscan conservation into broader environmental management plans is critical for the preservation of riverine biodiversity and ecosystem services.

KEYWORDS: Bivalves, Biodiversity, Bioindicators, Ecological, Ecosystems, Gastropods, Molluks.

1. INTRODUCTION
Rivers, as dynamic aquatic ecosystems, provide essential services that sustain biodiversity, regulate hydrological cycles, and support both human and environmental health [1]. Among the rich diversity of organisms inhabiting these freshwater systems, mollusks (including gastropods, bivalves, and other classes) play a crucial role in maintaining ecosystem function and health [2]. These invertebrates are integral to nutrient cycling, sediment stabilization, food webs, and bioindicators functions, making them essential components of riverine habitats [3]. Yet, despite their ecological significance, molluscan diversity in river ecosystems is often overlooked, with many species facing growing threats due to human-induced changes, such as habitat degradation, pollution, and climate change [4]. Molluscan communities in riverine habitats are highly diverse, ranging from microscopic larvae to large bivalves and snails, each occupying unique ecological niches [5]. The diversity of mollusks in rivers is a reflection of the intricate interactions between the physical, chemical, and biological aspects of freshwater ecosystems [6]. These organisms thrive in a wide range of environmental conditions, from the fast-flowing, oxygen-rich waters of mountain streams to the slow-moving, nutrient-rich stretches of lowland rivers [7].

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

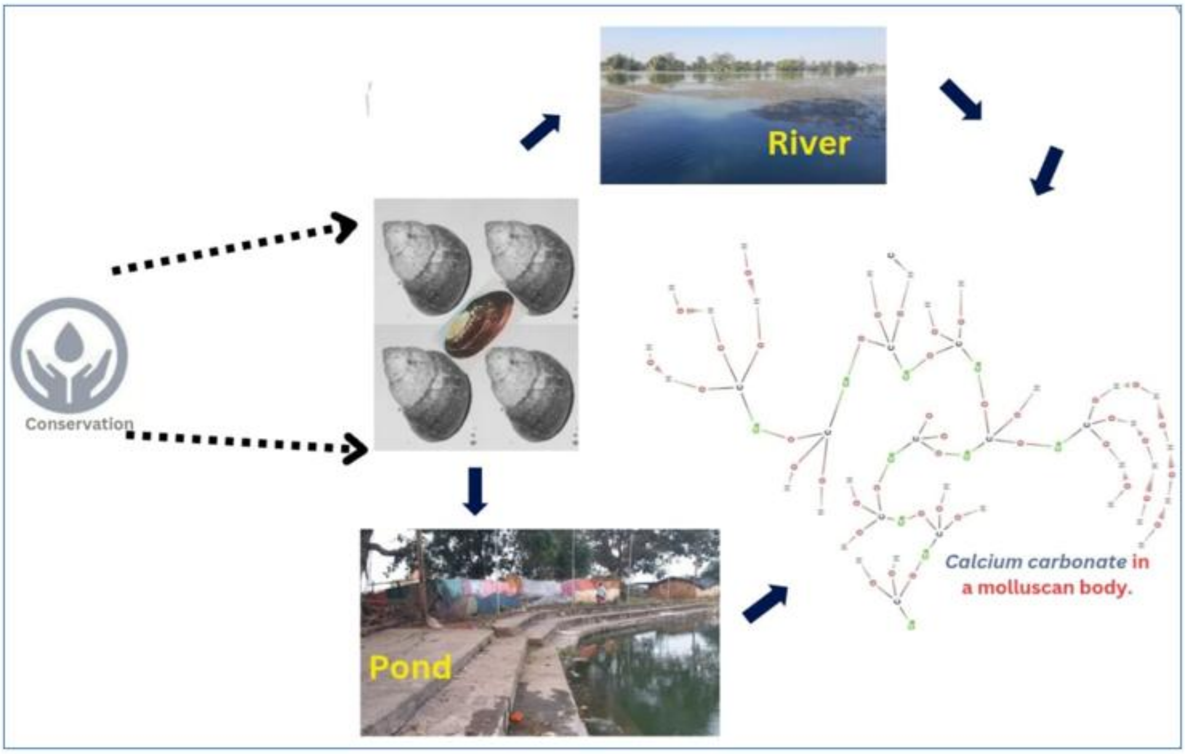

Fig 01: Graphical Abstract

The variety in Molluscan species reflects the heterogeneity of these habitats, which are shaped by water quality, substrate type, vegetation cover, and flow regimes [8]. However, the balance within riverine ecosystems is increasingly disrupted by anthropogenic activities such as industrialization, agriculture, urbanization, and climate change [9]. Habitat loss, pollution (e.g., heavy metals, pesticides, and nutrient runoff), and the alteration of natural flow patterns can lead to significant declines in molluscan diversity [10]. In some cases, species that once thrived in particular river segments are now endangered or extinct [11]. Consequently, the loss of molluscan species can have cascading effects on river ecosystems, including reduced water quality, altered nutrient dynamics, and destabilized food webs [12]. Therefore, understanding the status of molluscan diversity and the implications of its decline is crucial for effective conservation strategies [13]. This review aims to explore the significance of molluscan diversity in riverine ecosystems, emphasizing their role in maintaining ecosystem health and the potential consequences of their decline [14]. The review will examine the various factors influencing molluscan populations in rivers, such as water quality, habitat structure, and human impact [15]. Furthermore, the paper will highlight the importance of conserving molluscan species and their habitats, proposing potential management strategies to safeguard these vital organisms [16]. By focusing on the implications of molluscan diversity for conservation and ecosystem health, this review underscores the need for a holistic approach to riverine habitat management, one that integrates biodiversity conservation with sustainable ecosystem functioning [17].

2. REVIEW OF LITERATURE

Ethnoecological studies have demonstrated the impacts that even relatively small-scale human foraging has on targeted species of shellfish and the structure of biological communities in intertidal zones. There is compelling archaeological evidence that people in various parts of the world often had a depleting effect on shellfish populations. Shellfish and other marine resources have sometimes been perceived as lowly ranked foods and coastal archaeological sites have often been interpreted as temporary (possibly seasonal) sites for the exploitation of these 'inferior' food resources. This model has been challenged by studies of mid-Holocene Mesolithic hunter-gatherer sites in Atlantic Europe, which have shown that marine foods were the main component of the total diet and that human foraging can deplete shellfish resources [18].

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The caenogastropod component dominates in terms of species richness and diversity of morphology, physiology, life and reproductive modes and has produced several highly speciose endemic radiations. Ancient oligotrophic lakes (e.g., Baikal, Ohrid, Tanganyika) are key hotspots of gastropod diversity; also noteworthy are a number of lower river basins (e.g., Congo, Mekong, Mobile Bay). But unlike many other invertebrates, small streams, springs and groundwater systems have produced the most speciose associations of freshwater gastropods. Despite their ecological importance in many aquatic ecosystems, understanding of even their systematics is discouragingly incomplete. The world's freshwater gastropod fauna faces unprecedented threats from habitat loss and degradation and introduced fishes and other pests Strong [19].

Many shellfish species are consumed by finfish or other vertebrate and invertebrate predators (e.g., mammals, birds, finfish, other molluscs). Some shellfish support major commercial and recreational fisheries, and a subset create important habitats, particularly when they occur at high densities. The habitats created by molluscs can be classified into three major types: (1) reefs (veneer of living and dead animals), (2) aggregations (living and dead), and (3) shell (dead) accumulations (often called 'shell hash'). Some habitats can be grouped into either category 2 or 3, depending on the relative abundance of dead shell versus live organisms [20].

Invertebrate species represent more than 99% of animal diversity; however, they receive much less publicity and attract disproportionately minor research effort relative to vertebrates. Nonmarine mollusks (i.e., terrestrial and freshwater) are one of the most diverse and imperiled groups of animals, although not many people other than a few specialists who study the group seem to be aware of their plight. Nonmarine mollusks include a number of phylogenetically disparate lineages and species-rich assemblages that represent two molluscan classes, Bivalvia (clams and mussels) and Gastropoda (snails, slugs, and limpets). In this article we provide an overview of global nonmarine molluscan biodiversity and conservation status, including several case studies documenting the diversity and global decline of nonmarine mollusks. [21].

Molluscs constitute the second largest phylum in terms of the number of described species and possess a wide array of characteristics and adaptations for living in marine, terrestrial, and freshwater habitats. They are morphologically diverse and appear in the fossil record as far back as the early Cambrian (∼560 mybp). Despite their high diversity and long evolutionary history, molluscs are often underused as models for the study of general aspects of evolutionary biology. Freshwater snails in the family Ampullariidae have a global tropical and subtropical distribution and high diversity with more than 150 species in nine currently recognized genera, making them an ideal group to address questions of historical biogeography and some of the underlying mechanisms of speciation. They exhibit a wide range of morphological, behavioral, and physiological adaptations that have probably played a role in the processes of diversification. [22].

The Lower Mekong Basin (LMB) is a key biodiversity hotspot. To facilitate conservation and management, we examine mollusc biodiversity patterns and distribution along LMB's longitudinal gradients, identify environmental drivers, and discuss the importance of these drivers to management. Cluster analysis, redundancy analysis (RDA), and variation partitioning were conducted using mollusc data collected from 63 sampling sites. Results indicated that species diversity is dominated by gastropods (61%) and bivalves (39%) and feeding trait diversity by scrapers (52%) and filter-collectors (37%). Only 48 species (49%) out of 98 taxa have been assessed by the International Union for Conservation of Nature (IUCN) including a growing number of invasive species. The lack of complete, up-to-date information highlights the need for more research on both native and alien species. Cluster analysis revealed a clear mollusc biodiversity structure along the LMB's longitudinal segments [23].

Riverine floodplains are regarded as one of the most heterogenous and dynamic ecosystems. In natural state they encompass a variety of wetland sites like pools, lakes, channels etc. related and linked with the flood pulses; being the hot spots of high and specific biodiversity they are often under protection. The diversity and abundance of molluscs in the floodplain water bodies were investigated in order to find the shaping impact of chemical factors of water and sediments. The water bodies were located within 140 km section of the lower Bug River valley (eastern Poland, 190 to 50 km of the river course).

The investigations were carried out in the years 2007–2009 in 25 permanently flooded, 25 semi-permanent sites (i.e. habitats partly dried-up because the water volume has decreased significantly during low river discharge) and 24 temporary water bodies holding water for at least few months (up to 8–9 months) [24].

Beginning in 2011, the Freshwater Mollusk Conservation Society began updating that strategy, including broadening the scope to include freshwater snails. Although both strategy documents contained 10 issues that were deemed priorities for mollusk conservation, the identity of these issues has changed. For example, some issues (e.g., controlling dreissenid mussels, technology to propagate and reintroduce mussels, techniques to translocate adult mussels) were identified in the 1998 strategy, but are less prominent in the revised strategy, due to changing priorities and progress that has been made on these issues. In contrast, some issues (e.g., biology, ecology, habitat, funding) remain prominent concerns facing mollusk conservation in both strategies. In addition, the revised strategy contains a few issues (e.g., newly emerging stressors, education and training of the next generation of resource managers) that were not explicitly present in the 1998 strategy Freshwater Mollusk Conservation Society [25].

The present communication is aimed at assessing the molluscan diversity and distribution under the impact of some physico-chemical variables on them in Gho-Manhasan stream (a distributory of Chenab), Jammu (J & K). The study involved bottom sampling for 12 months (June, 2010 to July, 2011) from the banks of the stream and registered a total of 11 taxa of freshwater molluscs from class Gastropoda and Bivalvia representing 54.453 and 45.546% of the total population of molluscs. Numerically, Pissidium mitchelli (Bivalvia) was the most abundant taxa followed by Melanoides tuberculata (Gastropoda). Lymnea luteola, Bellamya bengalensis, Physella acuta, Gyraulus ladacensis showed less frequent appearance whereas Lamellidens corrianus and Corbicula cashmeriensis were recorded as rare taxa. Analysis of the data revealed that the physico-chemistry of the stream exercised profound effect on the diversity and distribution of the malacofauna. Significant changes in molluscan assemblages were primarily due to changes in the stream water quality. Coefficient of correlation (r) between molluscs and physico-chemical parameters revealed significant relationship with bivalves [26].

River estuaries are important aquatic environments characterized by large environmental gradients in their water quality, riverbed material, and microtopography in the longitudinal and transverse directions. The geography or habitats in river estuaries differ depending on the energy from the tide, waves, and river; therefore, the biota inhabiting river estuaries vary depending on the river estuary type. In view of this, for effective conservation in river estuaries, there is a need for information about potential habitats and biota based on objective data about the river estuary type. The objective of this study thus was to classify river estuaries by their molluscan fauna and physical indicators to reveal the relationship between molluscan fauna and the physical environment. The classification results using physical indicators indicated three types of river estuaries (wave energy-dominated group, tide energy-dominated group, and low tide and wave energy group) [27].

Freshwater molluscs (bivalves and gastropods) are found in a wide range of freshwater habitats, have varied life-history strategies and exhibit complex ecological interactions, all of which underscore their use as proxies for understanding our changing freshwater diversity. In general, the freshwater molluscs of Africa are less diverse than some continental faunas such as in North America and Europe, with only an estimated 560 species compared to around 880 species for North America and around 1,540 species for the Palaearctic (of which there are about 780 European species) (Seddon pers. comm.; Bogan 2008). Freshwater molluscs fall into two main groups, the Bivalvia and the Gastropoda, with the latter dividing into two informal groups, the prosobranchs and the pulmonates. The Bivalvia are less numerous than the Gastropoda, with the pulmonates containing a higher proportion of the widespread, more cosmopolitan species. Most research efforts in recent years have, however, concentrated on the freshwater Unionid mussels and the prosobranchs [28].

In sediment cores spanning ~500 years of history in the Gulf of Trieste, down-core changes in molluscan community structure are characterized by marked shifts in species and functional composition. Between the 16th and 19th century, a strong heavy metal contamination of the sediments, most notably by Hg, together with the effects of natural climatic oscillations (increased sedimentation and organic enrichment) drive community changes.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Since the early 20th century up to 2013, the combined impacts of cultural eutrophication, frequent hypoxic events and intensifying bottom trawling replace heavy metal contamination and climatic factors as the main drivers. The pollution-tolerant and opportunistic bivalve Corbula gibba and the scavenging gastropod Nassarius pygmaeus significantly increase in abundance during the 20th century, while species more sensitive to disturbances and hypoxia such as Turritella communis and Kurtiella bidentata become rare or absent. An infaunal life habit and scavenging emerge as the dominant life strategies during the late 20th century [29].

Identification of ecosystem services, i.e. the contributions that ecosystems make to human well-being, has proven instrumental in galvanising public and political support for safeguarding biodiversity and its benefits to people. Here we synthesise the global evidence on ecosystem services provided and disrupted by freshwater bivalves, a heterogenous group of >1200 species, including some of the most threatened (in Unionida) and invasive (e.g. Dreissena polymorpha) taxa globally. Our systematic literature review resulted in a data set of 904 records from 69 countries relating to 24 classes of provisioning (N = 189), cultural (N = 491) and regulating (N = 224) services following the Common International Classification of Ecosystem Services (CICES). Prominent ecosystem services included (i) the provisioning of food, materials and medicinal products, (ii) knowledge acquisition (e.g. on water quality, past environments and historical societies), ornamental and other cultural contributions, and (iii) the filtration, sequestration, storage and/or transformation of biological and physico-chemical water properties [30].

Molluscs are among the most diverse and widespread animal groups in freshwater habitats. Unfortunately, like most freshwater taxa, they are decreasing dramatically and are now among the most threatened animals on Earth, with many species already extinct or on the brink of extinction. Here, we review our current knowledge on the biodiversity and conservation of freshwater molluscs using the concept of knowledge shortfalls. We focus on seven previously proposed key shortfalls to review and analyse existing knowledge gaps relating to (1) taxonomy, the Linnean Shortfall; (2) distribution, the Wallacean Shortfall; (3) abundance and population dynamics, the Prestonian Shortfall: (4) evolution, the Darwinian Shortfall; (5) abiotic tolerances, the Hutchinsonian Shortfall; (6) traits, the Raunkiaeran Shortfall; and (7) biotic interactions, the Eltonian Shortfall.
In addition, we address a new shortfall, which relates to the application and effectiveness of conservation measures, including assessments, methods, funding, and policies [31].

Ganga basin is the largest river basin in India in terms of the catchment area, constituting more than 20% of the country's landmass and supporting about more than 40% of its population. This mighty river is the home for some of the rarest and strangest animals on the planet. Previous documentations on the diversity of Himalayan rivers show that they are increasingly vulnerable to a wide variety of anthropogenic activities. The faunal components of the river, both invertebrates and vertebrates have been stressed due to a variety of reasons. Macroinvertebrates such as molluscs are a significant component of the riverine resources which also have a major role in maintaining the ecosystem health. As per studies conducted from November 2020 to October 2021, diversity of freshwater molluscs in this river has been recorded as 12 bivalves and ten gastropods. In this review impacts of major threats to Ganga river molluscs such as low water level, habitat destruction, agricultural runoff and pollution, over-harvesting, dams, urban development and sand mining have been discussed [32].

Ecosystems provide essential services to people including food, water, climate regulation, and aesthetic experiences. Biodiversity can enhance and stabilize ecosystem function and the resulting services natural systems provide. Freshwater mollusks are a diverse group that provide a variety of ecosystem services through their feeding habits (e.g., filter feeding, grazing), top-down and bottom-up effects on food webs, provisioning of habitat, use as a food resource by people, and cultural importance.

Research focused on quantifying the direct and indirect ways mollusks influence ecosystem services may help inform policy makers and the public about the value of mollusk communities to society. The Freshwater Mollusk Conservation Society highlighted the need to evaluate mollusk ecosystem services in their 2016 National Strategy for the Conservation of Native Freshwater Mollusks, and, while significant progress has been made, considerable work remains across the research, management, and outreach communities. We briefly review the global status of native freshwater mollusks, assess the current state of knowledge regarding their ecosystem services, and highlight recent advances and knowledge gaps to guide further research and conservation actions.

ISSN: 2277-9655
Impact Factor: 5.164
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Our intention is to provide ecologists, conservationists, economists, and social scientists with information to improve science-based consideration of the social, ecological, and economic value of mollusk communities to healthy aquatic systems [33].

The increasing trend of eco-degradation of the different landscapes of the world, mostly because of human-mediated pollution has emerged as a burning environmental issue across the globe. This has necessitated to undertake sustainable eco-management in order not only to achieve proper eco-restoration of the disturbed and degraded ecosystems but also to ensure a continuous supply of ecosystem services. The embedded complexity and dynamism of the ecological problems of the riverine ecosystem require an in-depth analysis to achieve flexible, transparent, and viable environmental planning and management approaches incorporating and integrating a diversity of knowledge and values. Both the biomonitoring (an important component of eco-monitoring) and bioremediation (an integral part of any eco-restoration effort) help achieving the goal of sustainability of the functioning of the river ecosystem [34].

The Exclusive Economic Zone (EEZ) of Qatar is a rapidly developing region within the Arabian Gulf, where monitoring of changes in benthic biodiversity and its functioning is needed. The influence of mangroves and seasonality on the nearshore subtidal molluscan diversity at three distinct khors (nearshore tidal bays) – natural mangroves (Al Dhakhira), planted mangroves (Al Mafyar) and no-mangroves (Dawhat Zekreet) – are investigated in this study. This study concludes that even the sub-tidal area is influenced by mangroves, and mangroves increase the diversity of molluscs compared to the site that lacks mangroves.

The maximum salinity (59.8 psu) was observed at Dawhat Zekreet during summer, and the minimum (41.44 psu) at Al Dhakhira in winter. Chlorophyll a level was low for all the khors, and rarely exceeded 1 μg/L, depicting oligotrophic waters. Al Dhakhira demonstrated the highest molluscan species richness (32), and shared 28 species in common with Al Mafyar. Dawhat Zekreet had the fewest mollusc species number and no mangroves. When cumulative diversity over all seasons was considered, Dawhat Zekreet exhibited the lowest species richness; Al Dhakhira, the highest. Some mangrove regions have been already utilized for developmental activities, and Qatar needs to continue the program of mangrove conservation as a vital habitat for molluscs [35].

The concurrent impact of anthropogenic and bioclimatic factors on biodiversity is a key focus in macroecological and biogeographical considerations in conservation programs within riverine ecosystems. However, there is still a lack of understanding about how multidimensional alpha and beta diversity measures respond to anthropogenic and bioclimatic drivers. Here, we assess the variations in taxonomic, phylogenetic, and functional alpha and beta diversity of riverine macroinvertebrate communities across different watersheds in China. Our results show significant declines in most facets of alpha diversity across watersheds with low environmental heterogeneity, reflecting the loss of species with unique traits and evolutionary legacies. Both functional and phylogenetic beta-diversity values reveal a decreasing pattern along low heterogeneity environments, whereas taxonomic beta-diversity shows a contrasting pattern, which highlights the influence of microhabitat variation [36].

The survey aimed to evaluate the diversity of freshwater molluscs within the Gomti River. Near Saidpur, a village situated in the Jaunpur district of Uttar Pradesh, the Gomti River converges with the Ganga River, with approximate coordinates of around 25.7355° N latitude and 82.6853° E longitude. Despite its ecological significance, this riverine system remains largely understudied, particularly regarding information on its molluscan fauna. Throughout the present investigation, a total of 9 molluscan species were documented within the Gomti River. Among the collected specimens, these 9 species were identified across seven families, namely Viviparidae, Ampullariidae, Assimineidae, Pachychilidae, Lymnaeidae, Planorbidae, and Unionidae, encompassing both the Gastropoda and Bivalve classes. The molluscan community observed in this habitat holds promise as effective bio-indicators for assessing the ecological diversity of freshwater environments [37, 38].

3. CONCLUSION:

Mollusks play an essential and often underestimated role in maintaining the health and functionality of riverine ecosystems. Their contributions to nutrient cycling, sediment stabilization, food webs, and as bioindicators of environmental changes highlight their ecological importance. However, the growing threats from anthropogenic activities such as pollution, habitat destruction, and climate change are significantly impacting molluscan diversity, with potential cascading effects on river ecosystems. The decline of these species not only signals

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

broader ecological issues but also disrupts critical ecosystem services, such as water filtration and nutrient recycling.Therefore, it is crucial to prioritize the conservation of mollusks and their habitats. Effective management strategies, including habitat restoration, pollution control, and species monitoring, are essential to safeguard these vital organisms and preserve the overall health of river ecosystems. A holistic, integrated approach to riverine management will enhance biodiversity conservation, strengthen ecosystem resilience, and ensure the long-term sustainability of these critical freshwater habitats.

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