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Ecosystem engineering by the freshwater crab *Barytelphusa cunicularis*: Implications for nutrient cycling, habitat modification, and biodiversity conservation

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Abstract
Freshwater crabs play an important ecological role in maintaining the structure and functioning of aquatic and terrestrial ecosystems. Among these, *Barytelphusa cunicularis* is an ecologically significant freshwater crab distributed across parts of the Indian subcontinent. Through its burrowing, feeding, and sediment-disturbing activities, this species functions as an ecosystem engineer by modifying physical habitats and influencing important ecological processes. Burrowing and bioturbation enhance soil aeration, water infiltration, sediment turnover, and the decomposition of organic matter. Its feeding activities contribute to nutrient transformation and recycling, facilitating the availability of essential nutrients within the ecosystem. Crab burrows and modified substrates also provide shelter, breeding sites, and microhabitats for various aquatic and terrestrial organisms, thereby contributing to habitat heterogeneity and biodiversity. Despite these ecological functions, the ecosystem-engineering role of *B. cunicularis* remains comparatively understudied. This chapter reviews the available knowledge on the ecological significance of *B. cunicularis*, with particular emphasis on habitat modification, nutrient cycling, decomposition, soil and sediment processes, and biodiversity enhancement. It further highlights the threats faced by freshwater crabs, including habitat degradation, water pollution, overexploitation, and environmental changes. Understanding and conserving *B. cunicularis* and other freshwater crabs is therefore essential for maintaining ecosystem health, ecological stability, and biodiversity in freshwater and associated terrestrial habitats. statistical analyses were performed using the measurements of 12 burrow openings of *Barytelphusa cunicularis*. Major diameter, minor diameter and surface area of each burrow opening were summarized using mean, standard deviation, median, minimum and maximum values. Pearson's correlation coefficient (r) was calculated to determine the relationships among major diameter, minor diameter and burrow-opening surface area.

Keywords: Ecosystem engineering, freshwater crab, nutrient cycling, bioturbation, burrowing activity, habitat modification, biodiversity conservation, freshwater ecosystems

Introduction

Freshwater ecosystems are complex and dynamic environments that support diverse biological communities and provide essential ecological services such as nutrient cycling, decomposition, sediment transformation, water regulation, and habitat formation. Freshwater crabs (Crustacea: Decapoda: Brachyura) are important components of these ecosystems and occur in rivers, streams, lakes, wetlands, marshes, and semi-aquatic habitats. They contribute to food-web interactions, organic matter processing, nutrient transfer, and habitat modification, while their diverse morphological, physiological, and ecological adaptations enable them to occupy a wide range of freshwater environments (Yeo *et al*., 2008; Ng *et al*., 2008) [2].

The ecological importance of freshwater crabs extends beyond their role as consumers and prey. Through burrowing, excavation, sediment movement, feeding, and redistribution of organic materials, crabs actively modify their surroundings. Organisms that modify the physical environment and consequently influence resource availability and habitat conditions are termed ecosystem engineers (Jones *et al*., 1994) [1]. In freshwater habitats, crab burrowing and sediment disturbance can alter sediment structure, aeration, moisture, water infiltration, and nutrient exchange, while crab-created burrows may provide microhabitats for microorganisms, insects, molluscs, amphibians, and other small organisms (Jones *et al*., 1994; Cumberlidge, 2011) [1, 2].

One of the major ecosystem functions associated with crab activity is bioturbation and sediment turnover. By constructing and maintaining burrows, crabs transport sediments, redistribute organic matter and nutrients, and influence microbial activity, decomposition, and nutrient exchange. Xie *et al*. (2022) [8] demonstrated the importance of crab-mediated sediment disturbance in ecosystem processes, supporting the broader significance of crabs as ecosystem engineers. Freshwater crabs also occupy important positions in aquatic food webs, consuming detritus, algae, plant material, microorganisms, and small organisms while serving as prey for fish, amphibians, reptiles, birds, and mammals. Through feeding, excretion, and decomposition, they contribute to energy flow and nutrient redistribution (Cumberlidge, 2011; Yeo *et al*., 2008) [2].

Crab burrows and modified sediments can further increase habitat complexity and environmental heterogeneity by creating differences in moisture, oxygen concentration, temperature, organic matter, and water movement. These conditions may provide shelter and resources for other organisms and influence species interactions and local biodiversity. Evidence from crab-modified habitats also indicates that crab activities can interact with other ecosystem engineers and affect resource availability and ecosystem processes (El-Hacen *et al*., 2019) [8].

However, the ecosystem-engineering functions of freshwater crabs are increasingly threatened by habitat destruction, pollution, agricultural runoff, domestic effluents, pesticides, river-flow alteration, land-use change, and climate change. Exposure to pollutants can affect crab physiology and ecological performance; for example, Maharajan *et al*. (2015) [4] reported significant histological alterations in *Paratelphusa jacquemontii* following exposure to chlorpyrifos and cypermethrin. Similarly, Theuerkauff *et al*. (2018) [7] demonstrated that domestic effluent can affect energetic, osmoregulatory, and redox processes in crabs. Climate and land-use changes may also alter freshwater-crab distribution, habitat suitability, reproduction, behaviour, and ecosystem functions (Geng *et al*., 2026) [6].

In India, freshwater crabs are distributed across rivers, streams, lakes, wetlands, agricultural landscapes, and associated terrestrial habitats. Recent studies have documented crab diversity, burrow morphology, and ecological significance in Indian freshwater ecosystems, highlighting the need for greater understanding of crab–habitat relationships (Gupta *et al*., 2025) [5]. Accurate taxonomy and knowledge of distribution are equally important for assessing population status, ecological functions, and conservation priorities (Yeo *et al*., 2008; Ng *et al*., 2008) [2].

The ecosystem-engineering concept therefore provides a valuable framework for understanding the functional importance of freshwater crabs. Their burrowing, sediment movement, feeding, and organic-matter redistribution can influence sediment turnover, nutrient cycling, decomposition, habitat formation, water movement, and biodiversity maintenance (Jones *et al*., 1994; Cumberlidge, 2011; Xie *et al*., 2022) [1, 2, 8]. Declining crab populations may consequently reduce bioturbation, habitat heterogeneity, and nutrient dynamics, whereas conservation of crab populations and their habitats may help maintain ecosystem functioning and resilience.

Despite growing recognition of their ecological importance, considerable gaps remain regarding freshwater-crab burrow architecture, sediment turnover, nutrient cycling, decomposition, feeding ecology, population dynamics, reproductive biology, species interactions, pollutant responses, and the effects of climate and land-use change. Therefore, freshwater crabs should be viewed not merely as inhabitants of freshwater ecosystems but as active ecological agents that modify habitats and influence ecosystem processes. Understanding these functions is essential for evaluating their ecological value and developing effective conservation and sustainable-management strategies (Jones *et al*., 1994; Cumberlidge, 2011) [1, 2].

Ecosystem Engineering: Concept and Significance

Ecosystem engineers are like the builders of the environment. They change the world around them by modifying their habitats in ways. There are two types of ecosystem engineers:

Autogenic Engineers

These are organisms that change their habitats just by growing and having a physical presence.

Allogenic Engineers

These organisms actually alter the materials around them to change their habitats. The *Barytelphusa cunicularis* is an example of an allogenic ecosystem engineer. It changes the sediment and soil around it by digging and eating. This changes the conditions of its habitat.

Digging and burrowing are important forms of ecosystem engineering in which animals physically modify soil, sediment, and habitat structure. Through excavation, organisms create tunnels, chambers, pits, mounds, and depressions that alter the physical and chemical properties of the environment. These modifications can influence water movement, aeration, nutrient distribution, temperature, organic matter decomposition, and the availability of shelter for other organisms.

Digging and Burrowing Activity

Many animals dig burrows for shelter, reproduction, feeding, protection from predators, and maintaining suitable temperature and moisture conditions. Burrowing organisms include crabs, earthworms, termites, ants, rodents, crayfish, and several other invertebrates.

During digging, soil or sediment is removed from deeper layers and deposited on the surface. This process causes bioturbation, or biological disturbance and mixing of sediments. It can substantially change the structure of the habitat.

Habitat Modification by Freshwater Crabs

Freshwater crabs are particularly important because their burrowing activities can modify both aquatic and terrestrial portions of freshwater ecosystems. A crab may excavate a burrow along stream banks, ponds, wetlands, agricultural fields, or moist soil near water bodies. Repeated excavation can change the surrounding soil and create small-scale differences in moisture, temperature, oxygen availability, and organic matter.

Effects of Digging on Soil and Sediment

Digging can produce several important physical changes:

a. **Increased aeration:** Burrowing introduces air into otherwise compact soil or sediment and may increase oxygen availability.
b. **Increased porosity:** The formation of tunnels and chambers creates additional spaces within the soil.
c. **Improved water infiltration:** Burrows can act as channels through which water moves into deeper soil layers.
d. **Sediment mixing:** Material from deeper layers may be brought to the surface, while surface organic material can enter deeper layers.
e. **Redistribution of organic matter:** Leaves, plant debris, and other organic materials may be transported into burrows and become available for microbial decomposition.

Creation of Microhabitats

One of the most significant consequences of digging is the creation of microhabitats. Burrows provide relatively protected environments with different conditions from the surrounding habitat.

Thus, the activities of a single ecosystem engineer can have effects on organisms that do not directly interact with the engineer.

Influence on Nutrient Cycling

Digging can contribute to nutrient cycling by moving organic matter and mineral particles between different soil or sediment layers. Burrowing can also influence microbial communities responsible for decomposition.

Table 1: Descriptions of habitat and habitat ecology of five different Sampling sites.

Habitat Site type	Godavari river (Dhangar Takli)	Godavari river (Vishnupuri dam)	Asna River (Sanvgi road)	Asna River (Pasadgaon)	Lendi River
▪ Coastal vegetation ▪ Lime stone ▪ Agricultural land around swamp	-- -- √	-- -- √	√ -- √	√ -- √	√ -- √
▪ Vegetations in the water ▪ Plant/ bushes ▪ Trees ▪ flowers	*Acacea* *Azadircta indica*	*Azadircta indica*	*Ipomea*	*Ipomea*	*Ipomea*
▪ Habitat features ▪ Stony margin ▪ Muddy margin ▪ Plant debris ▪ Animals/ birds	√ √ √	√ √ √	√ √ √	√ √ √	√ √ √
▪ Types of weeds ▪ *Chara* ▪ *Hydrilla*	√ √	√ √	√ --	√ --	-- --
Microhabitat occupied by Animals	Nematodes, insects and insect larvae, small molluscs, other crustaceans plant roots	Nematodes, insects and insect larvae, small molluscs, other crustaceans plant roots	Nematodes, insects and insect larvae, small molluscs, other crustaceans plant roots	Nematodes, insects and insect larvae, small molluscs, other crustaceans plant roots	Nematodes, insects and insect larvae, small molluscs, other crustaceans plant roots

Fig.a) POP cast structure of burrow Fig. b) POP structure a burrow

Fig. c) Measurement of burrow depth Fig. d) POP cast structure of burrow

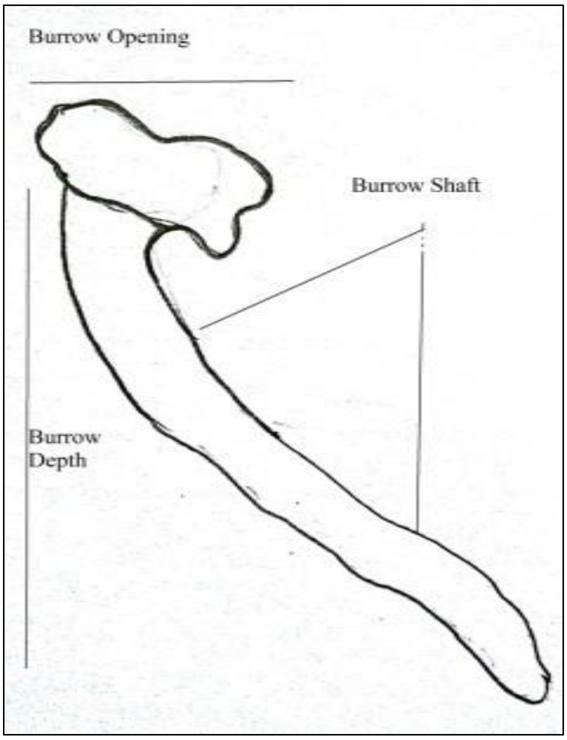

Fig. e) Sketching of burrow after excavation

Table 2: Burrow component with river description

Burrow Component	Description in the Godavari River Environment	Ecological Function
Entrance opening	The burrow begins with a visible opening on the riverbank, moist soil, muddy margins, or areas close to shallow water. The opening may vary in size depending on the crab's body size and soil conditions.	Provides access to the burrow and allows movement between the surface and underground habitat.
Tunnels	Narrow passages extend from the entrance into the soil or sediment. In the Godavari basin, these may occur in soft, moist, clayey or sandy-loamy substrates that are suitable for excavation.	Provide movement pathways and help the crab escape predators and unfavorable environmental conditions.
Chambers	Enlarged spaces may occur along the tunnel system where the crab can rest, remain inactive, or temporarily store food. Chambers are generally located below the exposed surface.	Provide protected resting and sheltering sites and help maintain a relatively stable microenvironment.
Branching passages	Some burrows may develop secondary passages or branches connecting different sections of the burrow system. Their development depends on soil texture, moisture, vegetation, and the crab's activity.	Increase the complexity of the habitat and provide alternative routes for movement and escape.
Deeper sections	The burrow may extend deeper into moist soil, particularly during periods of high temperature or reduced surface moisture. These sections provide protection from drying and extreme temperature fluctuations.	Maintain a more stable microclimate and provide refuge during drought, heat, flooding, or other unfavorable conditions.
Burrow walls and excavated soil	Excavation loosens and redistributes soil around the burrow entrance. The disturbed sediment may differ from the surrounding substrate in aeration, moisture, and organic matter.	Promotes bioturbation, soil aeration, sediment turnover, and nutrient redistribution.
Burrow-associated microhabitat	Moist soil, organic debris, roots, microorganisms, and small invertebrates may occur around or within the burrow environment.	Creates habitat heterogeneity and potentially provides shelter or resources for other organisms.

Table 3: Crab Burrow opening with surface area measured

Cast Number	Burrow opening (Cm)		Surface area of opening (cm^2)
	Major	Minor	
BC 1	5.1	4.5	18.01
BC 2	6.0	5.1	24.02
BC 3	4.5	3.7	13.07
BC 4	5.5	4.1	17.70
BC 5	5.2	4.9	20.00
BC 6	3.9	2.6	7.95
BC 7	5.1	4.9	19.61
BC 8	4.6	3.8	13.72
BC 9	4.7	3.9	14.38
BC 10	3.7	3.6	10.45
BC 11	5.8	4.6	20.94
BC 12	5.2	4.8	19.59

Table 4: Descriptive statistics

Variable	n	Mean ± SD (cm/cm²)	Median	Minimum	Maximum
Major diameter	12	4.94 ± 0.70 cm	5.10	3.70	6.00
Minor diameter	12	4.21 ± 0.73 cm	4.30	2.60	5.10
Surface area	12	16.62 ± 4.72 cm²	16.09	7.95	24.02

Table 5: Pearson correlation analysis

Variables	Pearson's r	p-value	Strength
Major diameter × Minor diameter	0.819	0.0011	Strong positive
Major diameter × Surface area	0.947	<0.001	Very strong positive
Minor diameter × Surface area	0.956	<0.001	Very strong positive

There is a strong positive correlation between major and minor diameters ($r = 0.819$, $p = 0.001$).
Major diameter has a very strong positive correlation with surface area ($r = 0.947$, $p < 0.001$).
Minor diameter has an even slightly stronger very strong positive correlation with surface area ($r = 0.956$, $p < 0.001$).
This means that larger burrow openings tend to have greater surface areas.

Discussion

The present study demonstrates that *Barytelphusa cunicularis* may function as an important ecosystem engineer through its burrowing, excavation, and sediment-disturbance activities. The construction of burrows modifies sediment structure and creates localized variations in moisture, aeration, organic matter, and nutrient availability. Such bioturbation can enhance sediment turnover and potentially promote decomposition and nutrient cycling. The observed relationships among burrow dimensions further indicate that burrow architecture is closely associated with crab size and excavation activity. These modifications may increase habitat heterogeneity and provide suitable microhabitats for microorganisms and other benthic organisms. Thus, the ecological role of *B. cunicularis* extends beyond its position in the food web, highlighting its potential importance in maintaining sediment dynamics, biodiversity, and overall ecosystem functioning in freshwater habitats.

Conclusion

Barytelphusa cunicularis plays a role in many freshwater and wetland ecosystems in India. This crab species digs burrows helps in sediment reworking breaks down matter and interacts with other species in the food chain. These activities have an impact on how nutrients are cycled how habitats are structured and how diverse the species are in these ecosystems. The crabs' actions also help to bring oxygen into the soil make nutrients more available allow water to seep into the ground and create a variety of habitats. All these helps to make the ecosystem more productive and able to withstand disturbances. So, it is crucial to protect *Barytelphusa cunicularis* and its habitats not to save the species but also to keep freshwater ecosystems healthy and sustainable. Conserving *Barytelphusa cunicularis* populations is essential, for maintaining the balance and sustainability of freshwater ecosystems. The *Barytelphusa cunicularis* helps to maintain the heal th of freshwater ecosystems and its conservation is vital

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