

Intertidal Bivalve and Gastropod Shell Morphology: Feasibility as Dry Specimens for Invertebrate Systematics Learning

Yudhistian, Zainul Mustofa, Tabitha Sri Hartati Wulandari*

Biology Education Department, Teacher Training and Education Faculty, Universitas PGRI Ronggolawe, Tuban, Indonesia.

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Corresponding Author:

Tabitha Sri Hartati Wulandari

tabithawulandari7@gmail.com

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Abstract: Invertebrate Systematics learning requires physical specimens, as digital media often fail to capture complete morphological traits. Addressing this limitation, this study aims to explore and characterize Bivalve and Gastropod shells from the Gadon coast to evaluate their feasibility as dry learning specimens. This evaluation employed a qualitative, exploratory design, utilizing purposive sampling to assess morphotype feasibility based on four indicators: structural integrity, diagnostic visibility, handling safety, and taxonomic authenticity. The assessment identified 22 species (15 Bivalves and 7 Gastropods) with varying feasibility levels. The feasibility variations demonstrated that thick-shelled specimens safely supported direct tactile observation, whereas spiny morphotypes required transparent resin casting to prevent injury. These findings explicitly present a novel framework for transforming neglected local coastal resources into standardized taxonomic media, effectively overcoming the reliance on scarce museum collections. By integrating conchological characterization with pedagogical safety standards, this research provides biology educators with a practical, replicable protocol to independently develop authentic and safe learning materials.

Keywords: Bivalve; Dry specimens; Gastropod; Intertidal zone; Invertebrate systematics

Introduction

Tropical intertidal ecosystems face continuous extreme physicochemical fluctuations (Horn et al., 2021; Zardi et al., 2024). Environmental fluctuations trigger global ecological pressures that require coastal organisms to adapt (Martínez-Ruiz et al., 2025). These ecological pressures are empirically represented in the intertidal zone of the northern coast of Gadon, Tuban. This coast exhibits substrate dynamics, salinity, and wave currents that reflect the conditions of tropical coastal ecosystems worldwide (Jesús-Carrillo et al., 2021; Li et al., 2025). Dynamic water conditions make the area a representative natural laboratory that stores valuable local potential, such as Bivalvia and Gastropod shells with unique morphological characteristics (C et al., 2024; Martínez-Ruiz et al., 2025).

Shell morphological characteristics are a form of evolutionary adaptation in the phylum Mollusca to the intertidal environment (Quiroz-Barroso et al., 2024). This adaptation is evident in Bivalvia and Gastropoda (Quiroz-Barroso et al., 2024; Vasconcelos et al., 2022). Both are the largest classes in the phylum Mollusca (Nge et al., 2023; Zardus, 2025). These taxa respond to coastal environmental pressures by modifying shell thickness, ornamentation, and geometry (Martínez-Ruiz et al., 2025; Vasconcelos et al., 2022). These physical structural modifications create high phenotypic variation (Martínez-Ruiz et al., 2025; Vasconcelos et al., 2020). This high variation represents a rich ecological track record of species (Quiroz-Barroso et al., 2024). This physical track record, in the form of a hard shell, holds great potential as authentic biological material for academic

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purposes. The use of this authentic material is relevant to learning needs in Invertebrate Systematics.

Invertebrate Systematics learning requires a spatial understanding of taxonomy and comparative morphology (Labranche et al., 2022). This spatial understanding is difficult to master when students rely solely on conventional textbooks, 2D illustrations, or emerging 3D printed replicas (Andić et al., 2024; Gul & Yalinkilic, 2025; Labranche et al., 2022; Miao et al., 2023; Renna et al., 2024). However, these 3D innovations present limitations in local contexts, including high implementation costs, restricted technology accessibility in local laboratories, and the loss of authentic local materials. Biology students need direct interaction with real physical objects to comprehensively dissect diagnostic characters (Renna et al., 2024). This need can be met through alternative learning media, such as dry specimens, which represent the original form in a stable, durable, and precisely (Daniel & Kukor, 2024). Direct interaction with these authentic materials facilitates students' mastery of taxonomic identification and classification (Labranche et al., 2022; Renna et al., 2024).

While previous studies have examined mollusk shells extensively, most have focused on their use as ecological indicators or economic commodities (Chahouri et al., 2023; C et al., 2024; Ibrahim et al., 2025; Makwarela et al., 2025; Potorti et al., 2024). The majority of conventional morphological research generally limits the results of exploration to merely an inventory of taxonomic species. This limitation ignores the strategic potential of local Bivalvia and Gastropod shells to overcome the scarcity of physical specimens in Invertebrate Systematics learning (Beck et al., 2014; Spence, 2022). The scarcity of authentic physical specimens in university biology laboratories remains a real structural obstacle in the development of students' taxonomic observation skills (Daniel & Kukor, 2024). Without such collections, students lose access to fundamental learning experiences (Price et al., 2020).

Addressing this gap constitutes the urgency of the present study, which proposes converting naturally occurring morphological materials from rich coastal ecosystems into standardized academic specimens. However, this natural richness remains rarely optimally explored, as is the case in the intertidal zone of the northern coast of Gadon, an area rich in the natural potential of Bivalve and Gastropod shells. Furthermore, classification mastery requires an understanding of phenotypic plasticity to prevent confusion when encountering non-standard morphological forms. Therefore, utilizing highly variable specimens from stressed habitats like the northern coast of Gadon trains students to accurately distinguish environmental adaptations from fundamental diagnostic characters, fostering a deeper understanding of taxonomy.

Given this urgency, this research establishes its novelty by directly converting local ecosystem resources into academic-standard specimens rather than substituting them with technological replicas. Utilizing these physical resources is critically important because it guarantees that students physically interact with real organisms to master complex morphological concepts. To facilitate this authentic interaction, the study explores and characterizes Bivalve and Gastropod shells from the northern coast of Gadon. By characterizing these local shells, the research firmly validates their feasibility as dry specimens learning media for the Invertebrate Systematics course. Thus, the formulation of the research problem is: what is the morphology of Bivalvia and Gastropod shells in the intertidal zone of the northern coast of Gadon?; and how is their feasibility as dry specimens in Invertebrate Systematics learning? In line with this formulation, the research aims to explore and characterize the morphology of the shells of the two classes while examining their feasibility as dry specimens in Invertebrate Systematics learning.

Method

This study employed a qualitative, exploratory design, focusing on in-depth observations of the shell morphology of bivalves and gastropods on the northern coast of Gadon to identify the diagnostic morphological characteristics of the specimens. The observed diagnostic characters were then evaluated for their feasibility as dry specimens.

The research was conducted in the intertidal zone of the northern coast of Gadon, Tuban Regency (Figure 1). The location was selected based on the oceanographic dynamics of the waters that support mollusk habitats. The intertidal habitat was observed at the lowest tide to facilitate researchers' access to the bottom substrate and direct exploration of specimens.

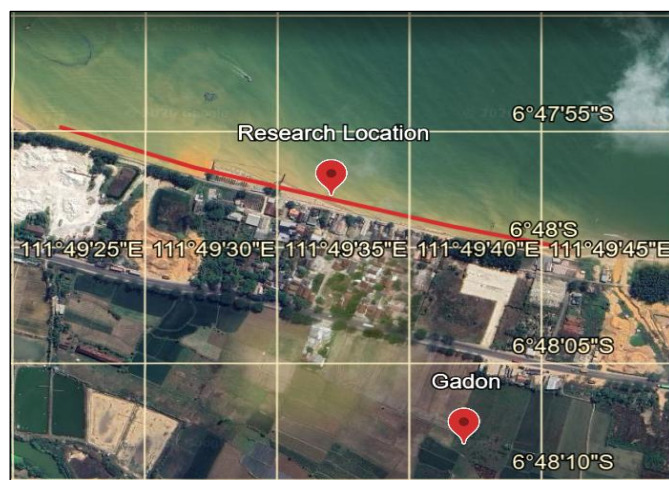


Figure 1. Research location

The main research object includes intact shells from the classes Bivalvia and Gastropoda. Representative specimens were collected using an exploratory survey method combined with purposive sampling. Each selected specimen represents a “holotype-like” morphotype, chosen specifically because it possesses the most complete and intact diagnostic characters for that species. While the study site exhibits high phenotypic variation due to environmental pressures, this research focuses on establishing a standardized baseline of

diagnostic characters through these representative specimens. Consequently, the selected specimens act as primary benchmarks for students to identify foundational taxonomic features, which serves as a necessary prerequisite before students further explore more complex, environmentally induced morphological variations. The research implemented a series of systematic procedural steps, as shown in the flowchart in Figure 2.

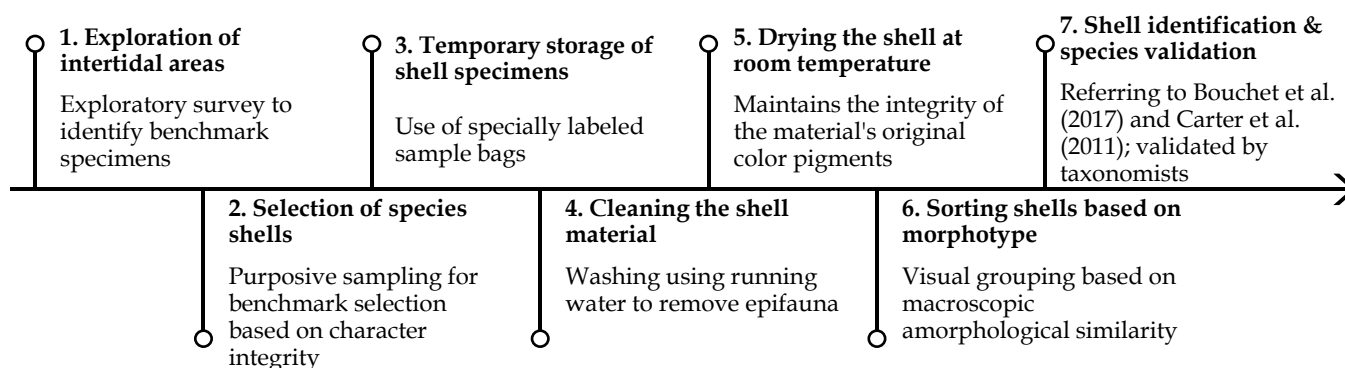


Figure 2. Procedural stages of research

Identification and validation of taxon status for specimens follow the Gastropoda taxonomic guide by Bouchet et al. (2017) and the Bivalvia determination key by Carter et al. (2011). Validated specimens were then analyzed for their macroscopic and comprehensive morphological structure. Diagnostic characters of the class Bivalvia include geometric shape, umbo position, hinge-tooth architecture, and surface ornamentation type. Meanwhile, the morphological analysis of Gastropoda focused on spire elevation, aperture shape, ornamentation type, and shell rotation direction. All physical characteristics were recorded visually into a description matrix and scaled macro photography to ensure data precision.

The description matrix, along with the physical specimens, serves as the basis for assessing the feasibility of the shells as learning media. The feasibility analysis examines each specimen based on four standardized indicators for biological learning media, which were developed and validated by an expert in Invertebrate Systematics to ensure scientific rigour and pedagogical relevance. These indicators include: structural integrity (resistance of shell material to mechanical degradation), diagnostic visibility (tactile and visual clarity of key characters), handling safety (absence of sharp structures that pose a danger during practical work), and taxonomic authenticity (ability to perfectly represent the characteristics of the species). This feasibility analysis aims to map the morphological profile of the species that has the highest level of reliability as a representative physical learning media.

Result and Discussion

Exploration in the intertidal zone of the northern coast of Gadon yielded a diverse collection of mollusk shell specimens. The collection identified 22 species, including 15 from the class Bivalvia and 7 from the class Gastropoda. All identified species were then evaluated for their morphological characteristics to determine their feasibility as dry specimens.

Morphological Characterization of Bivalve Shells

Exploration in the intertidal area of the northern coast of Gadon resulted in the collection of several specimens from the class Bivalvia in excellent physical condition. This facilitated a comprehensive characterization of the shell's external structure by recording the actual morphological variations in each species. The morphological variations of the collected specimens were visually documented through the macrophotographic collage in Figure 3, which was then sequentially mapped into the morphological characterization matrix in Table 1.

Macroscopic characterization reports diverse bivalve morphological profiles in Gadon, ranging from fragile architectures to massive armor forms. Massive armor forms are the primary defense strategy of mollusks in the high-energy intertidal zone (Wang et al., 2025a). This zone forces specimens to thicken their calcium carbonate material to respond to environmental stress and temperature fluctuations in shallow waters

(Marshall et al., 2026). This environmental response is clearly evident in the shells of *Anadara antiquata* and *Tegillarca granosa*. Both species use thick architecture to withstand the mechanical stress from ocean waves. The

impact of ocean waves demands absolute physical defense for organisms to settle safely on hard substrates (Hoerl et al., 2024).



Figure 3. Visualization of macroscopic characteristics of the shells of the class Bivalvia. The visualization presents the order of species: (1) *Mimachlamys sanguinea*; (2) *Donax faba*; (3) *Gafrarium tumidum*; (4) *Lioconcha castrensis*; (5) *Perna viridis*; (6) *Polymesoda erosa*; (7) *Saccostrea cucullata*; (8) *Mactra violacea*; (9) *Vasticardium flavum*; (10) *Dosinia exasperata*; (11) *Modiolus auriculatus*; (12) *Anadara antiquata*; (13) *Meretrix meretrix*; (14) *Anomalocardia squamosa*; and (15) *Tegillarca granosa*

Table 1. Morphological characterization matrix of the Bivalvia class shell

Species Name	Common Geometric Shapes	Umbo (Peak) Position	Exterior Ornament Type	Hinge Architecture (Hinge Teeth)	Edge Margin Thickness & Character	Color Pigmentation Pattern
<i>Mimachlamys sanguinea</i>	Auriculate (circular with asymmetrical "ear" projections)	Central orthogyrate (perpendicular)	Microscopic squamous radial costae	Modified isodont (uniform teeth)	Very thin, brittle; sharply wavy margins (scalloped)	Reddish brown polymorph with irregular white spots
<i>Donax faba</i>	Cuneiform (asymmetrical wedge-shaped, tapering posteriorly)	Sub-central points sharply posteriorly	Smooth surface with microscopic concentric striae	Modified heterodont (laterally elongated)	Solid; internal margin finely serrated (crenulate)	Faded purple gradation blends into porcelain white
<i>Gafrarium tumidum</i>	Thick sub-oval lenticular (double convex)	Sub-central prosogyrate (curved anteriorly)	Nodulose ornamentation (radial and concentric rib crossing)	Heterodont (three strongly divergent cardinal teeth)	Very thick solid; internal margins thickly serrated	Brownish cream decorated with dark transverse ribbons
<i>Lioconcha castrensis</i>	Ovate (ovoid) inflated (bulging)	Central prosogyrate prominent	Smooth surface with dense concentric growth lines	Heterodont (thick and sturdy cardinal)	Solid; internal margins are even and smooth	Creamy white background decorated with bold brown zigzag (chevron) motif
<i>Perna viridis</i>	Mytiliform (elongated like a water drop)	Extreme anterior terminal	Flat surface grooved with fine concentric growth lines	Dysodont (reduced to small protrusions/no teeth)	Moderate (prone to cracking); thin, sharp prismatic calcite edge	Bright malachite green fading to brownish in the umbo area
<i>Polymesoda erosa</i>	Sub-orbicular to sub-trigonal thick	Prosogyrate, sub-central position; prone to umbonal erosion	Rough irregular concentric lines with periostracum remnants	Heterodont (bifid cardinal)	Very thick massive; blunt flat margins	Jet black with a grayish abrasion zone in the dorsal area
<i>Saccostrea cucullata</i>	Xenomorph (asymmetrical irregularities following the topography of the substrate)	Flat blunt terminal free direction	Foliaceous lamella (irregular coarse layered structure)	Dysodontic expansion without true tooth structure	Solid but flaky; irregular margins	Dull gray with a faint purple tinge
<i>Macra violacea</i>	Thin equilateral trigonal (equilateral triangle)	Central orthogyrate pointed protruding upright	Very smooth surface glossy porcelain	Heterodont (inverted V-shaped cardinal/clear chondrophore)	Thin, brittle; very sharp, even margins	The light cream background radiates with brown radial bands spreading out.
<i>Vasticardium flavum</i>	Sub-ovate convex (high convex)	The anterior center is thickly rounded	Radial costae are closely spaced and protrude vertically.	Very strong cross heterodontism	Very thick solid; sharply serrated interlocking margins	Monochromatic dull ivory white evenly
<i>Dosinia exasperata</i>	Discoid (flat circular like a disc)	The central prosogyrate curves sharply anteriorly	Uniform concentric striae of very high density	Wide-angled plate heterodont	Solid; internal margins are even and blunt.	Dull white with brown pigmentation on the ventral margin
<i>Modiolus auriculatus</i>	Modioliform (convex rounded posteriorly)	Anterior sub-terminal (slightly offset from the sharp tip)	Flat surface dominated by sharp growth lines (hirsute)	Dysodont fade (obsolete)	Moderately thin; margins are flat and obtuse.	Glossy monochromatic blackish brown
<i>Anadara antiquata</i>	Ovate-oblique asymmetrical bloating	Sub-central anterior space is wide (umbonal distance)	Radial ribs are thick, tuberos, blunt nodules	Taxodont (row of identical teeth parallel along the hinge line)	Very thick solid; margins are crenulate	Ivory white covered with dark brown fibrous periostracum
<i>Meretrix meretrix</i>	Trigonal-ovate thick solid structure	Central prosogyrate straight tapering	Very smooth, shiny surface free of ornamental carvings	Heterodont (straight cardinals interlocking tightly)	Very thick, massive; margins are flat, blunt, and thick.	Light cream with thin brown radial stripe pattern fading
<i>Anomalocardia squamosa</i>	Sub-trigonal rostrate (sharply tapering posteriorly)	Anterior dominant prominence	Concentric, wrinkled, flexible growth lines	Heterodonts are densely concentrated in the center	Solid; even internal margins	Dull background with irregular brownish-black transverse bands
<i>Tegillarca granosa</i>	Sub-rhomboidal (rounded rhombic) has a sturdy structure	Sub-central shifted strongly anteriorly	Radial costae are very distinct and square in cross section.	Taxodont (straight rows of even precision)	Very thick solid; grooved margins lock in precision	Solid monochromatic snow white without any periostracum residue

Physical defense on hard substrates also triggers a different adaptation route in the species *Saccostrea cucullata*. This species survives by ignoring shell symmetry. This abandonment of symmetry results in a xenomorphic geometric architecture, controlled by the flexibility of crystal-microstructure formation in the shell layer (Vaquer et al., 2025). The flexibility of crystal formation allows the specimen to dynamically mold its body profile to follow the irregular contours of the coral topography. This contour drives the formation of a rough, layered shell (foliaceous lamella) that tightly adheres to the host surface. The host surface then takes over the function of a true hinge (dysodont) tooth system. This takeover of the hinge function permanently locks the animal from the pull of water currents using a strong adhesion mechanism (Lee et al., 2024). This demonstrates the high level of adaptive plasticity of the class Bivalvia in intertidal ecosystems.

This high adaptive plasticity represents a crucial evolutionary concept in Invertebrate Systematics. This evolutionary concept requires students to comprehend how environmental pressures dictate physical architecture. Comprehending such architectural adaptations necessitates direct observation of authentic specimens. This observational necessity justifies the transition from pure ecological analysis to applied pedagogical evaluation.

Morphological Characterization of Gastropod Shells

Research at the same location also successfully identified a rich morphotypic variation within the class Gastropoda. Observations of single spiral shells focused on examining diagnostic elements that determine taxonomic status. These diagnostic elements were then displayed through macroscopic visual recordings in Figure 4. Furthermore, the morphological parameters were mapped in detail and sequentially in Table 2.

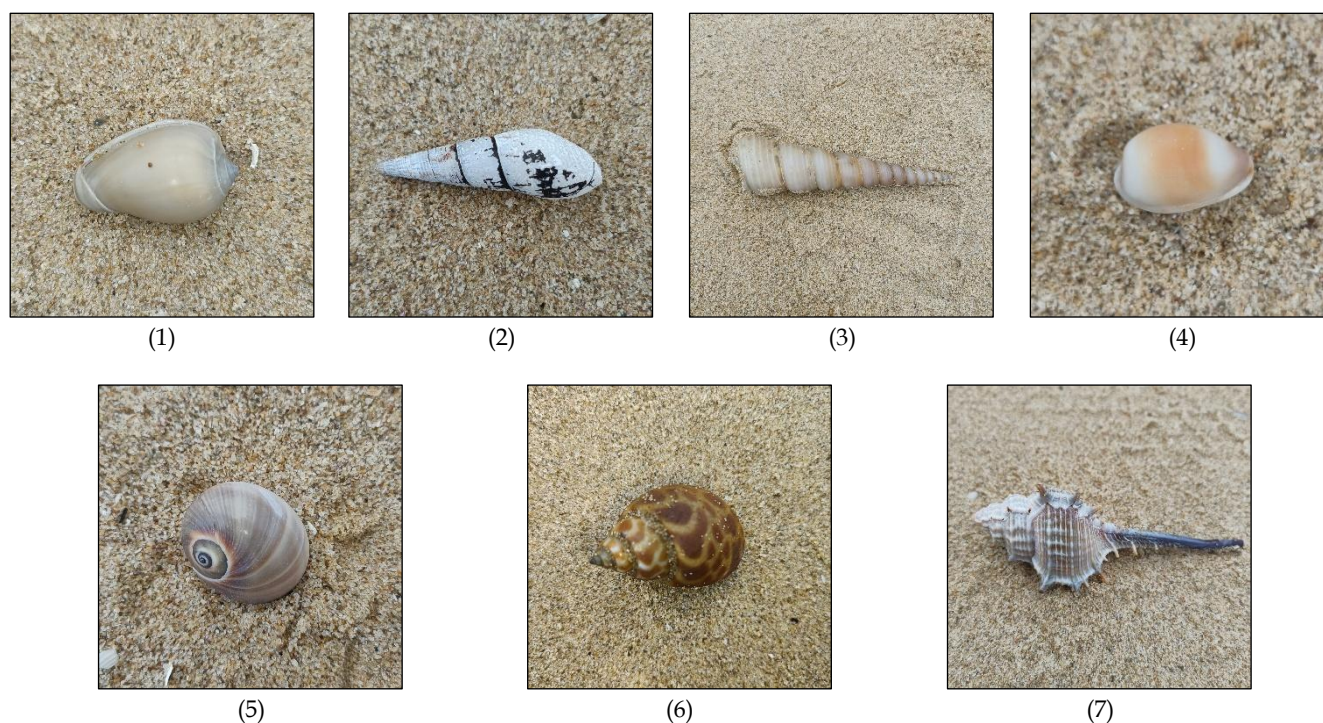


Figure 4. Visualization of macroscopic characteristics of the shell of the class Gastropoda. The visualization presents the arrangement of species in sequence: (1) *Oliva vidua*; (2) *Cerithium coralium*; (3) *Turritella terebra*; (4) *Cypraea carnea*; (5) *Neverita didyma*; (6) *Babylonia areolata*; and (7) *Murex tribulus*.

Macroscopic exploration reveals a high level of shell morphological disparity in the coastal Gastropod class Gadon. This high morphological disparity reflects the phenotypic response of mollusks to ecological selection pressures in intertidal environments (Liang et al., 2026). These pressures force species to develop complex defensive ornaments. One such complex defensive ornament is clearly visible in the axial spines of *Murex tribulus*. This species grows sharp, curved spines to

intimidate visual predators in shallow waters, such as coastal shell-crabs and shorebirds (Dominici, 2025). Coastal crabs and shorebirds abort attacks due to the physical barrier of the sharp shell structure. In addition to warding off attacks from coastal fauna, this physical threat ward helps disperse the mechanical impact energy of ocean waves before they reach the main body whorl (Wang et al., 2025b). The shell spines have proven effective at protecting the main body from wave impact

and also serve as a substitute for the relatively thin shell wall.

Table 2. Morphological characterization matrix of the Gastropoda class shell

Species Name	General Geometric Shapes (Spire Elevation)	Aperture Shape (Shell Mouth)	Exterior Ornament Type	Direction of Rotation & Character of Siphon	Thickness & Architectural Characteristics	Color Pigmentation Pattern
<i>Oliva vidua</i>	Cylindrical (elongated cylindrical); very low, sunken spire	Narrowly elongated along the body whorl; outer lips parallel	The porcelain surface is very smooth without any carvings.	Dextral; siphonal notch (tail notch) cut short	Very thick solid; abrasion resistant dense structure	Glossy surface with irregular light pigmentation patterns
<i>Cerithium coralium</i>	Turreted (conical tower) sturdy; tall, tapering spire	Ovate (ovoid) small with short canal	A series of blunt spiral nodules (protrusions) in a series on each thread	Dextral; the siphon duct turns sharply dorsally	Solid massive; intact spire top preserved	Alternating black and white circular band pattern
<i>Turritella terebra</i>	Turriculate (slender tower); very high, sharp spire elevation	Sub-quadrate (slightly rounded square) small	Spiral striae (lines) that are tightly coiled and evenly distributed	Dextral; holostomatous (mouth intact without siphon duct)	Moderately thin; prone to fracture at the apex	Monochromatic dull white all over due to abrasion
<i>Cypraea carneola</i>	Globose (rounded bloated); low spire depressed (depressed)	D-shaped (semicircular) widened; umbilicus closed	Smooth, glossy porcelain surface free of nodules	Dextral; holostomatous margin rounded to blunt	Solid, thick, flat; convex architecture dampens impact	The bright white background is crossed by a faded orange equatorial band
<i>Neverita didyma</i>	Thick globose-turbinate; blunt spire blending into the body whorl	Semi-circular with toothed columellar deck	Smooth surface with fine longitudinal growth lines	Dextral; holostomatous, thick serrated margin	Very thick and massive; ceramic-hard shell	Even brownish gray with circular line pattern
<i>Babylonia areolata</i>	Symmetrical swollen globose; very low, small, prominent spire	Ovate (ovoid) extremely widened	Smooth porcelain surface with microscopic growth lines	Dextral; holostomatous margin sharply curved	Moderately thin; prone to cracking on the outer lip	Bright background with a bold brown reticulate/zig-zag pattern
<i>Murex tribulus</i>	Fusiform (spindle-shaped); moderate spire elevation	Ovate circular protruding from the main coil	Axial varices are sharp protruding and decorated with curved spinose spines.	Dextral; has a very long straight siphon channel (long canal)	Solid irregular; outer spines are susceptible to wave erosion	Dull grayish with a faint purple gradation at the base of the spines

The substitution of defense strategies against environmental threats is also recorded through the restructuring of the spire elevation (the peak of the whorl). The restructuring of the spire elevation produces a rounded, swollen (globose) morphotype, as in *Cypraea carneola*. This species uses the swollen, smooth-surfaced morphotype to reduce hydrodynamic friction significantly (Chen et al., 2024). The reduction of friction allows seawater turbulence to flow smoothly through the porcelain shell without transferring excess stress. The dissipated excess stress protects the mollusk's external morphology from structural damage (Kim et al., 2026). Furthermore, this slippery, globose shape enables the species to wedge itself securely into coral crevices, providing an effective mechanical defense against predators such as crabs. Structural damage is successfully avoided through this specialized

morphological adaptation, ensuring Gastropoda's position as the class with the highest survival rate in rocky ecosystems.

This high survival rate establishes a fundamental framework for Invertebrate Systematics education. This educational framework compels students to analyze extreme morphological contrasts. These morphological contrasts distinguish the sharp defensive spines of *Murex tribulus* from the smooth hydrodynamic profile of *Cypraea carneola*. These distinct profiles necessitate direct tactile engagement to fully comprehend their functional anatomy. This tactile engagement subsequently requires educators to evaluate the physical safety and durability of each specimen prior to laboratory implementation.

Analysis of the Feasibility of Bivalve and Gastropod Shells as Preservation Specimen Media

Morphometric characterization assesses the potential use of Bivalvia and Gastropod shells as learning media for dry specimens. The use of the shells of both classes was objectively assessed using four standard curation feasibility indicators: structural

integrity, diagnostic visibility, handling safety, and taxonomic authenticity. The results of the feasibility assessment of physical parameters of all Bivalvia and Gastropod species are systematically documented in Table 3.

Table 3. Evaluation matrix for the feasibility of Bivalvia and Gastropod shells as media for dry specimens

Class	Species Name	Structural Integrity	Diagnostic Visibility	Handling Safety	Taxonomic Authenticity
Bivalvia	<i>Mimachlamys sanguinea</i>	++	+++	+++	+++
	<i>Donax faba</i>	+++	++++	++++	+++
	<i>Gafrarium tumidum</i>	++++	++++	++++	++++
	<i>Lioconcha castrensis</i>	++++	++++	++++	++++
	<i>Perna viridis</i>	+++	++++	++++	++++
	<i>Polymesoda erosa</i>	++++	+++	++++	++++
	<i>Saccostrea cucullata</i>	++++	++	++	+++
	<i>Mactra violacea</i>	+	+++	++++	++
	<i>Vasticardium flavum</i>	++++	++++	++++	++++
	<i>Dosinia exasperata</i>	++++	++++	++++	++++
	<i>Modiolus auriculatus</i>	+++	+++	++++	+++
	<i>Anadara antiquata</i>	++++	++++	++++	++++
	<i>Meretrix meretrix</i>	++++	++++	++++	++++
	<i>Anomalocardia squamosa</i>	++++	++++	++++	++++
	<i>Tegillarca granosa</i>	++++	++++	+++	++++
Gastropoda	<i>Oliva vidua</i>	++++	++++	++++	++++
	<i>Cerithium corallium</i>	++++	++++	++++	++++
	<i>Turritella terebra</i>	++	++++	+++	++++
	<i>Cypraea carneola</i>	++++	++++	++++	++++
	<i>Neverita didyma</i>	++++	++++	++++	++++
	<i>Babylonia areolata</i>	+++	++++	++++	+++
	<i>Murex tribulus</i>	+++	++++	+	++++

Note: (++++): Highly viable: maximum potential, ideal physical characteristics, and absolutely safe for direct observation; (+++) Viable: high potential, intact structural accuracy, but requires minor handling care; (++) Fairly viable: moderate potential, requires the use of basic protective containers due to minor degradation; (+) Less viable: potentially limited to raw conditions, requiring special preparatory intervention due to extreme architecture or major degradation.

The evaluation matrix differentiated high-potential taxa from limited-potential preservation media. *Meretrix meretrix* and *Cypraea carneola* demonstrated high potential, achieving top scores for thick architectures, clear diagnostic features, and safe tactile handling without sharp structures. Conversely, thin structural integrity and crush susceptibility reduced the feasibility of *Mactra violacea*. This vulnerability contrasted with the robust *Murex tribulus*, which scored the lowest in safety indicators due to long axial spines. These spines necessitate specialized preparations, such as transparent resin casting, before student distribution (Simmons, 2025).

The safe distribution of these evaluated specimens ensures the smooth implementation of Invertebrate Systematics practicums. These practicums guide students in building conceptual understanding through the identification of 3D diagnostic characters. Fully accommodating this identification remains difficult through textbooks or digital presentations, which often alter perceptions of space, scale, and original texture (Toma & Greca, 2018). Such perceptual alterations limit

sensory stimulation, ultimately hindering the shift from theoretical memorization to in-depth analytical understanding.

Analytical understanding necessitates tactile observation skills, which develop optimally through empirical exploration of dry specimens materials. This exploration requires direct physical interaction, such as palpating lamellar thickness, measuring whorl angles, and assessing radial rib textures, creating authentic learning experiences. These experiences meaningfully connect abstract taxonomic concepts with factual morphology, fostering scientific curiosity and motivation. Such pedagogical outcomes underscore the irreplaceable role of physical specimens over digital educational technology (Randler et al., 2005).

These pedagogical outcomes extend beyond the local intertidal zone of Gadon. Utilizing coastal resources as high-quality dry specimens opens methodological avenues for institutions in tropical regions previously reliant on commercial procurement. This methodological shift holds substantial potential given the untapped biodiversity of Indonesian coastal

areas. However, the present study restricts its characterization to a single temporal and spatial scope, leaving seasonal variations uncharted. This spatio-temporal limitation establishes a clear research agenda. Future curricula must integrate these standardized collections into guided discovery-based lab manuals (Beck et al., 2014; Spence, 2022). Furthermore, subsequent research should experimentally compare student groups using authentic specimens against those using resin-coated replicas, specifically evaluating tactile observation skills, psychomotor abilities, and taxonomic cognitive retention.

Conclusion

This research confirms that Bivalve and Gastropod shells from the Gadon coast serve as highly feasible, standardized dry specimens for Invertebrate Systematics. These specimens exhibit objectively measurable feasibility variations determined by their specific architectural complexity. Thick-shelled morphotypes safely support direct tactile observation, while extreme ornamentations require protective casing or controlled handling guidelines to prevent student injury. This research explicitly contributes a standardized curation framework that transforms neglected local marine resources into accessible, sustainable, and highly representative educational media. Such implementation offers a practical solution to the scarcity of museum collections in university laboratories. Future experimental research must now quantify the pedagogical effectiveness of these specimens, specifically evaluating their impact on students' tactile observation skills and long-term cognitive retention in systematic biology.

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Author Contributions

Conceptualization, Y.Y., Z.M., and T.S.H.W.; Methodology, Y.Y.; Investigation, Z.M.; Validation, T.S.H.W.; Visualization, Y.Y. and Z.M.; Writing-original draft, Y.Y.; Writing-review & editing, Y.Y. and T.S.H.W.; Supervision, T.S.H.W. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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