

Conserving endemic coastal biodiversity in Tomini Bay, Gorontalo: ecosystem-based and community-driven protection strategies

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Abstract. Tomini Bay in Gorontalo Province, Central Sulawesi, is recognized as one of Indonesia's marine biodiversity hotspots, harboring numerous endemic species associated with coral reefs, mangroves, and seagrass meadows. However, increasing pressures from coastal development, overfishing, destructive fishing practices, and land-based pollution threaten the integrity of these ecosystems and the survival of endemic taxa. This paper aims to highlight the conservation status of endemic coastal biodiversity in Tomini Bay and to propose practical protection techniques tailored to the local socio-ecological context. Drawing on available ecological surveys, grey literature, and conceptual analysis, the paper first outlines key endemic groups, including reef-building corals, gobiid and mudskipper fishes, as well as mangrove- and seagrass-associated fauna, and summarizes their ecological roles in maintaining productivity, shoreline stability, and fisheries. The second part analyzes major drivers of habitat degradation and biodiversity loss, emphasizing how weak enforcement, limited community awareness, and fragmented management exacerbate ecological vulnerability. The paper then presents a set of integrated conservation recommendations, such as establishing a network of community-based marine protected areas, restoring critical habitats through mangrove rehabilitation and coral transplantation, adopting ecosystem-based fisheries management, and strengthening environmental education that incorporates local knowledge and customary practices. By combining science-based planning with participatory governance, Tomini Bay's endemic biodiversity can be more effectively safeguarded while sustaining livelihoods for coastal communities. The insights from this paper are expected to support future policy formulation, academic research, and collaborative conservation initiatives in Gorontalo and the wider Tomini Bay region.

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1 Introduction

Global biodiversity is declining at an unprecedented rate due to a combination of anthropogenic pressures, including habitat destruction, pollution, overexploitation of resources, invasive species, and climate change. Coastal and marine ecosystems are among the most heavily impacted, even though they provide crucial ecosystem services such as food security, coastal protection, carbon sequestration, and cultural values for millions of people living in coastal regions. Indonesia, as a megadiverse country situated within the Coral Triangle, plays a central role in the conservation of marine biodiversity. The country's extensive coastline and archipelagic configuration create a mosaic of habitats that support high levels of species richness and endemism [1-3].

Tomini Bay, located in the northern part of Sulawesi and bordered in part by Gorontalo Province, is recognized as one of the important marine and coastal regions of Indonesia. The bay hosts diverse ecosystems, including coral reefs, mangroves, seagrass meadows, estuaries, and riverine systems that drain into the bay. These habitats support numerous species of fish, corals, mollusks, crustaceans, and marine plants, some of which are endemic or have restricted distributions. Endemic species are of particular conservation concern because their limited range increases their vulnerability to local disturbances and environmental change. If these species disappear from Tomini Bay, they may be lost at the global scale [4-6,26].

Despite the ecological importance of Tomini Bay, the region faces multiple threats. Coastal development, destructive fishing practices, unsustainable resource use, and land-based pollution are degrading key habitats. At the same time, management efforts are often fragmented across administrative boundaries and sectoral policies. In Gorontalo, there is growing concern about the future of endemic biodiversity, yet local conservation initiatives still need stronger scientific, policy, and community support [7-9].

This paper focuses on the conservation of endemic coastal biodiversity in Tomini Bay, with an emphasis on the Gorontalo region. The objectives are fourfold: (1) to describe the ecological characteristics of Tomini Bay and the significance of its endemic biodiversity; (2) to identify the major threats facing these endemic species and their habitats; (3) to discuss ecosystem-based and community-driven techniques for protecting endemic biodiversity; and (4) to provide policy and management recommendations to strengthen conservation efforts. The paper is intended as a conceptual and literature-based contribution that can inform seminar presentations, academic assignments, and local decision-making processes.

2 Research methods

Tomini Bay is a large semi-enclosed bay situated between the provinces of Gorontalo, Central Sulawesi, and North Sulawesi. The bay opens to the western Pacific Ocean and forms part of the broader Coral Triangle region. The coastline of Gorontalo along Tomini Bay is characterized by a combination of rocky shores, sandy beaches, mangrove-lined estuaries, and coral reef fringes. Several rivers flow from the inland highlands into the bay, transporting freshwater, sediments, and nutrients that influence coastal productivity and water quality. Climatically, the region experiences a tropical climate with relatively stable temperatures throughout the year and a monsoonal pattern of rainfall. Seasonal changes affect river discharge, coastal currents, and turbidity, which in turn influence biological processes such as coral spawning, fish migration, and primary productivity. The combination of geological,

oceanographic, and climatic factors contributes to the complexity of habitats and the opportunities for speciation and endemism [4-6,26].

Ecologically, Tomini Bay supports a mosaic of habitats that are tightly interconnected. Coral reefs provide three-dimensional structures that host diverse fish and invertebrate assemblages. Mangrove forests protect shorelines from erosion, serve as nursery grounds for fish and crustaceans, and trap sediments and pollutants. Seagrass meadows stabilize sediments, support herbivorous megafauna, and contribute to carbon storage. Together, these habitats form seascapes that sustain local fisheries and provide a foundation for coastal livelihoods in Gorontalo [3,24,26,28-30].

Human communities around Tomini Bay have long depended on marine resources for subsistence and income. Small-scale fisheries, aquaculture, and coastal agriculture are prominent economic activities. At the same time, cultural ties to the sea are reflected in traditional knowledge, local beliefs, and customary practices regulating resource use. However, population growth, increased market demand for fish and other marine products, and infrastructure development are placing additional pressure on coastal ecosystems. Understanding the ecological context of Tomini Bay is therefore essential for designing conservation strategies that are both scientifically sound and socially acceptable [10-12].

3 Results and discussion

3.1 Endemic biodiversity in Tomini Bay

Endemic biodiversity refers to species or distinct populations that are restricted to a particular geographic area. In the context of Tomini Bay, endemism can occur at several levels, ranging from species found only within the bay to populations that are genetically distinct from those in neighboring regions. Although comprehensive taxonomic surveys are still limited, existing studies and regional assessments suggest that Tomini Bay hosts a number of endemic or narrowly distributed taxa associated with coral reefs, mangroves, and seagrass meadows. Coral reef communities in Tomini Bay are particularly important for endemic biodiversity. The complex reef structures, including fringing reefs, patch reefs, and reef slopes, provide microhabitats for specialized fishes and invertebrates. Small benthic fishes, such as gobies and blennies, often exhibit restricted ranges and strong habitat associations with specific coral species or reef microhabitats. Some of these species may be endemic to Tomini Bay or the broader north Sulawesi region. Reef-building corals themselves can show patterns of endemism or unique genetic lineages, especially in areas where environmental conditions and historical biogeographic processes have promoted diversification. Mangrove ecosystems in Tomini Bay, though less species-rich in trees compared to coral reefs, harbor diverse assemblages of associated fauna, including crustaceans, mollusks, and fishes. Certain mangrove crabs, snails, and mudskipper species may have restricted distributions linked to specific estuaries or coastal segments. Given the strong environmental gradients in salinity, sediment type, and hydrology along the bay, there is potential for localized adaptation and micro- endemism among mangrove-associated organisms [4,5,25,27].

Seagrass meadows in shallow coastal areas also support endemic or regionally unique biodiversity. Seagrass beds provide habitat for juvenile fishes, invertebrates, and in some areas, threatened megafauna such as sea turtles and dugongs. Endemic algae, epiphytic organisms, and invertebrates associated with seagrasses contribute to the overall uniqueness of local biodiversity. Although many of these taxa remain poorly studied, their ecological roles in nutrient cycling, energy flows, and habitat provision are critical. The conservation

of endemic biodiversity in Tomini Bay is important not only from a global perspective but also for maintaining the resilience and functioning of local ecosystems. Endemic species often occupy specialized niches and contribute disproportionately to ecosystem processes. Their loss can lead to cascading effects on community structure and ecosystem services. Therefore, efforts to safeguard endemic biodiversity must be integrated into broader coastal management and development planning in Gorontalo [3].

3.2 Threats to endemic biodiversity

The endemic biodiversity of Tomini Bay is increasingly exposed to a range of anthropogenic and natural threats. Among the most pressing human-induced pressures are destructive fishing practices, unsustainable extraction of marine resources, coastal development, and pollution from land-based activities. In addition, climate change and ocean warming pose long-term risks to the structure and function of coastal ecosystems [3].

Destructive fishing techniques, such as the use of explosives and cyanide, have historically damaged coral reefs in various parts of Indonesia. These practices can shatter coral skeletons, kill non-target species, and reduce habitat complexity, thereby disproportionately affecting specialized and endemic organisms that depend on intact reef structures. Even when such practices decline due to enforcement and awareness campaigns, the legacy of degradation can persist for decades.

Overfishing and the use of non-selective fishing gear also threaten endemic species. Small-scale fishers operating in Tomini Bay often rely on gear such as nets, traps, and lines that can catch a wide range of species, including juvenile and non-target organisms. When fishing effort exceeds the reproductive capacity of fish populations, local depletions can occur, eroding genetic diversity and increasing vulnerability to environmental change. Endemic species with limited ranges are particularly at risk because the loss of a single population may represent a significant proportion of the global stock [7,813].

Coastal development, including the expansion of settlements, ports, aquaculture ponds, and tourism infrastructure, leads to the conversion and fragmentation of critical habitats. Mangroves may be cleared for shrimp ponds or housing, while seagrass meadows can be damaged by boat anchoring, dredging, and land reclamation. Such habitat loss reduces the area available for endemic species and disrupts ecological connectivity across the coastal landscape [7,26].

Land-based sources of pollution, such as agricultural runoff, domestic sewage, and solid waste, further degrade water quality in Tomini Bay. Increased nutrient loads can cause eutrophication and harmful algal blooms, while sedimentation from deforestation and poor land use practices can smother corals and seagrasses. Chemical pollutants, including pesticides and heavy metals, may accumulate in the tissues of marine organisms, affecting their health and reproductive success [10,14].

Climate change compounds these local stressors through rising sea temperatures, ocean acidification, and changes in storm frequency and intensity. Coral bleaching events associated with elevated temperatures can cause mass mortality of corals, undermining habitat availability for reef-associated endemics. Ocean acidification may impair calcification in corals and shell-forming organisms. Sea-level rise and altered precipitation patterns can change the salinity regimes and sediment dynamics of estuaries and mangroves. Endemic species with narrow physiological tolerances may be unable to adapt or migrate, leading to range contractions or extinctions [15,16].

These threats are exacerbated by governance challenges, including limited financial and human resources, gaps in scientific data, weak enforcement of regulations, and lack of coordination among government agencies. Addressing the conservation needs of endemic

biodiversity in Tomini Bay therefore requires integrated and multi-level responses that tackle both direct and underlying drivers of environmental degradation [8,13].

3.3 Conservation and protection techniques

Effective conservation of endemic coastal biodiversity in Tomini Bay demands a combination of ecosystem-based management and community-driven strategies. Ecosystem-based management recognizes the interconnectedness of species, habitats, and human activities, and seeks to maintain ecological integrity while supporting sustainable use. Community-driven approaches acknowledge the essential role of local stakeholders as stewards of coastal resources and incorporate their knowledge, needs, and aspirations into conservation planning. One key strategy is the establishment of a network of marine protected areas (MPAs) that includes both no-take zones and sustainably managed use areas. MPAs can be designed to represent the full range of habitats in Tomini Bay, including coral reefs, mangroves, seagrass meadows, and estuaries. Special attention should be given to sites known or suspected to harbor high concentrations of endemic species or unique genetic lineages. By protecting critical habitats and ecological processes, MPAs can enhance the resilience of populations and provide sources for the replenishment of exploited areas. For MPAs to be effective in Gorontalo, they should be embedded within a broader framework of community-based management. Local fishers and coastal residents can participate in the identification of important areas, the formulation of rules, and the monitoring of compliance. Community-based MPAs or locally managed marine areas (LMMAs) have been successful in various parts of Indonesia and the Pacific by fostering a sense of ownership and responsibility. Traditional institutions and customary norms can be integrated with formal legal frameworks to create hybrid governance arrangements that are both legitimate and enforceable [1, 9,10,17-20]].

Habitat restoration is another essential conservation technique, particularly in areas where degradation has already occurred. Mangrove rehabilitation projects can help restore shoreline protection, nursery habitats, and carbon sequestration capacity. Successful rehabilitation requires attention to hydrological conditions, species selection, and long-term maintenance, rather than simply planting trees without planning. Coral reef restoration, through methods such as coral gardening, transplantation, and the installation of artificial reefs, can accelerate the recovery of damaged sites and provide new structures for reef organisms. Seagrass conservation may focus on preventing further damage, establishing anchoring restrictions, and in some cases, active transplantation. Sustainable fisheries management is crucial for reducing pressure on endemic and vulnerable species. This may involve the adoption of gear restrictions to reduce by-catch, the implementation of size limits and seasonal closures to protect spawning stocks, and the promotion of selective fishing techniques. Co-management arrangements that share decision-making authority between government agencies and local communities can improve compliance and adapt management measures to changing conditions. The use of participatory monitoring and catch reporting systems can generate data to inform adaptive management. Environmental education and capacity building are cross-cutting components of conservation in Tomini Bay. Schools, universities, and community organizations can raise awareness about the importance of endemic biodiversity and the ecological roles of different habitats. Engaging youth, women, and marginalized groups in conservation activities can strengthen social support and generate innovative ideas. Citizen science initiatives, where community members help collect data on species occurrences, water quality, or habitat condition, can enhance both scientific knowledge and local ownership of conservation outcomes. Finally, modern tools such as geographic information systems (GIS), remote sensing, and participatory mapping can support spatial planning and

decision-making. Mapping the distribution of habitats, endemic species, and human uses can help identify priority areas for protection, restoration, and sustainable development. When combined with socio-economic information, these tools can guide trade-offs and synergies among different objectives, ensuring that conservation of endemic biodiversity is integrated into broader coastal management plans for Gorontalo and Tomini Bay [14,21,22,24,26,28,29].

3.4 Policy and community-based management implications

Implementing the conservation and protection techniques described above requires an enabling policy environment and strong support for community-based management. At the national level, Indonesia has developed various laws and policies related to environmental protection, marine and coastal management, and biodiversity conservation. These frameworks provide opportunities for the designation of marine protected areas, the regulation of fisheries, and the integration of environmental considerations into development planning. However, effective implementation at the local level remains a challenge. In Gorontalo, provincial and district governments play a critical role in translating national policies into concrete actions in Tomini Bay. Spatial planning processes, coastal zone management plans, and sectoral regulations should explicitly recognize the importance of endemic biodiversity and the need to protect critical habitats. Coordination among agencies responsible for fisheries, forestry, marine affairs, tourism, and public works is essential to avoid conflicting decisions and to promote coherent strategies. Universities and research institutions, including Universitas Negeri Gorontalo, can provide scientific input, conduct field studies, and support monitoring and evaluation [1,2,5].

Community-based management should be strengthened through legal recognition of local institutions and customary practices. Where traditional rules governing resource use exist, such as temporary fishing closures or taboos on harvesting certain species, these can be documented and supported as part of formal management arrangements. Participatory decision-making forums that include fishers, community leaders, women's groups, youth representatives, and other stakeholders can foster dialogue, build trust, and generate locally appropriate solutions. Mechanisms for benefit-sharing, such as revenue from ecotourism or payments for ecosystem services, can create incentives for communities to invest in long-term conservation [10,19].

Capacity building for local government staff and community members is equally important. Training in ecosystem-based management principles, data collection methods, conflict resolution, and project management can improve the quality of conservation initiatives. Partnerships with non-governmental organizations and donor agencies may provide additional technical and financial support. Overall, aligning policy frameworks with community-based initiatives can create a supportive environment for conserving endemic biodiversity in Tomini Bay. Such alignment can help ensure that local actions are reinforced by higher-level policies, while national and provincial goals are grounded in the realities and aspirations of coastal communities in Gorontalo [8,20,21].

In addition to regulatory instruments, livelihood-sensitive incentives can strengthen compliance. Ecotourism development (e.g., reef-based attractions and whale-shark tourism services) can generate local income streams, but it also requires carrying-capacity limits, transparent benefit sharing, and environmental safeguards to avoid new pressures on habitats and endemic taxa. [15, 16, 23]

4 Conclusion

Tomini Bay in Gorontalo is a region of high ecological significance, hosting diverse coastal and marine habitats that support numerous endemic species. These endemic organisms contribute to the uniqueness, resilience, and functioning of ecosystems, yet they face growing threats from destructive fishing, habitat loss, pollution, and climate change. The conservation of endemic biodiversity in Tomini Bay is therefore both a local and global priority.

This paper has highlighted the ecological context of Tomini Bay, the nature of its endemic biodiversity, the main threats it faces, and a range of conservation and protection techniques. Ecosystem-based management approaches, combined with community-driven initiatives, offer promising pathways for safeguarding endemic species while sustaining the livelihoods of coastal communities. Key strategies include the establishment of networks of marine protected areas, habitat restoration, sustainable fisheries management, environmental education, and the use of modern spatial planning tools.

Policy support and strong community engagement are essential for turning these strategies into reality. By aligning national and local policies with traditional knowledge and participatory governance, stakeholders in Gorontalo can work together to protect Tomini Bay's unique natural heritage. Continued research, monitoring, and adaptive management will be necessary to respond to changing conditions and to refine conservation measures over time.

Ultimately, conserving endemic coastal biodiversity in Tomini Bay is not only about preserving species; it is about maintaining the ecological foundations of human well-being and cultural identity in Gorontalo. The efforts made today will shape the environmental legacy passed on to future generations.

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