BIOEDUPAT:
Pattimura Journal of Biology and Learning
https://ojs3.unpatti.ac.id/index.php/bioedupat
e-ISSN 2775-4472

Research Article

Coastal area resources as a pillar of sustainable development: Reorienting education for biodiversity literacy

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Received: March 29, 2025 Accepted: September 03, 2025 Published: October 31, 2025

ABSTRACT

Coastal areas have high biodiversity, which is essential in supporting sustainable development. However, low biodiversity literacy among coastal communities challenges conservation efforts and sustainable resource utilization. Reorienting interdisciplinary-based education is a necessary strategy to improve people's understanding of coastal ecosystems, including coral reefs, mangrove forests, and seagrass beds. Therefore, this paper aims to analyze the potential of coastal resources as a pillar of sustainable development, identify interdisciplinary approaches that can support biodiversity literacy, and design interdisciplinary strategies in reorienting education. Various scientific fields, such as Marine Science, Agricultural Science, Education Science, Social and Political Science, Legal Science, and Education Management science, can contribute to building a holistic and community-based educational approach. Knowledge in the form of local wisdom can support coastal area management. For example, the Sasi tradition in Maluku is vital in preserving marine biodiversity by regulating the sustainable use of natural resources according to the ecosystem cycle. Through synergies between academia, government, and communities, adaptive education programs can be implemented to equip communities with sustainable marine resource management skills. This approach is in line with the Sustainable Development Goals (SDGs), particularly goals 14 (Marine Ecosystems), 4 (Quality Education) and 13 (Addressing Climate Change). With proper policy support, education in coastal areas is expected to create an environmentally aware generation, adapt to global challenges, and actively preserve marine ecosystems for sustainable prosperity.

Keywords: coastal area, biodiversity literacy, education reorientation, interdisciplinary

To cite this article:
Adinugraha, F., Sangur, K., Rumahlatu, D., & Zubaidah, S. (2025). Coastal area resources as a pillar of sustainable development: Reorienting education for biodiversity literacy. BIOEDUPAT: Pattimura Journal of Biology and Learning, 5(2), 310-326. https://doi.org/10.30598/bioedupat.v5.i2.pp310-326

INTRODUCTION

Coastal areas have a high biodiversity, with key ecosystems such as coral reefs, mangroves, and seagrass beds as habitats for various marine life. Coral reefs and mangrove and seagrass ecosystems provide natural coastal protection and serve as feeding, nursery, and spawning grounds for marine organisms (Tuwo & Tresnati, 2021). Coral reefs are unique ecosystems in the ocean and are found mainly in the Indo-Pacific tropics (Sukandar et al. 2022), including Maluku waters. Coral reefs are often called “rainforests of the sea” (Penniman, 2021; Prasad et al. 2023), and many are unaware that they exist (Penniman, 2021).

Coastal areas, mainly tropical and subtropical coasts, also contain mangrove forests that are very productive in supporting fish and shrimp life while providing benefits to humans and the environment (Sholeh et al. 2024). Mangroves have significant ecological, sociological, and commercial values for local and national communities

(Biswas & Biswas, 2021). Coastal areas also contain seagrass meadows and marine angiosperm plants that form extensive grasslands in shallow waters, providing ecosystem services such as food production, carbon sequestration, primary production, and ecotourism benefits (Lima et al. 2023; Short et al. 2016).

Various challenges threaten coastal areas including their ecosystem balance, ranging from overexploitation of resources (Elegbede et al. 2020; OECD, 2021; Shahnaz & Syaprillah, 2022), marine pollution (Elegbede et al. 2020; Shahnaz & Syaprillah, 2022; Steven et al. 2023), to climate change impacts such as coastal abrasion and sea level rise (Elegbede et al. 2020; Steven et al. 2023). This situation demands a deeper understanding of biodiversity and strategies for sustainable management of natural resources. Such understanding can be realized by promoting biodiversity literacy through interdisciplinary education.

Education is essential in increasing biodiversity literacy (Børresen et al. 2022) and encouraging public awareness to manage the environment sustainably (Hnatyuk et al. 2024). Such educational efforts are in line with the Sustainable Development Goals (SDGs), particularly SDG Goal number 4 (Quality Education), SDG Goal number 14 (Life Below Water), and SDG Goal number 13 (Climate Action) (United Nations, 2015, 2022). Quality education has a vital role in teaching biodiversity literacy to the community, which is the ability to understand, appreciate, and protect biodiversity in the surrounding environment. This biodiversity literacy is closely related to efforts to conserve ecosystems in coastal areas, which are habitats for various marine species and play a vital role in the balance of the global ecosystem. Education that synergizes with coastal resources plays a vital role in encouraging climate action to prevent the impacts of climate change on coastal areas through an understanding of ecosystems and biodiversity in coastal areas.

The potential of coastal areas is poorly supported by the level of biodiversity literacy among coastal communities. Biodiversity literacy is related to understanding biodiversity knowledge and actions to help protect biodiversity (Moss et al. 2014). Efe & Efe's (2022) research found that secondary school students have low biodiversity knowledge. The community also lacks literacy related to marine biodiversity (McCauley et al. 2019). Coastal areas can be supported through local wisdom, such as the *Sasi* tradition in Maluku. *Sasi laut* is a local wisdom in Maluku Islands that regulates the utilization of natural resources through community collaboration, is effective in maintaining ecosystems and preserving culture, and has the potential to be applied in other areas to support conservation and sustainable development (Muin & Rakuasa, 2023).

Various factors, such as limited access to education, lack of integration of biodiversity materials in the curriculum, and low public awareness, can cause a lack of biodiversity literacy. Coastal areas, for example, often face constraints in accessing adequate education (Martika et al. 2024). In addition, the integration of biodiversity and conservation materials in the formal education curriculum is still relatively limited (Kurniawan, 2016). Another contributing factor is low public awareness of the importance of biodiversity conservation, which is one of the leading causes of biodiversity loss (Ibrahim et al. 2023). Interdisciplinary collaboration is essential to address complex coastal issues (Deininger et al. 2021), including biodiversity literacy related to coastal resources.

Some of the general public still does not understand interdisciplinary collaboration efforts in coastal area management. Therefore, explaining the potential of coastal resources and the involvement of various disciplines in universities for coastal areas is necessary. Each study program in the university has a specific contribution to understanding and developing solutions to the challenges faced by coastal areas. This paper aims to analyze the potential of coastal resources as a pillar of sustainable development, identify interdisciplinary approaches that can support biodiversity literacy, and design interdisciplinary strategies in reorienting education to increase awareness and skills of coastal communities in sustainable natural resource management.

An interdisciplinary approach is essential in designing strategies to reorient education in coastal areas by combining various fields of science to create solutions that increase biodiversity literacy. With the collaboration of different scientific fields, including marine science, agriculture, education, law, socio-politics, and education management, education in coastal areas is expected to play a more effective role in communities with certain local wisdom. In addition, local wisdom, such as the *Sasi* tradition in Maluku, can also be integrated as a culture-based learning model that instils conservation values in the community. Other disciplines, such as information technology, communication, and sociology, also have the potential to make significant contributions in supporting innovative educational strategies that are relevant to the needs of coastal communities.

METHODS

This research uses a literature study method by analyzing various literature sources, such as scientific articles, research reports, government policies, and academic documents related to education, coastal biodiversity, and sustainable development. The analysis was conducted using an interdisciplinary approach, involving perspectives from various fields of science, including (1) Marine Science by explaining coastal biodiversity and factors that affect its sustainability, (2) Fisheries and Aquaculture Science by explaining sustainable practices that can improve the welfare of coastal communities, (3) Education Science by examining educational methods that can improve

biodiversity literacy for coastal communities, (4) Law by reviewing policies and regulations related to marine resource conservation and the rights of coastal communities, (5) Social and Political Science by evaluating the socio-economic impacts of low biodiversity literacy in coastal areas, and (6) Education Management by identifying effective education management strategies for coastal areas. A qualitative analysis approach was used to understand the linkages between the various disciplines, coastal resources, and biodiversity.

RESULTS AND DISCUSSION

Coastal Resources

Coral reef ecosystem

Coral reefs are habitats for various species of microflora, such as microscopic algae and macrophytes, such as seaweed and the like, along with other marine flora. This ecosystem comprises coral animals that act as reef builders (Tuwo & Tresnati, 2021). The term "coral" refers to soft corals, hard corals, and sometimes colonies of animals of the Cnidaria or *Coelenterata* groups, but generally refers to hard corals with skeletons (Veron, 2009). Hard corals act as reef architects by secreting calcium carbonate to form skeletons that provide habitat for various living things. Meanwhile, soft corals do not contribute to reef formation but form colonies with structures resembling trees, fans, whips, and grasses (Penniman, 2021).

Coral reef ecosystems in Maluku province have good conditions with diverse coral species and have become essential habitats for various fish species. Coral reefs are one of the marine resources in Maluku province. Limmon & Manuputty (2021) reported that the condition of coral reef closure in the waters of Hulalui village was classified as good at a depth of 3 m and 10 m. Coral species in Southeast Maluku waters include *Pocillopora verrucosa, Porites lutea, P. lobata, Montipora informis, P. cylindrica, Merulina ampliata,* and *Stylophora pistillata* with moderate diversity and low dominance (Sahetapy et al. 2021). The coral reef ecosystem on Isau Island, Seram, is also in good condition as a habitat for the reef fish families Pomacentridae and Labridae (Mualo et al. 2024).

Coral reefs provide ecological value, namely as a habitat for organisms, a place for food chains, and biogeochemical cycles. Coral reef ecosystems provide habitats for a variety of aquatic fauna, including invertebrates such as crustaceans, snails, clams, and echinoderms such as sea urchins, sea anemones, sea cucumbers, starfish, and sea lilies; fish with various diets, such as carnivorous, herbivorous, omnivorous, and opportunistic planktivorous fish; and reptiles such as sea snakes and sea turtles (Tuwo & Tresnati, 2021). Coral reef fishes play a role in reef ecology and influence the carbonate cycle by modifying reef structure through bioerosion, sediment breakdown, production, and transport (Perry et al. 2022).

Coral reefs also provide consumption and economic values, namely livelihoods, nutrition, and ecotourism. Coral reefs are a source of fisheries and livelihoods for coastal communities (Chaijaroen, 2016; Penniman, 2021). Coral reefs benefit humans as fishing grounds and provide raw materials for lime (Prasad et al. 2023). Coral reefs also have the potential to improve the economy through marine ecotourism (Lima et al. 2023; Shahnaz & Syaprillah, 2022; Tuwo & Tresnati, 2021). Corals protect wave action (Prasad et al. 2023; Tuwo & Tresnati, 2021), which protects shorelines from abrasion and large waves, reducing the cost of damage to coastal infrastructure.

Human activities can also threaten coral reefs. Threats to coral reef ecosystems in the region can come from tourist and fishing boat activities, which cause damage, particularly from anchors (Sukandar et al. 2022). Climate change threatens coral reef ecosystems through rising sea levels and temperatures, changes in carbonate solubility, increased UV radiation, and intensification of storms and currents, leading to mass bleaching (Tuwo & Tresnati, 2021). Coral bleaching is one of the most apparent signs that coral reefs are in trouble: without beneficial algae, corals begin to die (Penniman, 2021). Coral bleaching occurs when corals lose pigment due to the release of symbiotic zooxanthellae and can last up to 40 meters deep (Tuwo & Tresnati, 2021). In addition, pollution in the water can also damage coral reefs (Shahnaz & Syaprillah, 2022).

Mangrove ecosystems

Mangroves are coastal swamp forests in tropical and subtropical regions consisting of salt-tolerant, rainforest-like dicotyledonous trees and shrubs (Alongi, 2016; Duke, 2011; Sholeh et al. 2024) and grow in tidal zones (Alongi, 2016; Sholeh et al. 2024), i.e., coastal intertidal and estuaries (Duke, 2011). True mangroves and their hybrids comprise 18 families of flowering plants, with Rhizophoraceae being one of the major families (Kumar et al. 2021). Mangroves are an ecological assemblage of woody plant species, allowing them to live in saline soils inundated by relatively warm tidal waters. Mangroves adapt to saline environments through aerial roots, viviparous embryos, and tidal dispersal of propagules (Alongi, 2016).

Mangrove biodiversity in Maluku waters is diverse and spread in various regions, with ecotourism potential in some areas. Mangrove biodiversity in Maluku waters includes *Rhizophora mucronata, Bruguiera cylindrica, Bruguiera gymnorhiza, Sonneratia alba,* and *Nypa fruticans* in Sehati village, Central Maluku (Sipahelut et al. 2019). *Rhizophora mucronata, Bruguiera gymnorrhiza,* and *B. Cylindrica* have the potential for ecotourism in

Kotania Bay, West Seram (Lelloltery et al. 2021). *Rhizophora mucronata, Rhizophora apiculata, Rhizophora stylosa*, and *Bruguieria gymnorhiza* species were found on Buano island (Salampessy et al. 2024). Meanwhile, the genera *Sonneratia, Rhizophora, Bruguiera, Ceriops, Xylocarpus,* and *Lumnitzera* dominate in the Kei islands (Dharmawan et al. 2022).

Mangroves provide ecological values, such as protecting the coast, reducing carbon emissions, natural water filters, and organism habitats. Ecologically, mangroves play an essential role in maintaining coastal stability by controlling coastal erosion, maintaining sediment stability, and even helping the process of land expansion (Sholeh et al. 2024). Mangroves also contain fauna, including land and marine animal species (Khairnar et al. 2018). Mangroves help reduce global carbon emissions and sequester and store carbon (Akram et al. 2023; Kumar et al. 2021). Mangrove forests act as natural water filters for coastal areas, improving water quality by capturing sediment and other solid debris with their roots (Sultana et al. 2023).

Mangroves provide consumption and economic values, such as nutrition, livelihoods, and ecotourism. Various marine resources in mangroves, such as fish, shrimp, crabs, lobsters, molluscs, reptiles, aquatic animals, and aquatic plants, are utilized directly from the sea for human needs (Elegbede et al. 2020). Mangroves can also be a source of medicine (Kumar et al. 2021) for traditional communities based on their ethnobotanical knowledge (Bibi et al. 2019). Mangroves also have the potential for conservation-based ecotourism (Elegbede et al. 2020; Khairnar et al. 2018; Sholeh et al. 2024).

The main threats to mangroves are deforestation, climate change, sea level rise, and biological invasions (Biswas & Biswas, 2021). Aggressive deforestation is practised in many mangrove forest areas for land use purposes for agriculture, aquaculture, and coastal development (Bhowmik et al. 2022). Pollution, including heavy metal impacts, organic and inorganic pollutants, chemical pollution, accumulation, and biotransformation, can significantly reduce mangrove biodiversity (Maiti & Chowdhury, 2013). Scientists have also predicted the future impacts of climate change on mangroves (Kumar et al. 2021). Anthropogenic drivers of climate change include aquaculture and agriculture, settlement and urbanization, industrialization and pollution, and flow modification (Bhowmik et al. 2022).

Seagrass ecosystems

Seagrasses are submerged flowering plants that grow on all continents except Antarctica in coastal and estuarine environments; seagrasses are found in tidal areas to depths of 90 m (Short et al. 2016). Seagrasses are marine macrophytes commonly found in coastal or submerged marine environments, are angiosperms capable of flowering, and are thought to have evolved from terrestrial monocots (Tang & Hadibarata, 2022). Seagrass meadows have roles and benefits in shallow water ecosystems, including producers of organic matter, habitats for various marine biota, and providers of services that benefit fishing communities (Supriyadi et al. 2024).

Maluku waters have diverse seagrass species spread in various regions, with varying species in each location. *Cymodocea rotundata, Halodule pinifolia, Halophila ovalis*, and *Thalassia hemprichii* were found in the waters of Tulehu, Central Maluku (Lokollo et al. 2022). Meanwhile, *Syringodium isoetifolium* species were found in the waters of Haya village, Central Maluku (Namakule et al. 2017). *Enhalus acoroides, Thalassia hemprichii, Cymodocea serrulata, Cymodocea rotundata, Halodule pinifolia, Halophila ovalis, Syringodium isoetifolium,* and *Halodule pinifolia* species were found in Southeast Maluku waters (Fitrian et al. 2017). *Enhalus acoroides, Thalasia hemprichii, Halodule uninervis, Syringodium isoetifolium,* and *Halophila ovalis* were found in the waters of Mahu, Saparua Island (Tuapattinaya et al. 2023).

Seagrass meadows also provide ecological values, such as oxygen, feeding, and shelter for marine biota, biogeochemical cycling, and preventing marine erosion. Seagrass meadows are autotrophic throughout the year, with the potential for higher oxygen productivity in bottom waters and increases usually in spring (Aramburu et al. 2024). Seagrass meadows support food webs (Short et al. 2016). Seagrass meadows provide essential habitat and breeding grounds for many marine species (Huijting & Goldewijk, 2024). Organic particles buried in carbonate-rich seagrass ecosystems act as blue carbon stores, while seagrass-mediated biogeochemical processes influence sediment alkalinity (Zeller et al. 2024).

Seagrass meadows also provide economic value, such as livelihoods. Seagrass meadows serve as feeding and nursery grounds for many fish species in coastal waters (Manangkalangi et al. 2022), shellfish, and juvenile shrimp (Short et al. 2016). Seagrass meadows also have ecotourism potential through the diversity of seagrass species such as *Enhalus acoroides* and *Caamodocea*, which provide habitat for Echinodermata and Bivalves that attract tourists, including for snorkeling at high tide to enjoy the diversity of fish and other marine life (Syukur et al. 2021). Seagrass species *E. acoroides* and *T. hemprichii* are habitats for several fish species such as *Naso hexacanthus*, *Myripristis murdjan*, *Caranx melampygus*, *Scolopsis lineata*, and *Epinephelus merra* (Latuconsina & Buano, 2021).

The main threats to seagrass meadows include human-induced deforestation, pollution and sedimentation, and climate change. Seagrass meadows are experiencing high loss rates globally due to direct threats such as

sedimentation, eutrophication, dredging and aquaculture, and climate change (Short et al. 2016). These threaten seagrass communities' resilience and productivity (Tang & Hadibarata, 2022). Seagrasses worldwide are in decline, and significant seagrass losses have occurred due to coastal development and anthropogenic pollution pressures, land cover change, and direct physical impacts (Short et al. 2016).

Sasi as Local Wisdom of Maluku Province

The Sustainable Development Goals (SDGs) implemented by the United Nations are essential pillars in achieving sustainability and environmental preservation. Goal 14 of the 17 SDGs is "Life Below Water," which focuses on maintaining and conserving marine biodiversity and ecosystems. Marine ecosystems are service providers that support the economy, shipping, aquaculture fisheries, mining, tourism, and renewable energy (Cavanagh et al. 2021; Visbeck et al. 2014). Harborne et al. (2017) continued that living systems in marine ecosystems are corals, algae, plankton, invertebrates, plankton eaters, herbivores, and tertiary consumers; marine ecosystems provide energy transfer and storage during the food chain process (Bellwood et al. 2019). Maluku Province has an ocean area of 658,294.69 km2 (92.4%) and a land area of 54,185 km2 (7.6%) (Dinas Perikanan dan Kelautan Provinsi Maluku, 2009). Thus, Maluku Province is a high contributor to marine biodiversity, with seagrass, mangrove, and coral reef ecosystems as habitats for other marine biota.

Every coastal community in a region has local wisdom that plays a vital role in protecting its environment. In Maluku, for example, a *Sasi* tradition regulates the sustainable use of marine resources to preserve coastal areas. The people of Maluku province have a habit of utilizing marine biodiversity through Bameti, fishing, and mangrove tree cutting (Salampessy et al. 2024). The utilization of Maluku province's natural resources that are continuously taken, even exceeding the regeneration rate of biota in their natural habitat, can cause a decline in species in their habitat. Koning & McIntyre (2021) explained that this condition is referred to as overheating and threatens the survival of a species. Thus, as academics, it is crucial to apply sustainable management practices to marine biota resources to establish prudent harvest times and harvest periods based on the natural cycles of marine biota. These efforts can help ensure that natural resource utilization is sustainable and does not threaten the sustainability of ecosystems or species.

The practice of sustainable management can be done with the practice of *sasi* laut, which is the culture of the Maluku people. According to Muin & Rakuasa (2023), *sasi* laut is a local wisdom practice in the Maluku Islands to maintain natural resources with community restrictions and collaboration, effectively prevents ecosystem degradation, preserves cultural heritage, and has the potential as a solution to natural resource management that can be applied in other areas, requiring cooperation between the community and the government for conservation and sustainable development. Persada et al. (2018) also explained that *sasi* aims for the community to preserve and use marine resources wisely and sustainably without overexploiting them.

The practice of *Sasi* Laut has been carried out in several areas in Maluku, such as Negeri Noloth and Central Maluku Regency, on marine biota and fish (Mony et al. 2017). A sustainable conversion strategy has been carried out by the local community of Southwest Maluku to protect and preserve the environment and natural resources, which also has the support of the community and village government, which is referred to as the *sasi* laut culture (Kennedy et al. 2019). Research by Betaubun et al. (2019) also explained that coastal communities in the Kei Islands also support the protection of water areas by implementing formal rules, such as the practice of *Sasi* culture, as well as the implementation of local governments to support the sustainable use of marine biodiversity by issuing regional regulations.

Challenges of Biodiversity Literacy in Coastal Areas

The main challenges in improving biodiversity literacy in coastal areas include the lack of integration of marine science in education, so people still exploit resources without understanding the impacts. Sustainable agriculture and aquaculture practices are still limited, with many using environmentally destructive fishing gear. In addition, coastal education is less adaptive as conservation materials are not yet a significant part of the curriculum. Lack of regulation and weak law enforcement further exacerbate the exploitation of coastal resources (Sitanala, 2018). The lack of stakeholder involvement in community education also causes environmental education programs to run sporadically without strong synergy.

The lack of integration of marine science in education has led to a low understanding of coastal areas and their sustainability among communities, especially in coastal areas. Some coastal communities still depend on the exploitation of natural resources without realizing the ecological impacts (Saengsupavanich et al. 2024), such as habitat degradation (Huijting & Goldewijk, 2024; Maiti & Chowdhury, 2013; OECD, 2021) and decreased biodiversity (Ibrahim et al. 2023; OECD, 2021). The lack of marine materials in school curricula and educational programs focusing on marine conservation has limited environmental awareness among the younger generation (O'Brien et al. 2023). Therefore, there is a need to integrate marine science into the education system, both through

formal curricula and non-formal education programs that involve various parties, such as academics, government, and local communities.

The limited application of sustainable agriculture and aquaculture practices has resulted in the prevalence of environmentally unfriendly fisheries practices, such as destructive fishing gear. Some fishermen still use trawl nets (Hilborn et al. 2023), fish bombs (Bai et al. 2024), and certain poisons that damage coastal ecosystems and threaten the sustainability of marine resources (Febriyanto & Setiaji, 2022). In addition, the lack of education and support for sustainable fisheries methods makes it difficult for coastal communities to switch to more environmentally friendly techniques (Nismawati et al. 2022). Existing regulations are often not optimally implemented, so violations continue without strict sanctions (Widayanti et al. 2022). Therefore, a more holistic approach is needed through education, more stringent policies, and incentives for fishermen who implement sustainable fisheries practices.

The lack of adaptive coastal education means environmental conservation materials are often not a significant part of the school curriculum. The lack of adaptive coastal education means environmental conservation is often not a substantial part of the school curriculum (Gough, 2017). As a result, young people in coastal areas lack an understanding of the importance of protecting coastal areas (Wootton et al. 2024), such as seagrass beds, coral reefs, and mangrove forests. In addition, limited teaching materials and lack of training for educators further exacerbate this condition (Leasa et al. 2023). Therefore, there is a need to reorient education to be more responsive to coastal issues and collaborate between schools, academics, and government to improve coastal communities' environmental literacy.

Interdisciplinary Roles in Reorienting Coastal Education

Reorienting education efforts requires an interdisciplinary-based research approach with specific roles from various fields of science. Interdisciplinary research involves experts from different disciplines integrating theories, methodologies, perspectives, and skills across fields in every research stage (Aboelela et al. 2007). However, interdisciplinary work faces three main obstacles: (1) the short-term nature of projects, (2) the challenges of sharing knowledge through networks and partnerships, and (3) limited data access and availability (Deininger et al. 2021). The interdisciplinary sciences that enable the reorientation of coastal education to support biodiversity literacy are marine science, agricultural science, educational science, social and political science, legal science, and academic management science.

Marine science

Marine science has a crucial role in analyzing the condition of coastal and marine ecosystems and their impact on biodiversity. An analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords marine science and coastal is presented in Figure 1. Marine science is closely related to coastal area management, especially in ecosystem conservation, policy, and climate change impacts. The bibliometric map generated using VOS viewer shows that the research that is often carried out revolves around the topics of citizen science (Falk-Andersson, 2019; Merlino, 2021), management (Thom, 2020; Turicchia, 2021), science (Birchenough, 2020), and review (Ferro-Azcona, 2019) which are indicated by large spheres. Large spheres suggest that much of the marine and coastal science research focuses on citizen science and how management and research are applied to the conservation, monitoring, and distribution of information related to the marine environment. The interconnections between topics show that coastal and marine resource management using scientific approaches and based on community participation are often studied together.

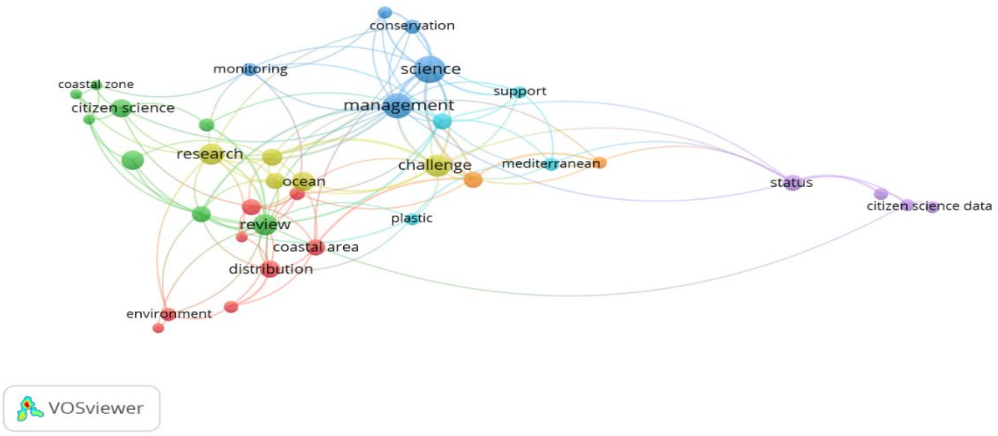

Figure 1. Bibliometric analysis: Relationship of research topics in marine science and coastal management

On the other hand, several topics in the field of marine science have received less attention, such as data science, coastal zones, and plastic. Data science uses data analysis technology to understand marine ecosystem patterns, environmental change, and evidence-based marine resource management. Research related to the coastal zone includes studies on the dynamics of coastal ecosystems, human interactions with coastal areas, and disaster mitigation strategies that are very important for people living there. Meanwhile, the topic of plastic highlights the impact of plastic pollution in the ocean, both on marine organisms and the overall health of the ecosystem. The lack of research on these topics indicates the need for more attention from researchers to develop studies that focus on utilizing scientific data in marine management, mapping and protecting coastal zones, and addressing plastic pollution. Thus, research results are expected to contribute to preserving marine ecosystems and support sustainable marine resource management policies.

Agricultural science

Agricultural science is essential in coastal area management, especially in supporting food security by developing aquaculture and sustainable fisheries. An analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords agriculture and coastal is presented in Figure 2. In agricultural sciences, research on climate change, land use, and ecological risks in coastal areas is often carried out. The prominence of these topics is indicated by the large spheres in keywords such as climate change (Chételat, 2022; Khan, 2015), land use (Ekumah, 2020), ecological risk (Mirzaei, 2020), and coastal area (Syakti, 2017). The linkages between these topics show that many studies focus on how climate change affects agricultural systems, especially land use and groundwater availability (Amiri, 2020; Narany, 2018). In addition, ecological risks are also widely studied in the context of agricultural sustainability in coastal areas, especially related to sediment pollution (Kahal, 2020) and heavy metal distribution (Jannat, 2023), which can affect soil productivity and agricultural yields.

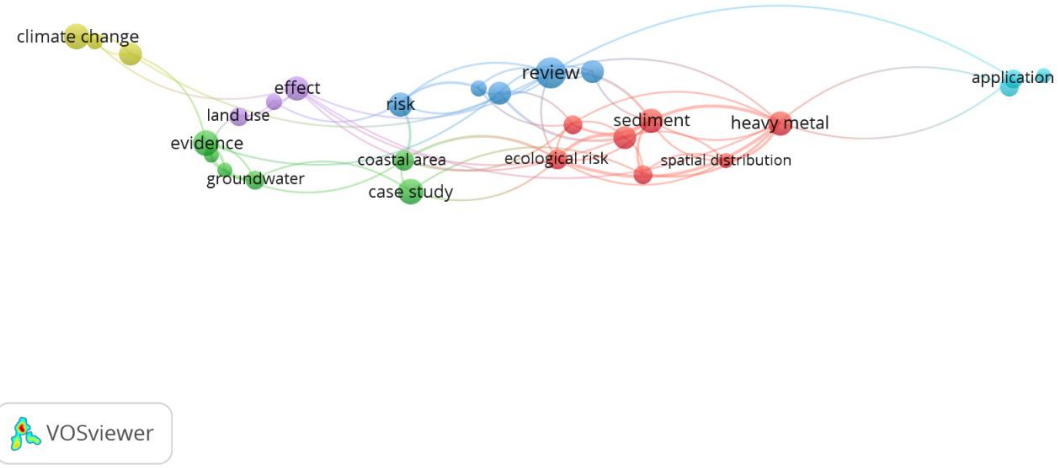

Figure 2. Bibliometric analysis: Relationship of research topics in agricultural science and coastal management

Although research in the field of agricultural science continues to grow, some topics still receive less attention, such as application, spatial, and distribution. The topic of application focuses on applying research results, technologies, or agricultural innovations directly in the field to increase the productivity and sustainability of farming systems. Meanwhile, spatial studies highlight aspects of agricultural resources' location and distribution patterns, such as the distribution of fertile land, crop types, or pest-prone areas, which are crucial in supporting data-based agrarian planning. The topic of distribution discusses how agricultural products, means of production, and technology are distributed to various regions to ensure equitable access and availability of resources. The lack of studies on these topics shows the need for more in-depth research so that agricultural research results are oriented towards innovation and consider their application in the field and distribution patterns to support food security and sustainable agricultural development.

Education science

Education science has a strategic role in improving the quality of human resources in coastal areas through various adaptive and contextual learning approaches. An analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords educational and coastal is presented in Figure 3. In the field of Education Science, frequent research focuses on perception (García-Llorente, 2020; Irani, 2021), community (Jadin, 2022), and evaluation (Yang, 2023). Figure 3 shows that many studies discuss how communities perceive education and how the education system in coastal areas is evaluated. In addition, there is a strong link between community (Jadin, 2022) and climate (Furmankiewicz, 2021), which indicates that the study of education in coastal areas is often

related to the impacts of climate change and how local communities respond to it. Coastal cities (Wang, 2023) and factors (Martin, 2020) also emerged as important topics, indicating that research often explores the factors that influence education in coastal cities.

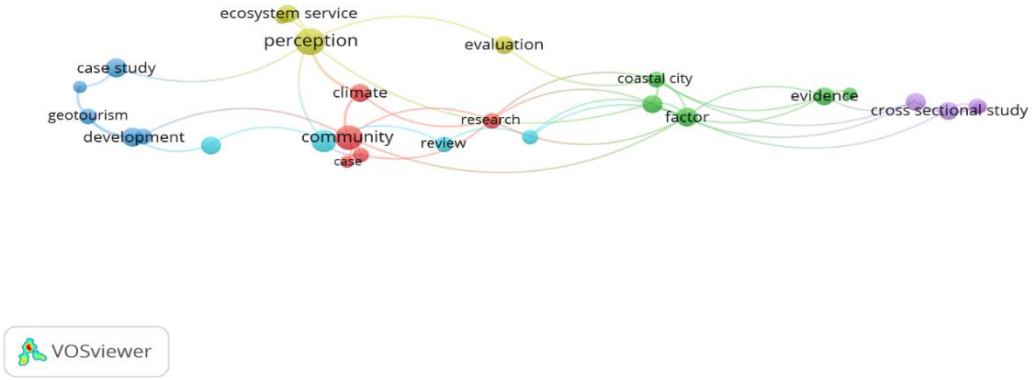

Figure 3. Bibliometric analysis: Relationship of research topics in education and coastal management science

Although research in Education Science in coastal areas continues to grow, several topics, such as tourism, coastal cities, and ecosystems, have received less attention. Geotourism focuses on utilizing the potential of geology and the coastal environment as a learning resource that combines education, tourism, and nature conservation. Meanwhile, the study of coastal cities highlights the social, economic, and environmental dynamics in coastal cities, including how education can play a role in raising public awareness of complex coastal issues. The ecosystem topic focuses on understanding coastal ecosystems as learning spaces that can improve biodiversity literacy and encourage education-based conservation practices. The lack of research on these topics shows the need for more in-depth and innovative studies in the future. Research that integrates the concepts of tourism, coastal city dynamics, and ecosystems in the context of education is expected to produce more effective, relevant, and sustainable learning strategies for coastal communities.

Legal science

Legal science is essential in regulating and protecting coastal areas through regulations and policies that support marine resource management and environmental conservation. Analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords law, coastal is presented in Figure 4. In the field of Legal Science, research that is often carried out is related to management (Gullestad, 2020; Halim, 2020), challenges and strategies (Arifanti, 2022), and reviews (Ding, 2021). Figure 4 shows that legal studies in coastal areas discuss how regulations and policies are managed and the challenges in their implementation. In addition, sea (Li, 2020) and monitoring (Bäuerlein, 2023) are topics that are often studied, indicating that there is attention to maritime law, especially in monitoring the marine environment and its influence on legal policies. The relationship between microplastics (Bissen, 2020) and the marine environment (Simeoni, 2023) also indicates that regulating marine pollution due to microplastics is an essential concern in coastal law studies.

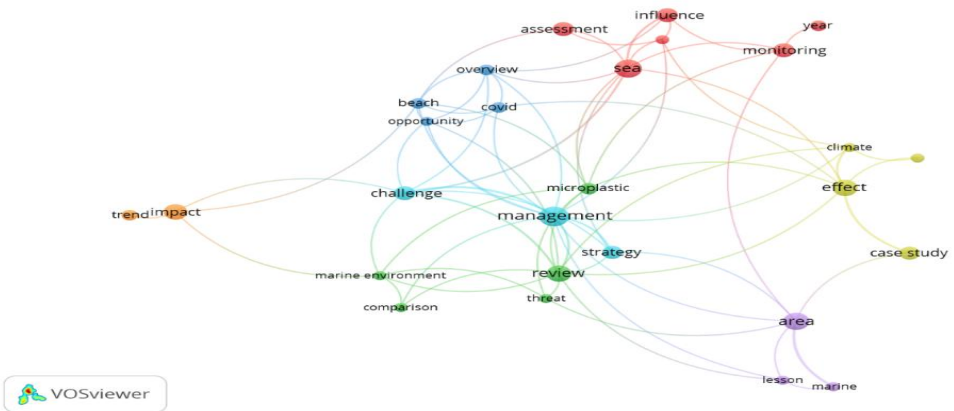

Figure 4. Bibliometric analysis: Relationship between research topics in law and coastal management

However, some topics, such as marine environment, microplastics, and climate, still have not received much attention in legal research. The marine environment topic focuses on the legal aspects governing protecting and managing marine ecosystems, including pollution-related policies, resource exploitation, and conservation efforts. Meanwhile, the microplastic topic highlights legal issues related to small plastic pollution that pollutes marine and coastal waters. The topic of climate change highlights the role of law in regulating mitigation and adaptation efforts to the impacts of climate change that affect coastal areas, such as sea level rise, coastal abrasion, and damage to coastal ecosystems. The lack of research on these topics shows the need for more attention from academics and legal researchers to develop studies focusing on marine environmental protection, regulation of microplastic pollution, and climate change adaptation policies. This research is expected to create more responsive and sustainable legal policies for marine ecosystems and coastal communities.

Social and political science

Social and political sciences play an essential role in water-related research, especially in assessing the socio-economic dynamics of coastal communities and the effectiveness of sustainable development policies. An analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords social, political, and coastal is presented in Figure 5. In the field of Social and Political Science, research that is often carried out centres on management (Alencar, 2020), case stud*ies* (Ryan, 2021), and approach (Celliers, 2020). Figure 5 shows that many studies in this field focus on how policies and management strategies are applied in the socio-political context of coastal areas. Topics such as climate change (Ekoh, 2023), vulnerability (Selvaraj, 2022), and sea level rise (Covi, 2021) also appear frequently, indicating that environmental issues have socio-political impacts. In addition, the link between knowledge (Celliers, 2021) and the global south (Kadfak, 2020) highlights the attention to coastal development in developing countries and the importance of knowledge-based research in coastal management.

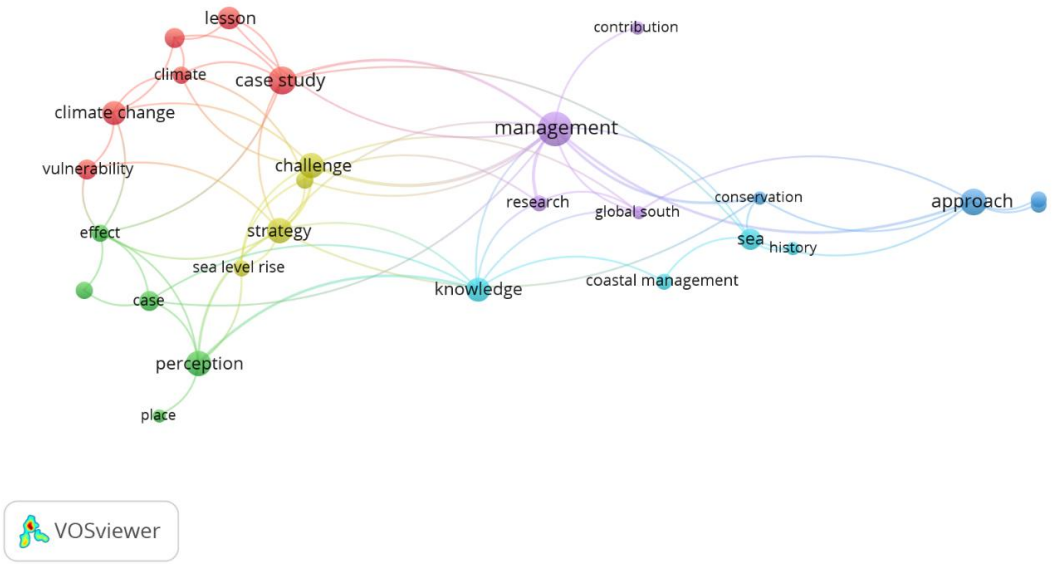

Figure 5. Bibliometric analysis: Relationship between research topics in social and political sciences and coastal management

However, some aspects of research have received less attention, such as conservation, coastal management, and history. Conservation in social and political studies focuses on the role of policy, culture, and community participation in environmental conservation efforts, especially in coastal areas. Meanwhile, the topic of coastal management highlights how public policy, resource governance, and community involvement can support the sustainable development of coastal areas. History focuses on the study of social, cultural, and political dynamics in coastal areas from time to time. The lack of research on these topics shows the need for more in-depth studies on the role of communities, public policies, and historical values in supporting coastal conservation and management efforts. With more comprehensive research, more effective and sustainable policy recommendations for coastal areas are expected.

Education management science

Education Management Science in the aquatic context focuses on management strategies of educational institutions, curricula, and policies relevant to coastal areas. An analysis of 200 Scopus-indexed articles from 2015 to 2025 with the search keywords education management and coastal is presented in Figure 6. In the field of

Education Management Science, frequent research is related to management (Palm, 2021), impact (Chetty, 2022), and perception (Mukarram, 2023). These three aspects show that many studies in this field discuss how education management has an impact on various factors, such as policy evaluation (Morante-Carballo, 2023), resource conservation (Adams, 2023), and community readiness to accept change (Suryawan, 2024). In addition, a case study-based approach is often used to analyze various perspectives on implementing education policies in coastal communities and urban environments. This topic shows that education management focuses on administrative aspects and how the community accepts and adapts policies.

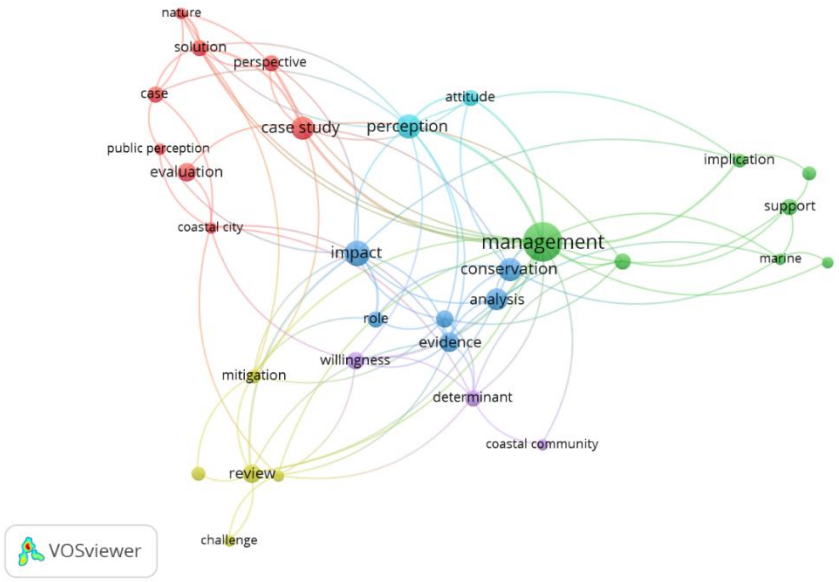

Figure 6. Bibliometric analysis: Relationship between research topics in education management and coastal management

Although research in education management continues to grow, some topics are under-explored, such as implication, support, mitigation, and coastal community. The implication topic focuses on the impact of education policy on the quality of learning, access to education, and human resource development in coastal areas. Meanwhile, the topic of support highlights the importance of the involvement of various parties, such as the government, educational institutions, non-governmental organizations, and communities, in creating an inclusive and sustainable education ecosystem in coastal areas. The mitigation topic relates to educational strategies and policies in dealing with challenges often faced by coastal communities, such as natural disasters, climate change, or limited educational infrastructure. The coastal community topic focuses on developing an education model that suits coastal communities' needs, social characteristics, and local potential. The lack of studies on these topics shows the need for more in-depth research related to the role of education management in supporting access, quality, and relevance of education in coastal areas. This research will produce effective strategies to sustainably improve coastal communities' literacy, skills, and welfare.

Coastal education reorientation strategy for biodiversity literacy

Figure 7 presents the linkages between the three aspects, namely Coastal Resources, Biodiversity Literacy, and Education Reorientation, in building sustainable coastal areas. Coastal resources include coastal biodiversity such as coral reefs, mangroves, seagrass beds, and local wisdom in utilizing biodiversity values. Biodiversity literacy emphasizes understanding coastal ecosystems and attitudes and actions supporting environmental sustainability. Meanwhile, education reorientation focuses on teaching methods, learning media, and formal and non-formal skills to increase community awareness and skills in managing coastal areas.

Figure 7 shows the intersection of the three aspects of coastal resources: biodiversity literacy and education reorientation. Coastal education emerges from the intersection of coastal resources and biodiversity literacy, emphasizing the importance of environmentally based learning. An integrative approach to coastal management links coastal resources with education, ensuring that resource management is science-based. An interdisciplinary approach is key to developing sustainable coastal areas, linking different disciplines to create holistic and practical solutions.

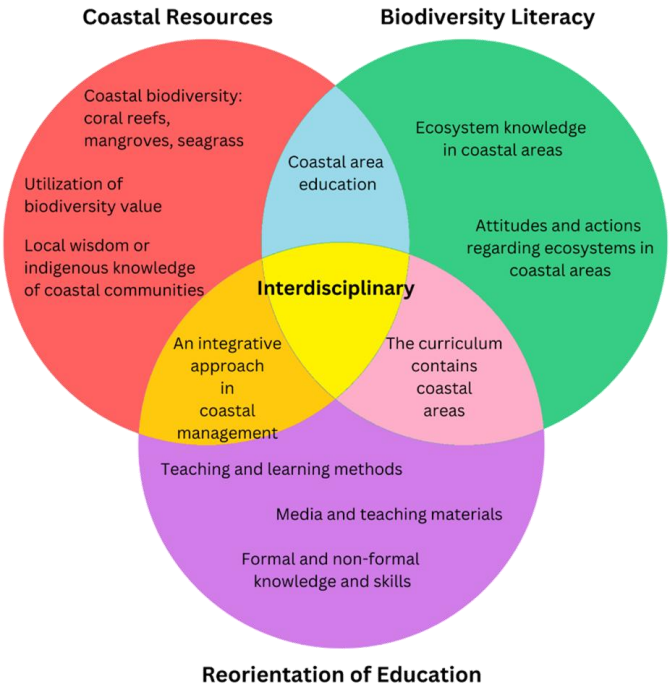

Figure 7. Linkages between coastal resources, biodiversity literacy, and education reorientation in building sustainable coastal areas

Figure 7 also highlights coastal resources, including aquatic ecosystems such as coral reefs, mangroves, and seagrass beds, which are essential elements in marine ecosystems. SDG 14 focuses on the conservation and sustainable use of marine resources. The education reorientation section in the diagram shows SDG 4, which is how education can significantly improve understanding of the coastal environment. Coastal curricula, innovative teaching methods, and teaching media and materials contribute to enhanced biodiversity literacy and better management of marine resources. Mangroves and seagrass beds, mentioned in the Coastal Resources section, serve as natural carbon sinks that can mitigate the impacts of climate change. This diagram emphasizes that education, coastal ecosystem conservation, and climate action are interconnected in realizing sustainable development. By integrating these three aspects, we not only protect marine biodiversity (SDG 14) but also improve the quality of education (SDG 4) and strengthen people's resilience to climate change (SDG 13).

Based on interdisciplinary analysis, strategies for reorienting education in coastal areas can be carried out by integrating coastal conservation-based curriculum, increasing the capacity of teachers and communities, cross-sector collaboration in coastal education, utilizing digital technology, and strengthening policies and regulations. Integration of a conservation-based curriculum can be done through 1) developing learning modules that combine marine ecology concepts with social, economic, and legal aspects and 2) involving scientists and practitioners from various fields in the preparation of teaching materials that apply to coastal communities. One crucial step that can be taken is to increase the capacity of teachers and communities.

Capacity building for teachers and communities can be done through 1) training for educators to have a broader insight into coastal biodiversity and conservation and 2) counselling coastal communities on the impacts of resource exploitation and sustainability-based economic alternatives. Cross-sector collaboration in coastal education can be achieved through two key strategies: 1) building partnerships between universities, government, NGOs, and communities to support coastal education, and 2) developing an eco-education centre model in coastal areas as a hub for environment-based learning and innovation. The utilization of digital technology can support these steps.

Digital technology can be utilized by 1) developing online-based learning platforms to expand access to information for students and college students in coastal areas and 2) utilizing social media and interactive educational applications to raise awareness about biodiversity. This step aligns with SDG 4's goal of inclusive and equitable quality education. Strengthening policies and regulations can be done by 1) encouraging policies that support conservation education in coastal schools and 2) optimizing law enforcement against destructive marine resource exploitation activities.

Local wisdom, such as *Sasi* in Maluku, can be optimized by strengthening community monitoring, involving traditional leaders, and consistently enforcing customary rules. Continuous socialization is also crucial so that people understand and support *Sasi* as an effective strategy in marine resource management. Meanwhile, offline-

first learning media such as digital modules and local educational videos can support education in coastal areas with limited digital access. This approach strengthens marine resource conservation and sustainably improves community literacy, in line with SDG 14 on sustainable marine ecosystems and SDG 13 on addressing climate change through education and local action.

CONCLUSION

Reorienting education in coastal areas through an interdisciplinary approach is key to improving biodiversity literacy and supporting sustainable development. Reorienting education in coastal areas requires an interdisciplinary approach to improve biodiversity literacy and support sustainable development. Marine Science, Agricultural Science, Education Science, Social and Political Science, Legal Science, and Education Management Science are some fields that can play a role in understanding, managing, and protecting coastal resources, such as coral reefs, mangrove forests, and seagrass beds. This cross-disciplinary collaboration enables the creation of adaptive and community-based education strategies while equipping coastal communities with sustainable marine resource management skills. Coastal resources can also be studied through local wisdom, such as *Sasi* in the Maluku islands. This approach is in line with the Sustainable Development Goals (SDGs), particularly goals 4 (Quality Education), 13 (Climate Change Management) and 14 (Marine Ecosystems). With the proper policy support and synergy between academics, government, and the community, an interdisciplinary approach can produce a coastal generation that is environmentally aware, able to adapt to the challenges of the times and play an active role in maintaining the sustainability of marine ecosystems.

CONFLICTS OF INTEREST

The authors declare that they have no competition interest in this work

REFERENCES

Aboelela, S. W., Larson, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S. A., Haas, J., & Gebbie, K. M. (2007). Defining interdisciplinary research: Conclusions from a critical review of the literature. *Health Services Research*, 42(1I), 329–346. https://doi.org/10.1111/j.1475-6773.2006.00621.x

Adams, A. (2023). Conservation connections: incorporating connectivity into management and conservation of flats fishes and their habitats in a multi-stressor world. *Environmental Biology of Fishes*, 106(2), 117–130. https://doi.org/10.1007/s10641-023-01391-4

Ahmad, M., Satria, A., & Kinseng, R.A. (2017). Sasi laut in Maluku: Transformation and sustainability of traditional governance in the face of globalisation. In *Governing the Coastal Commons* (1st ed., p. 198). Taylor & Francis Group.

Akram, H., Hussain, S., Mazumdar, P., Chua, K. O., Butt, T. E., & Harikrishna, J. A. (2023). Mangrove health: A review of functions, threats, and challenges associated with mangrove management practices. *Forests*, 14(9), 1–38. https://doi.org/10.3390/f14091698

Alencar, N. M. P. de. (2020). Circles of coastal sustainability: A framework for coastal management. *Sustainability (Switzerland)*, 12(12). https://doi.org/10.3390/SU12124886

Alongi, D. M. (2016). Mangroves. In *Encyclopedia of Estuaries*. https://doi.org/10.1007/978-94-017-8801-4

Amiri, V. (2020). Fluoride occurrence and human health risk from groundwater use at the west coast of Urmia Lake, Iran. *Arabian Journal of Geosciences*, 13(18), https://doi.org/10.1007/s12517-020-05905-7

Aramburu, P. A., Flecha, S., Lujan-Williams, C. A. M., & Hendriks, I. E. (2024). Water column oxygenation by Posidonia oceanica seagrass meadows in coastal areas: A modelling approach. *Science of the Total Environment*, 942, 173805. https://doi.org/10.1016/j.scitotenv.2024.173805

Arifanti, V. B. (2022). Challenges and strategies for sustainable Mangrove management in Indonesia: A Review. *Forests*, 13(5). https://doi.org/10.3390/f13050695

Bai, Y., Hu, R., Wang, L., & Li, D. (2024). Reduce pollution, establish protected areas, manage fisheries properly? How to protect coral reefs based on carbon trading. *Frontiers in Marine Science*, 11, 1–17. https://doi.org/10.3389/fmars.2024.1331045

Bäuerlein, P. S. (2023). A monitoring and data analysis method for microplastics in marine sediments. *Marine Environmental Research*, 183. https://doi.org/10.1016/j.marenvres.2022.105804

Bellwood, D. R., Streit, R. P., Brandl, S. J., & Tebbett, S. B. (2019). The meaning of the term 'function' in ecology: A coral reef perspective. *Functional Ecology*, 33(6), 948–961. https://doi.org/10.1111/1365-2435.13265

Betaubun, A. D. S., Laiyanan, S. E. B., Renyaan, D., & Pentury, F. (2019). Persepsi penerapan sasi laut di wilayah perairan Kepulauan Kei: Upaya mendukung keberlanjutan sumber daya laut. *Agrikan: Jurnal Agribisnis Perikanan*, 12(1), 136. https://doi.org/10.29239/j.agrikan.12.1.136-144

Bhowmik, A. K., Padmanaban, R., Cabral, P., & Romeiras, M. M. (2022). Global mangrove deforestation and its interacting social-ecological drivers: A systematic review and synthesis. *Sustainability (Switzerland)*, 14(8), 1–24. https://doi.org/10.3390/su14084433

Bibi, S. N., Fawzi, M. M., Gokhan, Z., Rajesh, J., Nadeem, N., Rengasamy Kannan, R. R., Albuquerque, R. D. D. G., & Pandian, S. K. (2019). Ethnopharmacology, phytochemistry, and global distribution of mangroves-a comprehensive review. *Marine Drugs*, 17(4). https://doi.org/10.3390/md17040231

Birchenough, S. N. R. (2020). Science in support of ecologically sound decommissioning strategies for offshore man-made structures: Taking stock of current knowledge and considering future challenges. *ICES Journal of Marine Science*, 77(3), 1075–1078. https://doi.org/10.1093/icesjms/fsaa039

Bissen, R. (2020). Microplastics on beaches along the eastern Gulf of Thailand – A preliminary study. *Marine Pollution Bulletin*, 157. https://doi.org/10.1016/j.marpolbul.2020.111345

Biswas, P., & Biswas, S. R. (2021). Mangrove forests: Ecology, management, and threats. In *Mangrove Forests: Ecology, Management, and Threats*. https://doi.org/10.1007/978-3-319-95981-8

Børresen, S. T., Ulimboka, R., Nyahongo, J., Ranke, P. S., Skjaervø, G. R., & Røskaft, E. (2022). The role of education in biodiversity conservation: Can knowledge and understanding alter locals' views and attitudes towards ecosystem services? *Environmental Education Research*. https://doi.org/10.1080/13504622.2022.2117796

Cavanagh, R. D., Melbourne-Thomas, J., Grant, S. M., Barnes, D. K. A., Hughes, K. A., Halfter, S., Meredith, M. P., Murphy, E. J., Trebilco, R., & Hill, S. L. (2021). Future risk for southern ocean ecosystem services under climate change. *Frontiers in Marine Science*, 7. https://doi.org/10.3389/fmars.2020.615214

Celliers, L. (2020). A capital approach for assessing local coastal governance. *Ocean and Coastal Management*, 183. https://doi.org/10.1016/j.ocecoaman.2019.104996

Celliers, L. (2021). Negotiation of knowledge for coastal management? Reflections from a transdisciplinary experiment in South Africa. *Humanities and Social Sciences Communications*, 8(1). https://doi.org/10.1057/s41599-021-00887-7

Chaijaroen, P. (2016). Coral reef deterioration and livelihoods of coastal communities: An economics perspective. *Intech*, 1, 13. https://doi.org/http://dx.doi.org/10.5772/57353

Chételat, J. (2022). Climate change and mercury in the Arctic: Abiotic interactions. *Science of the Total Environment*, 824. https://doi.org/10.1016/j.scitotenv.2022.153715

Chetty, P. (2022). Impact of environmental education on waste disposal behavior of Beachgoers on the Durban Central Beachfront. *African Journal of Hospitality, Tourism and Leisure*, 11(6), 1899–1912. https://doi.org/10.46222/ajhtl.19770720.331

Covi, M. P. (2021). Sea level rise hazardscapes of North Carolina: Perceptions of risk and prospects for policy. *Ocean and Coastal Management*, 212. https://doi.org/10.1016/j.ocecoaman.2021.105809

Deininger, A., Martin, A. H., Pardo, J. C. F., Berg, P. R., Bhardwaj, J., Catarino, D., Fernández-Chacón, A., Martinez-Swatson, K., Ono, K., Oomen, R. A., Sodeland, M., Sørdalen, T. K., Synnes, A. E. W., Thorbjørnsen, S. H., & Thormar, J. (2021). Coastal research seen through an early career lens—A perspective on barriers to interdisciplinarity in Norway. *Frontiers in Marine Science*, 8. https://doi.org/10.3389/fmars.2021.634999

Dharmawan, I. W. E., Renyaan, J., & Nurdiansah, D. (2022). Mangrove zonation, community structure and healthiness in Kei Islands, Maluku, Indonesia. *Biodiversitas*, 23(9), 4918–4927. https://doi.org/10.13057/biodiv/d230962

Ding, Y. (2021). A review of China's municipal solid waste (MSW) and comparison with international regions: Management and technologies in treatment and resource utilization. In *Journal of Cleaner Production*, 293. https://doi.org/10.1016/j.jclepro.2021.126144

Duke, N. C. (2011). Mangrove. In *Encyclopedia of Modern Coral Reefs* (Issue December). https://doi.org/10.1007/978-90-481-2639-2

Efe, H. A., & Efe, R. (2022). An investigation of secondary school students' biodiversity literacy level. *Dinamika Ilmu*, 20(2), 237–249.

Ekoh, S. S. (2023). Climate change and coastal megacities: Adapting through mobility. *Global Environmental Change*, *80*. https://doi.org/10.1016/j.gloenvcha.2023.102666

Ekumah, B. (2020). Assessing land use and land cover change in coastal urban wetlands of international importance in Ghana using Intensity Analysis. *Wetlands Ecology and Management*, 28(2), 271–284. https://doi.org/10.1007/s11273-020-09712-5

Elegbede, I. O., Kies, F., & Jolaosho, T. L. (2020). Marine and coastal resources. *Encyclopedia of Sustainable Management* (Issue December). https://doi.org/10.1007/978-3-030-02006-4

Falk-Andersson, J. (2019). Citizen science for better management: Lessons learned from three Norwegian beach litter data sets. *Marine Pollution Bulletin*, 138, 364–375. https://doi.org/10.1016/j.marpolbul.2018.11.021
Febriyanto, T., & Setiaji, M. L. (2022). Illegal fishing by other countries: Complicated law enforcement in Indonesia. *Indonesian Journal of Environmental Law and Sustainable Development*, *1*(2), 189–212. https://doi.org/10.15294/ijel.v1i2.58123
Ferro-Azcona, H. (2019). Adaptive capacity and social-ecological resilience of coastal areas: A systematic review. In *Ocean and Coastal Management. 173*, 36–51. https://doi.org/10.1016/j.ocecoaman.2019.01.005
Fitrian, t., Kusnadi, A., & Persilette, R. N. (2017). Seagrass community structure of Tayando-Tam Island, Southeast Moluccas, Indonesia. *Biodiversitas Journal of Biological Diversity*, 18(2), 788–794. https://doi.org/10.13057/biodiv/d180246
Furmankiewicz, M. (2021). Climate change challenges and community-led development strategies: Do they fit together in fisheries regions? *Energies*, 14(20). https://doi.org/10.3390/en14206614
García-Llorente, M. (2020). Local perceptions of ecosystem services across multiple ecosystem types in Spain. *Land*, 9(9). https://doi.org/10.3390/LAND9090330
Gough, A. (2017). Educating for the marine environment: Challenges for schools and scientists. *Marine Pollution Bulletin*, 124(2), 633–638. https://doi.org/10.1016/j.marpolbul.2017.06.069
Gullestad, P. (2020). Management of transboundary and straddling fish stocks in the Northeast Atlantic in view of climate-induced shifts in spatial distribution. *Fish and Fisheries*, 21(5), 1008–1026. https://doi.org/10.1111/faf.12485
Halim, A. (2020). Transforming traditional management into contemporary territorial-based fisheries management rights for small-scale fisheries in Indonesia. *Marine Policy*, 116. https://doi.org/10.1016/j.marpol.2020.103923
Harborne, A. R., Rogers, A., Bozec, Y.-M., & Mumby, P. J. (2017). Multiple stressors and the functioning of coral reefs. *Annual Review of Marine Science*, 9(1), 445–468. https://doi.org/10.1146/annurev-marine-010816-060551
Hilborn, R., Amoroso, R., Collie, J., Hiddink, J. G. J., Kaiser, M. J., Mazor, T., Mcconnaughey, R. A., Parma, A. M., Pitcher, C. R., Sciberras, M., & Suuronen, P. (2023). Evaluating the sustainability and environmental impacts of trawling compared to other food production systems. *ICES Journal of Marine Science*, 80(6), 1567–1579. https://doi.org/10.1093/icesjms/fsad115
Hnatyuk, V., Pshenychna, N., Kara, S., Kolodii, V., & Yaroshchuk, L. (2024). Education's role in fostering environmental awareness and advancing sustainable development within a holistic framework. *Multidisciplinary Reviews*, 7(Special Issue). https://doi.org/10.31893/multirev.2024spe012
Huijting, H., & Goldewijk, A. (2024). *The distribution of seagrass meadows in the mediterranean sea: Its changes and implications for climate change*. Utrecht University.
Ibrahim, M. S. N., Assim, M. I. S. A., Johari, S., Mohammad, S. K. W., Afandi, S. H. M., & Hassan, S. (2023). Public awareness on biodiversity conservation and well-being: case of Gunung Mulu National Park, Sarawak. *GeoJournal*, 88(3), 3471–3496. https://doi.org/10.1007/s10708-022-10818-x
Irani, T. (2021). Agricultural stakeholders' perceptions of occupational health and safety in the southeastern U.S. coastal states. *International Journal of Environmental Research and Public Health*, 18(12). https://doi.org/10.3390/ijerph18126605
Jadin, J. (2022). Local community attitudes towards mangrove forest conservation. *Journal for Nature Conservation*, 68. https://doi.org/10.1016/j.jnc.2022.126232
Jannat, J. N. (2023). Pollution trends and ecological risks of heavy metal(loid)s in coastal zones of Bangladesh: A chemometric review. In *Marine Pollution Bulletin*, 191). https://doi.org/10.1016/j.marpolbul.2023.114960
Kadfak, A. (2020). An (Urban) political ecology approach to small-scale fisheries in the global south. *Geoforum*, 108, 237–245. https://doi.org/10.1016/j.geoforum.2019.11.008
Kahal, A. (2020). Contamination and ecological risk assessment of the Red Sea coastal sediments, southwest Saudi Arabia. *Marine Pollution Bulletin*, 154. https://doi.org/10.1016/j.marpolbul.2020.111125
Kennedy, P. S. J., Tobing, S. J. L., Lina, S., Heatubun, A. B., Tampubolon, E., & Toruan, R. T. (2019). Diskusi mengenai program pendidikan tinggi di wilayah perbatasan Kabupaten Maluku Barat Daya. *Kolaborasi Inovatif Pengabdian Kepada Masyarakat*, 348–355.
Khairnar, S. O., Angad, G., & Veterinary, D. (2018). Mangrove ecosystem- Its threats and conservation. *Aquafind*, 1–5.
Khan, A. (2015). Assessing climate change readiness in Seychelles: implications for ecosystem-based adaptation mainstreaming and marine spatial planning. *Regional Environmental Change*, 15(4), 721–733. https://doi.org/10.1007/s10113-014-0662-4
Koning, A. A., & McIntyre, P. B. (2021). Grassroots reserves rescue a river food web from cascading impacts of overharvest. *Frontiers in Ecology and the Environment*, 19(3), 152–158. https://doi.org/10.1002/fee.2293

Kumar, A., Anju, T., Archa, V., Warrier, V. P., Kumar, S., Goud, G. S., Kashyap, A. K., Singh, S., Komal, Singh, P., Kumar, R., Sharma, S., Radhakrishnan, A. M., & Ramchiary, N. (2021). Mangrove forests: Distribution, species diversity, roles, threats and conservation strategies. In *Wetlands Conservation: Current Challenges and Future Strategies,* (Issue September). https://doi.org/10.1002/9781119692621.ch12

Kurniawan, A. (2016). Education for marginalized communities as alternative solution an the coastal areas. *Cendekia: Journal of Education and Society*, 14(2), 175. https://doi.org/10.21154/cendekia.v14i2.821

Latuconsina, H., & Buano, T. (2021). Biodiversity and density of marine intertidal gastropods in tropical seagrass meadows on Gorom Island, East Seram, Maluku, Indonesia. *Animal Biology & Animal Husbandry*, 13(2), 74–83.

Leasa, M., Batlolona, J. R., & Jamaludin. (2023). Islands education studies and challenges in learning science. *Jurnal Penelitian dan Pengembangan Pendidikan*, *7*(1), 79–87. https://doi.org/10.23887/jppp.v7i1.55810

Lelloltery, H., Rumanta, M., & Kunda, R. M. (2021). Strategy for marine ecotourism development based on natural resource management: Case study in Kotania Bay, Western Seram District, Maluku, Indonesia. *Nusantara Bioscience*, 13(1), 91–99. https://doi.org/10.13057/nusbiosci/n130113

Li, F. (2020). Change of sea reclamation and the sea-use management policy system in China. *Marine Policy*, 115. https://doi.org/10.1016/j.marpol.2020.103861

Lima, M. do A. C., Bergamo, T. F., Ward, R. D., & Joyce, C. B. (2023). A review of seagrass ecosystem services: providing nature-based solutions for a changing world. *Hydrobiologia*, 850(12–13), 2655–2670. https://doi.org/10.1007/s10750-023-05244-0

Limmon, G. V., & Manuputty, G. D. (2021). Coral reef condition at north coastal of Haruku Island Maluku Tengah. *IOP Conference Series: Earth and Environmental Science*, 777(1). https://doi.org/10.1088/1755-1315/777/1/012042

Lokollo, F. F., Sangaji, S. N., Loupatty, S. R., & Pattiasina, T. F. (2022). Community structure and spatial distribution of seagrass in Tulehu coastal waters, Central Maluku Regency, Indonesia. *AACL*, 15. http://www.bioflux.com.ro/aacl

Maiti, S. K., & Chowdhury, A. (2013). Effects of anthropogenic pollution on mangrove biodiversity: A review. *Journal of Environmental Protection*, 04(12), 1428–1434. https://doi.org/10.4236/jep.2013.412163

Manangkalangi, E., Sembel, L., Tebaiy, S., Manuputty, A., Rumayomi, M. R., Musyeri, P., Sawaki, D., Orissu, D., Manumpil, A. W., & Kaber, Y. (2022). Evaluation of seagrass beds as a foraging and nursery habitat based on the structure of the fish community in Nusmapi Island, West Papua, Indonesia. *Biodiversitas*, 23(10), 5165–5174. https://doi.org/10.13057/biodiv/d231024

Martika, L. D., Hamzah, A., & Puspasari, O. R. (2024). The dynamics of financial literacy and accounting literacy in coastal communities. *Jurnal Akuntansi*, 28(2), 300–318. https://doi.org/10.24912/ja.v28i2.1856

Martin, S. (2020). Factors associated with early childhood stunted growth in a 2012-2015 birth cohort monitored in the rural Msambweni area of coastal Kenya: A cross-sectional study. *BMC Pediatrics*, 20(1). https://doi.org/10.1186/s12887-020-02110-z

McCauley, V., McHugh, P., Davison, K., & Domegan, C. (2019). Collective intelligence for advancing ocean literacy. *Environmental Education Research*, 25(2), 280–291. https://doi.org/10.1080/13504622.2018.1553234

Merlino, S. (2021). Citizen science for marine litter detection and classification on unmanned aerial vehicle images. *Water (Switzerland)*, 13(23). https://doi.org/10.3390/w13233349

Mirzaei, M. (2020). Spatial-seasonal variations and ecological risk of heavy metals in Persian gulf coastal region: Case study of Iran 05 Environmental Sciences 0502 Environmental Science and Management 04 Earth Sciences 0402 Geochemistry. *Journal of Environmental Health Science and Engineering*, 18(1), 91–105. https://doi.org/10.1007/s40201-019-00441-3

Morante-Carballo, F. (2023). Evaluation of the potential of coastal cliffs as geosites for the promotion of geotourism. *Geography and Sustainability*, 4(4), 356–371. https://doi.org/10.1016/j.geosus.2023.08.003

Moss, Andrew., Jensen, Eric., & Gusset, Markus. (2014). *A global evaluation of biodiversity literacy in zoo and aquarium visitors* (Issue October). WAZA Executive Office.

Mualo, A., Tuhumena, L., Hisyam, M., Rumahorbo, B. T., Hamzah, H., Wambrauw, D. Z. K., & Manalu, K. A. A. (2024). *Diversity of coral reef and reef fish in Isau Island, Central Maluku, Indonesia*. *AACL*, 17. http://www.bioflux.com.ro/aacl

Muin, A., & Rakuasa, H. (2023). Sasi laut as a culture of natural resources conservation to overcome the tragedy of the commons in Maluku Province. *International Journal of Multidisciplinary Approach Research and Science*, 1(03), 277–287. https://doi.org/10.59653/ijmars.v1i03.139

Mukarram, M. M. T. (2023). Perception of coastal citizens on the prospect of community-based rainwater harvesting system for sustainable water resource management. *Resources, Conservation and Recycling*, 198. https://doi.org/10.1016/j.resconrec.2023.107196

Nadia Putri Rachma Persada, Fachruddin M Mangunjaya, & Imran S L Tobing. (2018). Sasi sebagai budaya konservasi sumber daya alam di Kepulauan Maluku. *Ilmu Dan Budaya*, 41(59), 6869–6900.

Namakule, U., Rehena, J. F., & Rumahlatu, D. (2017). Seagrass community structure in various zones in coastal waters of Haya village, Central Moluccas district. *AACL*, 10. http://www.bioflux.com.ro/aacl

Narany, T. S. (2018). The long-term impacts of anthropogenic and natural processes on groundwater deterioration in a multilayered aquifer. *Science of the Total Environment*, 630, 931–942. https://doi.org/10.1016/j.scitotenv.2018.02.190

Nismawati, N., Oruh, S., Kamaruddin, S. A., Agustang, A., & Wirda, M. A. (2022). Awareness of the importance of children's education in the small island fisherman community (Case study of Liukang Loe Island). *Jurnal Geografi*, 15(1), 12. https://doi.org/10.24114/jg.v15i1.34027

O'Brien, M., Freitas, C., Venzo, P., & Francis, P. (2023). Fostering ocean literacy through informal marine education programs. *Marine Pollution Bulletin*, 193(May). https://doi.org/10.1016/j.marpolbul.2023.115208

OECD. (2021). *Adapting to a changing climate in the management of wildfires* (Issue ENV/EPOC/WPCID(2021)6).

Palm, K. E. (2021). Management of local fisheries: A case study of Laoang, Northern Samar, Philippines. *Marine Policy*, 132. https://doi.org/10.1016/j.marpol.2021.104657

Sipahelut, P., Wakano, D., & Sahertian, D.E. (2019). Keanekaragaman jenis dan dominansi mangrove di pesisir pantai Desa Sehati Kecamatan Amahai, Kabupaten Maluku Tengah. *BIOSEL (Biology Science and Education): Jurnal Penelitian Science Dan Pendidikan*, 8(2), 160–170.

Penniman, T. (2021). *Coral reefs: Strategies for ecosystems on the edge* (pp. 1–10). International Institute for Sustainable Development.

Perry, C. T., Salter, M. A., Lange, I. D., Kochan, D. P., Harborne, A. R., & Graham, N. A. J. (2022). Geo-ecological functions provided by coral reef fishes vary among regions and impact reef carbonate cycling regimes. *Ecosphere*, 13(12), 1–20. https://doi.org/10.1002/ecs2.4288

Prasad, H., Desai, A. Y., Temkar, G. S., & Neelmani. (2023). Coral reef: Their importance, threats and conservation strategies. 13, 65–68.

Ryan, C. (2021). Social consequences of airbnb–a New Zealand case study of cause and effect. *Journal of Sustainable Tourism*, 29(10), 1565–1585. https://doi.org/10.1080/09669582.2020.1860073

Saengsupavanich, C., Agarwala, N., Magdalena, I., Ratnayake, A. S., & Ferren, V. (2024). Impacts of a growing population on the coastal environment of the Bay of Bengal. *Anthropocene Coasts*, 7(1). https://doi.org/10.1007/s44218-024-00055-9

Sahetapy, D., Limon, G. V., Tetelepta, J. M. S., Pattikawa, J. A., Rijoly, F., Masrikat, J. A. N., & Loupatty, S. R. (2021). Coral reef condition in the coastal waters of Kei Besar Island, Southeast Maluku-Indonesia. *IOP Conference Series: Earth and Environmental Science*, 805(1). https://doi.org/10.1088/1755-1315/805/1/012002

Salampessy, M. L., Nugroho, B., Kartodiharjo, H., & Kusmana, C. (2024). Local institutions performance in mangrove forest management on small islands: Case study in Buano Island, Maluku Province, Indonesia. *Jurnal Sylva Lestari*, 12(2), 296–323. https://doi.org/10.23960/jsl.v12i2.840

Selvaraj, J. J. (2022). The economic vulnerability of fishing households to climate change in the south Pacific region of Colombia. *Heliyon*, 8(5). https://doi.org/10.1016/j.heliyon.2022.e09425

Shahnaz, L., & Syaprillah, A. (2022). Legal management of natural resources in coastal region of Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1083(1). https://doi.org/10.1088/1755-1315/1083/1/012034

Sholeh, S., Evianovita, D. I. N., Mayasari, A. Y., & Sudewo, A. A. (2024). The role of the community in the vevelopment of mangrove forest ecotourism in Pasar Banggi, Rembang Regency. *Indonesian Journal of Environment and Disaster*, 3(1), 121–132. https://doi.org/10.20961/ijed.v3i1.1207

Short, F. T., Short, C. A., & Novak, A. B. (2016). Seagrasses. In: C.M. Finlayson, G.R. Milton, R.C. Prentice and N.C. Davidson (eds.). In *The Wetland Book: II: Distribution, Description and Conservation*. *Springer*, (Issue February).. https://doi.org/10.1007/978-94-007-6173-5

Simeoni, C. (2023). Evaluating the combined effect of climate and anthropogenic stressors on marine coastal ecosystems: Insights from a systematic review of cumulative impact assessment approaches. *Science of the Total Environment*, 861. https://doi.org/10.1016/j.scitotenv.2022.160687

Sitanala, R. S. D. (2018). Efektifitas penegakan hukum terhadap eksploitasi sumber daya perikanan di Zona Ekonomi Eksklusif ditinjau dari Undang-Undang Nomor 5 Tahun 1983. *Sasi*, 24(2), 161–167.

Steven, A., Addo, K. A., Llewellyn, G., Ca, V. T., Boateng, I., Bustamante, R., Doropoulos, C., Gillies, C., Hemer, M., Lopes, P., Kairo, J., Rahman, M., Ravaoarinorotsihoarana, L. A., Saunders, M., Sumaila, U. R., Sidik, F., Teh, L., Vanderklift, M., & Vozzo, M. (2023). Coastal development: Resilience, restoration and infrastructure requirements. *The Blue Compendium*. https://doi.org/10.1007/978-3-031-16277-0_7

Sukandar, Samuel, P. D., Dewi, C. S. U., Pratiwi, I. D., Anam, M. C., Beno, J. E., & Fatmawati, R. (2022). Current status of the coral reef ecosystem in Gresik Regency, East Java. *AACL Bioflux*, 15(4), 1692–1702.

Sultana, S., Huang, R., Van Zwieten, L., Wang, H., & Wu, J. (2023). Trapping effect of mangrove and saltmarsh habitats on geochemical elements: a case study in Ximen Island, Zhejiang, China. *Journal of Soils and Sediments*, 23(6).

Supriyadi, I. H., Iswari, M. Y., Rahmawati, S., Riniatsih, I., Suyarso, & Hafizt, M. (2024). Seagrass ecosystems in Eastern Indonesia: Status, diversity, and management challenges. *Ilmu Kelautan: Indonesian Journal of Marine Sciences*, 29(4), 503–518. https://doi.org/10.14710/ik.ijms.29.4.503-518

Suryawan, I. W. K. (2024). Importance-performance dynamics and willingness to pay in coastal areas for climate-adaptive Marine Debris Management. *Regional Studies in Marine Science*, 77. https://doi.org/10.1016/j.rsma.2024.103596

Syakti, A. D. (2017). Beach macro-litter monitoring and floating microplastic in a coastal area of Indonesia. *Marine Pollution Bulletin*, 122(1), 217–225. https://doi.org/10.1016/j.marpolbul.2017.06.046

Syukur, A., Al Idrus, A., Zulkifli, L., & Mahrus, M. (2021). The potential of seagrass ecotourism as an indicator of conservation in the Coastal Waters of East Lombok. *Journal of Science and Science Education*, 1(1), 41–63. https://doi.org/10.29303/jossed.v1i1.643

Tang, K. H. D., & Hadibarata, T. (2022). Seagrass meadows under the changing climate: A Review of the impacts of climate stressors. *Research in Ecology*, 4(1), 27–36. https://doi.org/10.30564/re.v4i1.4363

Thom, B. (2020). The role of coastal processes in the management of the mouth of the River Murray, Australia: Present and future challenges. In *River Research and Applications*. 36(4), 656–667. https://doi.org/10.1002/rra.3551

Tuapattinaya, P., Pattiasina, E. B., Pattipeilohy, J., Sahetapy, M., & Wattimena, C. (2023). Profil struktur komunitas lamun di perairan pantai Kelapa Indah Desa Mahu Kecamatan Saparua Timur sebagai sumber pembelajaran biologi. *BIOPENDIX: Jurnal Biologi, Pendidikan dan Terapan*, 10(1), 148–155. https://doi.org/10.30598/biopendixvol10issue1page148-155

Turicchia, E. (2021). MedSens index: The bridge between marine citizen science and coastal management. *Ecological Indicators*, 122. https://doi.org/10.1016/j.ecolind.2020.107296

Tuwo, A., & Tresnati, J. (2021). Coral reef ecosystem. In *Advances in Biology Sciences and Biotechnology*. (Issue May, 77–104). Integrated Publications Integrated. https://doi.org/10.1007/978-3-030-73613-2_2

United Nations. (2015). *The 2030 agenda for sustainable development's 17 Sustainable Development Goals (SDGs)*.

United Nations. (2022). *The sustainable development goals report 2022*.

Veron, J. E. N. (2009). Corals and corals reefs. In *Encyclopedia of Earth Sciences Series*. 198–206.

Visbeck, M., Kronfeld-Goharani, U., Neumann, B., Rickels, W., Schmidt, J., van Doorn, E., Matz-Lück, N., Ott, K., & Quaas, M. F. (2014). Securing blue wealth: The need for a special sustainable development goal for the ocean and coasts. *Marine Policy*, 48, 184–191. https://doi.org/10.1016/j.marpol.2014.03.005

Wang, W. (2023). Cultural ecosystem services evaluation in a coastal city of China using social media data. *Ocean and Coastal Management*, 242. https://doi.org/10.1016/j.ocecoaman.2023.106693

Widayanti, T. F., Djafar, E. M., Hakim, M. Z., Rivanie, S. S., & Ashri, M. (2022). Legal protection concerning marine environment and coastal areas in Indonesia based on the convention on biological diversity (CBD). *IOP Conference Series: Earth and Environmental Science*, 1119(1). https://doi.org/10.1088/1755-1315/1119/1/012006

Wootton, N., Nursey-Bray, M., Holland, S., & Gillanders, B. M. (2024). Better understanding ocean awareness: Insights from young people. *Marine Policy*, 164(August 2023), 106159. https://doi.org/10.1016/j.marpol.2024.106159

Yang, Y. (2023). Evaluation and optimization of cultural perception of coastal Greenway landscape based on structural equation model. *International Journal of Environmental Research and Public Health*, 20(3). https://doi.org/10.3390/ijerph20032540

Zeller, M. A., Van Dam, B. R., Lopes, C., McKenna, A. M., Osburn, C. L., Fourqurean, J. W., Kominoski, J. S., & Böttcher, M. E. (2024). The unique biogeochemical role of carbonate-associated organic matter in a subtropical seagrass meadow. *Communications Earth and Environment*, 5(1), 1–13. https://doi.org/10.1038/s43247-024-01832-7