Integrated analysis of human activities and environmental pressures along the coast of Ciletuh-Palabuhanratu UNESCO Global Geoparks, Indonesia: An ODEMM linkage framework and TOPSIS approach

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Abstract. Ciletuh-Palabuhanratu is a Unesco Global Geopark that is notable for its coastal features, but it also faces a number of environmental challenges. A comprehensive understanding of environmental concerns in the coastal regions of Ciletuh-Palabuhanratu Unesco Global Geopark (CPUGG) requires the implementation of an integrated analysis. This study finds the human activities that change the environment along the CPUGG coast and the pressure types that these activities put on the ecosystem that is affected, by using the Options for Delivering Ecosystem-Based Marine Management (ODEMM) method. This study also uses the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) calculations in order to determine the pressures that have the most influence on the CPUGG ecosystem. According to the results of the study, seven key sectors, including agriculture, aquaculture, coastal infrastructure, fisheries, power stations, shipping, and tourism, exert pressure on CPUGG's diverse ecosystems. Tourism is identified as the main source of pressure, and the most significant challenges encountered are the introduction of marine litter, siltation changes, and synthetic compounds. The majority of human activities occuring in the CPUGG ecosystems of littoral rock, sublittoral sediment, littoral rock, and littoral sediment. The ODEMM linkage framework and TOPSIS approaches provide a first step in understanding the causes of environmental problems on the CPUGG coast.
Key Words: environmental management, impact chain, decision making.

Introduction. Geoparks can include a variety of geological, biological, and cultural features and may encompass a large area of land. A geopark with a coastline can offer visitors the chance to explore and learn about the geological and geomorphological characteristics of the coastal area, such as cliffs, beaches, and volcanic rocks (Santangelo et al 2020). Indonesia has a total of ten geoparks that have been officially acknowledged as UNESCO Global Geoparks (UNESCO 2023). Among these, Ciletuh-Palabuhanratu UNESCO Global Geoparks (CPUGG), located in the West Java Province, stands out due to its coastal features. CPUGG has a 117 km coastline facing the Indian Ocean, where the beaches give the impression of beauty with an abundance of biodiversity and are supported by cultural diversity, making it a sustainable natural tourism area of priority (Nandi 2019; Osmaleli et al 2023; Wulung et al 2020; Ramadanti et al 2022; Sari et al 2021; Sobandi & Santosa 2019; Yudhistira et al 2021). Aside from that, the coastline of CPUGG is a bay with multiple coves, so some of the beaches serve as fishing ports. Similarly to the coasts of the world, beaches in CPUGG experience environmental and social issues. On the beaches of CPUGG, the increase in tourist visits has caused environmental degradation, waste management issues, and water pollution (Hengky 2022; Taryono & Wulandari 2021; Wahidah et al 2022). Sedimentation has occurred in the waters surrounding CPUGG as a result of changes in land use within the watershed (Damayani et al 2019; Yuniarti et al 2019). As a fishing region, the coastal area of the CPUGG is also impacted by fishing-related issues, such as the overexploitation of fishery resources, which leads to decreased catches (Imron et al 2021), waste from the fishing industry (Irawan et al 2021), and social conflicts within fishing communities (Royandi 2021; Royandi et al 2019).

Research on the environment along the coast of the CPUGG is still conducted separately, focusing on isolated human activities or on the pressures they generate; thus, it does not link the various impacts of human activities on existing ecosystem components. In addition, there is a lack of information regarding the human activities that have the greatest impact on environmental conditions along the coast of the CPUGPP and the ecosystem components the most affected by these human activities. To obtain a complete picture of environmental issues in the coastal of CPUGG and to make decisions regarding the management of environmental risks, an integrated analysis is required. Options for Delivering Ecosystem-Based Marine Management (ODEMM) is one method for analysing environmental problems along the coast of the CPUGG. The ODEMM evaluates coastal and marine conditions based on the relationships between human activity sectors, the pressures caused by these sectors, and the pressures on habitats (Skein et al 2022).

The objective of the ODEMM was to provide a framework for ecosystem-based marine management that was adaptable to specific needs and permitted the identification of risks (Pedreschi et al 2019). The ODEMM methodology has been implemented in diverse regions and contexts. It has been utilised, for instance, for an integrated evaluation of the ecosystem surrounding the islands on the tropical South Mid-Atlantic Ridge (Rodrigues et al 2023). In South Africa, the approach was also used to prioritise key sectors, pressures, and affected ecosystem components (Smit et al 2022). The ODEMM has been utilised in the development of frameworks for measuring and evaluating ecosystem interactions in cultured seaweed (Tonk et al 2021). The ODEMM contributes to these efforts by providing a framework for an ecosystem-based marine management that considers trade-offs and the sustainable provision of ecosystem services (Culhane et al 2020).

This study identifies various human activities that influence environmental conditions along the CPUGG coast and analyses the pressure caused by these human activities on the associated ecosystem, by using the ODEMM approach. In addition to ODEMM, TOPSIS calculations are used to determine which pressure has the greatest impact on the CPUGG ecosystem. TOPSIS is used to figure out pressure levels at CPUGG because there isn't enough specific data on the CPUGG coast for the ODEMM quantitative method. For example, there isn't enough data on the amount, intensity, and frequency of human activities that affect the ecosystem there. TOPSIS is based on the principle that the priority of choice among several criteria is determined by the closest ideal solution. Some examples of research using TOPSIS for environmental discussions include environmental assessments in South Korea (Park et al 2021), evaluation of the impact of restoration projects on the environment in Saihanba National Forest Park (Sun et al 2023), and the evaluation of the land ecological security in Guangdong Province, China (Qu et al 2023). The current study provides an overview of the relationships between diverse human activities and environmental conditions along the coast of CPUGG. CPUGG was selected as an area of research due to its rich biodiversity, as a UNESCO Global Geopark; therefore, this research can serve as one of the scientific bases for evaluating Ciletuh-Palabuhanratu's status. Moreover, this study provides an alternative method for analysing the impact of human activities on coastal ecosystems. This study was conducted in general on the entire coast of the CPUGG and does not specifically address each pressure-affected region.

Material and Method

Area of interest. CPUGG is located in the Sukabumi Regency, West Java Province, Indonesia. Based on exposure to waves, the CPUGG coastline generally consists of two parts, namely the inner part of the bay known as Palabuhanratu Bay and the outer part of the bay, which is the Ciletuh area (Figure 1). According to the geological conditions, CPUGG is classified into three distinct geo-areas, namely Cisolok, Simpenan, and Ciletuh (Rahmawati et al 2021). Cisolok and Simpenan geo-areas are located in the

Palabuhanratu Bay, an optimal location for fishing and associated industries. In contrast, the Ciletuh region exhibits a natural condition characterised by an abundance of plant and animal species, diverse geological features, and a natural amphitheatre (Rahmat et al 2022; Rosadi et al 2022; Wulandari et al 2019).

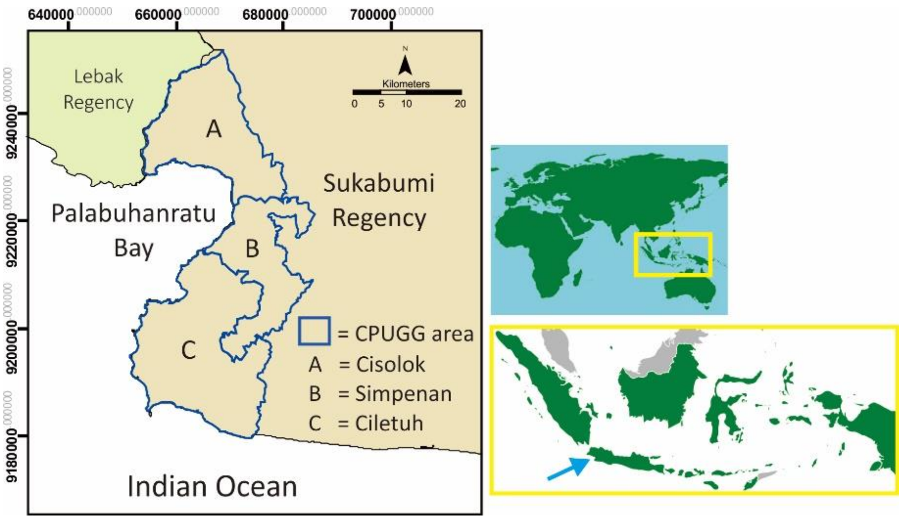

Figure 1. The location of CPUGG.

ODEMM linkage framework. A group of researchers, scientists, and stakeholders working in the field of marine management and conservation initiated the ODEMM. ODEMM aims to provide a framework and method for ecosystem-based marine management that takes into account the cumulative effects of multiple human pressures on marine ecosystems. The ODEMM approach is based on the linkage framework between sectors, the pressures caused by these sectors, and the impact of these pressures on coastal and marine ecosystems (Knights et al 2011; Pedreschi et al 2019; Robinson et al 2013; Robinson et al 2014). Overall, ODEMM consists of 18 sectors with a total of 98 activities, 24 potential pressures, and 11 coastal and marine ecosystem components at risk of being impacted (White et al 2013). Each activity will generate one or more types of pressure, which can have an effect on some or all of the ecosystem's components. Figure 2 depicts the relationships between several components of the ODEMM linkage framework. For instance, the aquaculture and coastal infrastructure sectors generate multiple pressures (represented by smothering and marine litter) that impact a variety of ecosystem components (represented by littoral sediment, fish pelagic and seabirds). Smothering has no direct effect on the ecosystem of seabirds, so there is no connection link. In Figure 2, the black numbers on the link indicate the number of activities that cause pressure. Meanwhile, the blue numbers show the total activity of a pressure that has an impact on an ecosystem. Figure 2 also shows that the littoral sediment and pelagic fish ecosystems are subject to two pressures, namely smothering and marine litter, whereas the seabird ecosystem is subject to only marine litter.

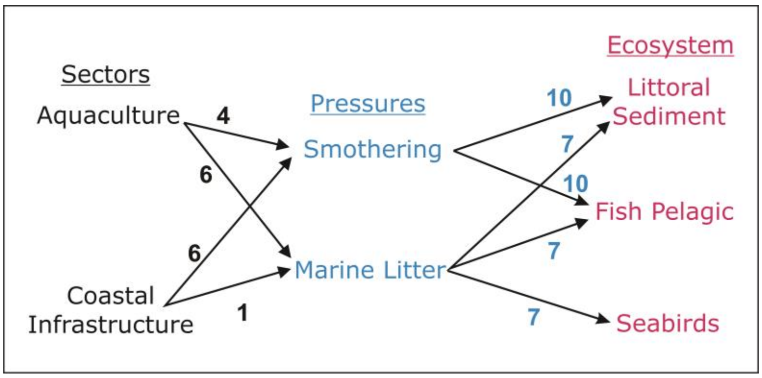

Figure 2. The concept of a linkage framework.

The linkage framework is a preliminary analysis of how the factors that affect human activity, the pressures they put on ecosystems, and the ecosystems that are most at risk are linked, but it does not inform on the strength, duration, overlap, and resilience of these factors. The linkage framework in Figure 2 can also be interpreted as a table, as explained in Tables 1 and 2. This study employs the ODEMM linkage framework to categorize and analyze CPUGG's existing sectors, emerging activities, potential pressures, and at-risk ecosystems. Previous research studies of White et al (2013) and Pedreschi et al (2019) present more comprehensive information about the sectors, sources, types of activities, pressures, and affected ecosystems, as well as on the framework of their linkage.

Table 1

The number of activities that cause pressure from each sector

Sectors	*Pressures*	
	Smothering	*Marine litter*
Aquaculture	4	6
Coastal infrastructure	6	1
Total	10	7

Table 2

The total activity of a pressure that influences an ecosystem

Pressures	*Ecosystem*		
	Littoral sediment	*Fish pelagic*	*Seabirds*
Smothering	10	10	
Marine litter	7	7	7
Total	17	17	7

TOPSIS. The Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) is a multi-criteria decision-analysis technique based on the idea that the best alternative is the one that is closest to the ideal solution and farthest from the worst solution. The method measures the distance to the optimal solution, as determined by the evaluation criteria. In 1981, Ching-Lai Hwang and Yoon were the first to develop TOPSIS (Krohling & Pacheco 2015), followed by Yoon in 1987 (Thanh 2022). TOPSIS is a widely utilised technique in a variety of fields, including the evaluation and selection of coastal site locations. In the context of ecology, TOPSIS has been utilised in numerous studies to assess and evaluate various environmental aspects. In South Korea, TOPSIS was used to determine the optimal method for debris removal and to prioritise strategic environmental assessments (Park et al 2021). In a separate study, a TOPSIS was applied to an environmental risk assessment of Iran's Helleh protected area (Jozi et al 2011). For a brief explanation, the TOPSIS steps are as follows:

1. Determine the normalised decision matrix (r_{ij}).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, (i = 1, 2, ..., n; j = 1, 2, ..., m)$$

2. Determine the weighted decision matrix (y_{ij}).

$$y_{ij} = \left(w_j r_{ij}\right)$$

3. Determine the positive (A^+)and negative ideal solution matrices (A^-).

$$A^+ = (y_1^{\ +}, y_2^{\ +}, \cdots, y_j^{\ +})$$

$$A^- = (y_1^-, y_2^-, \cdots, y_j^-)$$

4. Determine the distance between alternative values in the positive (d_i^+) and negative (d_i^-) ideal solution matrices.

$$d_i^+ = \sqrt{\sum_{j=1}^{m}\left(y_{ij} - y_{ij}^+\right)^2}; i = 1, 2, ..., m$$

$$d_i^- = \sqrt{\sum_{j=1}^{m}\left(y_{ij} - y_{ij}^-\right)^2}; i = 1, 2, ..., m$$

5. Determine the performance score (P_i).

$$P_i = \frac{d_i^-}{(d_i^-) + (d_i^+)}$$

Where:

x_{ij} - the i alternative's performance value in relation to the j attribute;

w_j - the weight of the j criterion;

y_j^+ - criteria associated with positive impact;

y_j^- - criteria associated with negative impact.

Results and Discussion

Identification of key human activities. Observations indicate that the CPUGG coast is the site to multiple sectors, including agriculture, aquaculture, coastal infrastructure, fisheries, power station, shipping, and tourism. Each sector is identified by the number of activities that can cause pressure. Observations and literature reviews were also utilised to identify ecosystem components in CPUGG (Table 3). Observational data indicates that the tourism sector causes the highest activity, while the agricultural sector causes the lowest activity. In total, there are 39 activities from 7 sectors that cause 16 types of pressure that affect the ecosystem on the CPUGG coast. Table 4 shows the number of activities that cause pressure.

Table 3

Sectors, pressures and ecosystems in CPUGG

Code	*Sector*	*Code*	*Pressure*	*Code*	*Ecosystem*
I	Agriculture	A	Abrasion	1	Sublittoral rock
II	Aquaculture	B	Changes in Siltation	2	Sublittoral sediment
III	Coastal infrastructure	C	Death or injury by collision	3	Littoral sediment
IV	Fishing	D	Input of organic matter	4	Littoral rock
V	Power station	E	Introduction of microbial pathogens	5	Pelagic water column
VI	Shipping	F	Introduction of Non-indigenous Species (NIS) and translocations	6	Fish Demersal
VII	Tourism	G	Introduction of non-synthetic compounds	7	Fish Pelagic
		H	Introduction of Synthetic compounds	8	Marine mammals & Reptiles
		I	Marine litter	9	Seabirds

Code	Sector	Code	Pressure	Code	Ecosystem
		J	Nitrogen and phosphorus enrichment		
		K	pH changes		
		L	Sealing		
		M	Selective extraction of non-living resources from seabed and subsoil		
		N	Selective extraction of species		
		O	Smothering		
		P	Thermal changes		
		Q	Underwater noise		
		R	Water flow rate changes		

Table 4

The number of activities that cause pressure

Code	*Pressure*	*The number of pressure-causing activities*
A	Abrasion	17
B	Changes in Siltation	19
C	Death or injury by collision	6
D	Input of organic matter	7
E	Introduction of microbial pathogens	7
F	Introduction of Non-indigenous Species (NIS) and translocations	4
G	Introduction of non-synthetic compounds	12
H	Introduction of synthetic compounds	16
I	Marine litter	23
J	Nitrogen and phosphorus enrichment	3
K	pH changes	1
L	Sealing	5
M	Selective extraction of non-living resources on seabed and subsoil	2
N	Selective extraction of species	5
O	Smothering	9
P	Thermal changes	1
Q	Underwater noise	12
R	Water flow rate changes	2

Agriculture. Agriculture at CPUGG extends from the highlands to the coast (Figure 3). The land use in the CPUGG highlands has changed from forest to agricultural land, including rice fields, mixed gardens, and plantations (Damayani et al 2019; Wulandari et al 2018). Agriculture in the highlands relies on rivers that empty into the coast of CPUGG (Tartila et al 2019). Clearing agricultural land in the CPUGG highlands could have negative effects on its coastal regions. Excessive use of fertiliser in the highlands causes excess nutrient flow into the sea, which stimulates the growth of marine algae, which depletes oxygen, raises carbon dioxide levels, and lowers the pH of coastal waters (Sulthonuddin et al 2018). In addition, the use of pesticides and the clearing of agricultural land in the highlands have a negative effect on the quality of coastal water and the health of marine ecosystems (Nienhuis et al 2015). Some communities in CPUGG are developing local economic activities based on traditional agriculture to alleviate pressure (Munandar et al 2022).

Aquaculture. The cultivation of shrimp and seaweed at CPUGG is a growing and vital contributor to the local economy. Shrimp cultivation has a negative impact on the environment, so the government is committed to constructing shrimp ponds at CPUGG that are environmentally friendly to support sustainable shrimp cultivation (Antara News 2020). A high nitrogen concentration of nearly 3.2 mg L^{-1} is one of the effects of shrimp ponds in CPUGG (Yuniarti et al 2019). Shrimp farming waste consists of shrimp food waste, faeces, and other organic substances that increase nutrients in pond water, such as nitrogen and phosphorus. Additionally, the use of pesticides and chemicals generates chemical waste that pollutes water sources. The cultivation of shrimp frequently results in sedimentation and seawater intrusion, degrading aquatic ecosystems and water quality (Marinho-Soriano et al 2002; Muahiddah et al 2022).

Smallholder farmers dominate the seaweed farming industry in CPUGG (Figure 3), which they find appealing due to its low capital and operating costs, low labour requirements, and quick production cycles (Rimmer et al 2021). The cultivation of seaweed in CPUGG waters is predominantly focused on *Ulva reticulata*, *Padina* sp., *Turbinaria* sp., or *Gracilaria foliifera*, and the longline technique is still used (Erlania et al 2015). The most significant pressure resulting from this technique is the disruption of the bottom-water substrate. Marine litter, which consists of longline technique waste such as plastic rope, styrofoam, and other plastic materials, is an additional threat posed by seaweed cultivation.

Coastal infrastucture. The coast of the CPUGG has several ports, the majority of which are small and traditional fishing ports (Figure 3). The largest port is located in Palabuhanratu Bay, which is administered by the Ministry of Marine Affairs and Fisheries. Several coastal infrastructures have also been constructed to support community activities, particularly those associated with the geopark tourism (Isdahartati et al 2022). In areas prone to tsunamis and abrasion, mitigation infrastructure is also present (Arifah & Supriatna 2021). Additionally, coastal infrastructure was constructed to support coal-fired power station operations in Palabuhanratu Bay (Figure 3).

Figure 3. Sectors in CPUGG (a) Agricultural land, (b) Seaweed harvest, (c) Coastal infrastructure, (d) Traditional fishing port (original photos).

Fishing. The waters around CPUGG are renowned for their fish resources, which support fishing communities and the local economy (Imron et al 2021). Several fishing companies also contribute to the fisheries sector in Palabuhanratu Bay, making fishing important for local livelihoods in CPUGG. The fishing activities in CPUGG waters involve various environmentally friendly fishing methods, especially hook and line, such as handlines (Imron et al 2021), troll lines (Aprilia et al 2021), and longlines (Anggawangsa et al 2022). In order to deploy nets (Figure 4), fishermen there commonly use floating liftnets

(Eko et al 2022) and Danish-seine (Mujib et al 2013), while at CPUGG pooting is commonly used to catch lobsters (Tomi 2019). Fishing equipment, such as cantrang, trawl nets, and gillnets, that damage the marine environment is prohibited in Indonesia (Anwar et al 2022; Dharmawan et al 2022; Supono et al 2021; Tirtadanu & Suprapto 2017). The pressure that exists in this industry is primarily a result of ship engines and fishing operations, which have a significant impact on the emergence of abrasion, marine litter, and underwater noise. Other pressures that arise due to fishing activities are the input of organic matter from fishing waste and the selective extraction of species resulting from non-target catches.

Power station. Since 2013, a coal-fired power station (CFPS) the Pelabuhan Ratu Power Station has been operating in Palabuhanratu Bay (Figure 4). This CFPS is comprised of three power plant units, each with a capacity of 350 megawatts (Global Energy Monitor 2023). The majority of coal is barge-shipped from Kalimantan Island. CFPS activities may contribute to heavy metal contamination in waters. Heavy metals, such as lead and chromium, can be released into the environment when coal is burned (Pandiangan & Audah 2022). Heavy metals found on CPUGG beaches, particularly where green turtles lay their eggs, are believed to have originated from coal waste (Elfidasari et al 2022). Additionally, the presence of CFPS in CPUGG causes the surrounding sea surface temperature to rise (Firdaus et al 2020).

Shipping. Since CPUGG waters have not been used as a national transportation route, there is no long-distance shipping of goods and passengers. Shipping is primarily used for fishing and tourism. Coal transportation to supply CFPS is the only large-scale cargo shipping activity in CPUGG waters. This sector exerts less pressure than shipping for fisheries and tourism. The most risky pressure to occur at CPUGG due to shipping is the introduction of non-synthetic compounds as a result of coal spilling into the sea (Global Atlas of Environmental Justice 2022). In addition, because the barge travels so far between the islands of Kalimantan and Java (more than 1,000 km), the possibility of non-native species introduction and translocation is very high.

Tourism. Due to the Ciletuh area's designation as a Global Geopark by UNESCO, there has been an increase in tourism-related activities and publicity (Haryanto & Sudradjat 2018). Tourism can bring economic benefits to CPUGG, but it also presents environmental and social challenges (Taryono & Wulandari 2021; Wahidah et al 2022). At CPUGG, marine tourism activities can be conducted on the beach and in its waters, so pressure can develop in both areas (Figure 4).

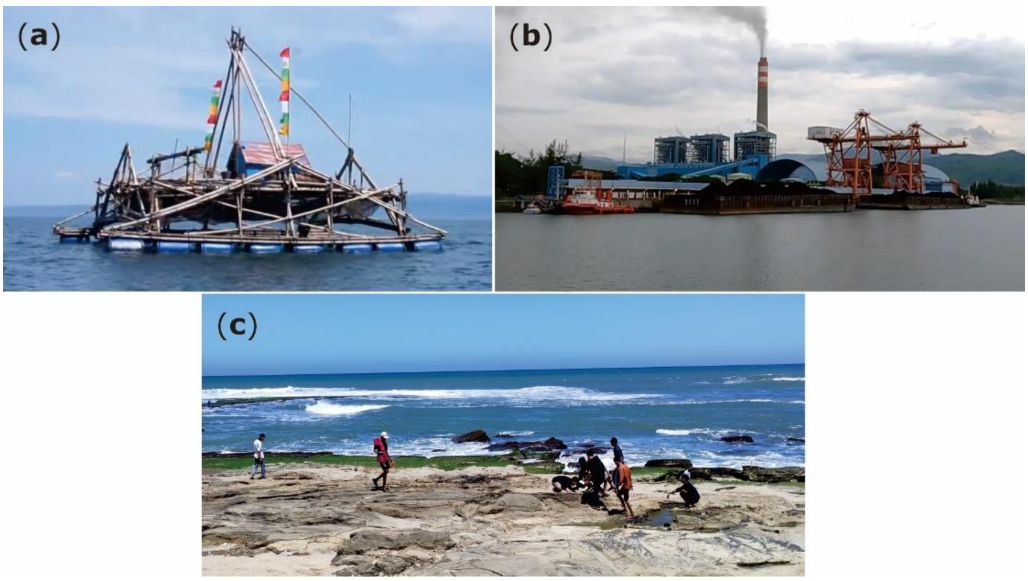

Figure 4. Sectors in CPUGG (a) Floating liftnets, (b) Coal-fired power station, (c) Tourism activities (original photos).

Activities in waters such as angling and diving have almost the same impact as hook and line fishing activities, but there is no input of organic matter, introduction of microbial pathogens, introduction of Non-indigenous Species (NIS), or translocations because the activity duration is shorter and the ships are relatively smaller. Meanwhile, for activities at the beach, the pressure that is very likely to occur apart from marine litter is pathogenic bacteria and synthetic compounds. The contamination of beaches and water by sewage and faeces can increase the risk of infection for tourists and negatively affect human health. In addition, tourism activities can introduce synthetic compounds into the coastal environment, such as contaminated sunscreen, which has the potential for high toxicity and can disrupt endocrine systems, bioaccumulate, and harm marine organisms (Casas-Beltrán et al 2020).

Impact on ecosystem components. Sublittoral rock, sublittoral sediment, littoral sediment, and littoral rock are ecosystems that regulate marine nutrient cycles (Sundbäck et al 2004); however, at CPUGG, these ecosystems are subjected to the most pressure (Table 5).

Table 5

The total activity of a pressure that influences an ecosystem in CPUGG

Pressure	*Ecosystem code*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Abrasion	17	17	17	17					
Changes in siltation	19	19	19	19	19	19	19	19	19
Death or injury by collision						6	6	6	6
Input of organic matter	7	7	7	7	7	7	7		
Introduction of microbial pathogens	7	7	7	7	7	7	7	7	7
Introduction of NIS and translocations	4	4	4	4	4	4	4	4	4
Introduction of non-synthetic compounds	12	12	12	12		12	12	12	12
Introduction of Synthetic compounds	16	16	16	16	16	16	16	16	16
Marine Litter	23	23	23	23	23	23	23	23	23
Nitrogen and phosphorus enrichment	3	3	3	3	3	3	3		
pH changes	1	1	1	1	1	1	1	1	
Sealing	5	5	5	5	5	5	5	5	5
Selective extraction of non-living resources on seabed and subsoil	2	2	2	2	2	2	2		
Selective extraction of species	5	5	5	5	5	5	5	5	5
Smothering	9	9	9	9					
Thermal changes	1	1	1	1	1	1	1	1	1
Underwater noise						12	12	12	
Water flow rate changes	2	2	2	2	2	2	2	2	2
Total	133	133	133	133	95	125	125	113	100

The dominant organisms in this ecosystem are crustaceans, mollusks, and algae, which serve as crucial habitats for numerous species. The presence of phytoplankton is essential for CPUGG water productivity. Phytoplankton serves as a primary source of organic and inorganic substances, contributing to the overall productivity of the water (Firdaus et al 2020). The presence of phytoplankton and the abundance of chlorophyll-a in CPUGG waters significantly affects the distribution and availability of tuna and other fish prey (Simbolon & Girsang 2017). Oceanographic factors such as salinity and turbidity have a significant impact on the distribution and abundance of crustaceans, mollusks, and algae in CPUGG waters (Akbar et al 2019). Disruption of these ecosystems can lead to a decline in the quality of seawater, which in turn leads to a decline in the populations of species that depend on these ecosystems.

Overfishing and unsustainable fishing practices have a significant negative impact on the fish populations in CPUGG waters. These practices deplete fish stocks, disrupt marine ecosystems, and have negative socioeconomic effects on local communities. Overfishing, which occurs when fish are captured faster than they can reproduce, is a major concern. It not only depletes target species but also inadvertently traps non-target species, disrupting marine ecosystems and causing biodiversity loss (Tomi 2019). In addition, the lack of effective fisheries management and regulation in CPUGG waters contributes to the problem of overfishing and unsustainable practices. Weak enforcement of fishing regulations, such as size restrictions and fishing seasons, permits continued overexploitation of fish stocks (Abdillah et al 2020). Figure 5 depicts the outcomes of capturing spinetail devil ray and shark, both listed on appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); however, spinetail devil ray is especially vulnerable to extinction (Novyanti et al 2023). The CPUGG coastal landform characteristics, such as volcanic, marine deposition, and organic coasts, can also influence fish catches (Giovani et al 2018). Pollution levels, including water pollutants and atmospheric corrosion, may have a negative impact on fish populations and their habitats (Nuraini et al 2018; Prifiharni et al 2020). High levels of pollution can reduce water quality, which can negatively affect the health and abundance of fish.

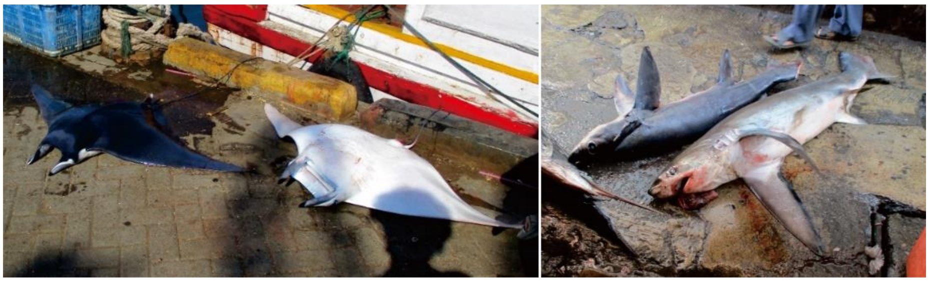

Figure 5. Spinetail devil ray and shark were captured by fishermen at CPUGG (original photos).

One of the activities that has the greatest impact on coastal and marine ecosystems is the use of fossil fuels to power motorised watercraft. Although motorised boats, ships, and other types of maritime vehicles provide access to the sea and marine resources, motorised activities in the water have a negative impact on the marine environment. In addition to air and water pollution, motorised activities generate noise pollution, which has an effect on vertebrates. Underwater noise disturbs marine mammals, especially whales, and can result in whale stranding. This occurs due to the disruption of the acoustic waves that determine their swimming orientation (Allen et al 2013; Savage et al 2021). Local media have reported the multiple stranding of whales in CPUGG, including two different incidents in 2019 involving the stranding of a whale shark and a pilot whale (The Jakarta Post 2019) and one incident in 2023 involving the stranding of a bottlenose whale (VOI 2023). Another threat caused by motorised activities at sea is the risk of death or injury from collisions. Despite the fact that there has never been a collision between a boat and a marine animal in CPUGG, the possibility of this occurring is high given that CPUGG waters are a migration route for several protected fish species (Kanedi et al 2023).

Along the coast of the CPUGG, human activity has a negative impact on turtles, particularly green turtles (*Chelonia mydas*). Pangumbahan Beach, which is part of the CPUGG, is known as the largest nesting site for green turtles in West Java (Wiadnyana & Nastiti 2013). The threat to the existence of green turtles on the CPUGG coast is very complex. Increased water traffic by fishermen and tourists, as well as abrasion damage to vegetation, has degraded the habitat of turtles (Afif & Yulianda 2020). Given the turtles' sensitivity to light, sound, and homing behaviour, activities such as sand mining, prawn farming, and intensive tourism have also contributed to their decline along the coast of the CPUGG (Nastiti et al 2015). It is believed that excessive levels of heavy metals in turtle nesting sites have a negative impact on the health of the parent turtles. Due to the nesting location's proximity to coal barge transportation routes (Elfidasari et al 2022). Turtle habitat in CPUGG is also threatened by fishing activities, both intentionally and unintentionally, employing gill nets, longlines, and trawls to capture turtles (Nurhayati et al 2020). There are indications of microbial contamination in turtle eggs at CPUGG, which adds to the strain on turtle habitats (Gifari et al 2018). CPUGG is a habitat for numerous species of birds that inhabit coastal ecosystems, mangrove forests, and mountainous regions. Several species of seabirds are found in CPUGG, the majority of which have the International Union for Conservation of Nature (IUCN) status of least concern and the appearance is becoming increasingly rare, such as white-bellied sea-eagle, grey plover and family of Alcedinidae (Iskandar et al 2021). Compared to other ecosystems in CPUGG, the seabird ecosystem is subject to less direct human pressure; this is due to the expansive and dynamic nature of bird habitats. Apart from that, the impact on seabird ecosystems is influenced by the conditions of other coastal ecosystems, especially sublittoral rock, sublittoral sediment, and littoral rock ecosystems as a food source. The majority of threats to birds are caused by direct human capture.

Decision table. Table 5 is a matrix for TOPSIS calculations. The TOPSIS performance score (Pi) indicates the level of intensity of the pressure at CPUGG. A Pi value close to 1 indicates a higher activity, affecting more ecosystems. TOPSIS provides calculations for determining pressure levels based on the amount of activity and the number of affected ecosystems. For instance, the introduction of synthetic compounds (Pi=0.696) has a greater influence than abrasion (Pi=0.370), despite the fact that the activity number causing abrasion is greater than the activity causing the introduction of synthetic compounds; however, the introduction of synthetic compounds has an impact on all ecosystems in CPUGG (Table 6). The top three pressures that impact the ecosystem at CPUGG are marine litter, changes in siltation, and the introduction of synthetic compounds. These three pressures have an impact on all ecosystems, with more activity than other pressures. Marine waste, particularly plastic waste, will decompose into synthetic compounds known as microplastics (Browne et al 2011). Ship traffic, propeller blades, and anchoring cause siltation, which is the lifting of sediment particles from the bottom of the water, floating in the water column, and then settling back to the bottom of the water. Siltation is detrimental to marine ecosystems and their dependent organisms (Malesa et al 2022; Uhrin & Holmquist 2003). Each pressure has different causes of activity; not all pressures will have a direct effect on coastal and marine ecosystems.

Table 6, which depicts Pi, the number of activities, affected ecosystems, and percentage of causal sectors, provides preliminary information on recommendations for CPUGG coastal management. For example, if the solution to environmental problems at CPUGG involves a technical approach, the pressures are of concern. Technical solutions that can be implemented to overcome the pressures that occur include waste bank services (Masrohatun 2022), waste composting technology (Yunus et al 2020), and controlling nutrient inputs to mitigate the impact of eutrophication on coastal ecosystems (Duarte & Krause-Jensen 2018). If the approach is based on regulation or law enforcement, then sector parameters must be considered, for example, reducing the number of sector activities, monitoring the sector activities, or zoning each sector. The prioritisation of decisions should be based on the relationship between the pressures and the sectors causing them.

Marine litter, changes in siltation, and the introduction of synthetic compounds are the most influential pressures in CPUGG, with tourism (Figure 6) being the most dominant causal sector; consequently, the solution focuses on the tourism sector, without reducing the oversight of other sectors. Aside from this, there are a number of pressures caused by only one or two sectors, but these pressures have an impact on all ecosystems in CPUGG, such as the selective extraction of species caused by fishing and tourism sector activities; therefore, efforts to prevent the selective extraction of species are prioritised in both sectors.

Table 6

Table of decisions for identifying sectors and pressures to address

Pressure	*Pi*	*Activities*	*Affected ecosystem*	*Activity percentage*						
				Sectors code						
				I	*II*	*III*	*IV*	*V*	*VI*	*VII*
Marine litter	1	23	All	0%	17%	9%	30%	4%	4%	35%
Changes in siltation	0.826	19	All	5%	21%	16%	16%	5%	5%	32%
Introduction of synthetic compounds	0.696	16	All	7%	21%	0%	21%	0%	7%	43%
Introduction of non-synthetic compounds	0.456	12	Except pelagic water column	10%	0%	0%	30%	0%	20%	40%
Abrasion	0.370	17	Sublittoral (rock& sediment), litoral (rock & sediment)	0%	24%	18%	24%	6%	6%	24%
Introduction of microbial pathogens	0.304	7	All	14%	29%	14%	14%	0%	0%	29%
Underwater noise	0.260	12	Fish demersal, pelagic, marine mammals and reptile	0%	0%	17%	33%	8%	8%	33%
Input of organic matter	0.253	7	Except marine mammals, reptiles and seabirds	14%	14%	0%	43%	0%	0%	29%
Smothering	0.222	9	Sublittoral (rock& sediment), litoral (rock & sediment)	0%	33%	22%	0%	22%	0%	22%
Sealing	0.217	5	All	0%	20%	40%	0%	20%	0%	20%
Selective extraction of species	0.217	5	All	0%	0%	0%	60%	0%	0%	40%
Introduction of NIS and translocations	0.174	4	All	0%	50%	0%	25%	0%	25%	0%
Death or injury by collision	0.167	6	Fish (demersal-pelagic), marine mammals, reptile, seabirds	0%	0%	0%	33%	0%	17%	50%
Nitrogen and phosphorus enrichment	0.112	3	Except marine mammals, reptiles and Seabird	33%	33%	0%	0%	0%	0%	33%
Water flow rate changes	0.087	2	All	0%	0%	100%	0%	0%	0%	0%
Selective extraction of non-living resources on seabed and subsoil	0.075	2	Except marine mammals, reptiles and seabird	0%	0%	0%	0%	50%	0%	50%
Thermal changes	0.043	1	All	0%	0%	0%	0%	100%	0%	0%
pH changes	0.041	1	Except seabirds	100%	0%	0%	0%	0%	0%	0%
			Average	10%	15%	13%	18%	12%	5%	27%


Figure 6. Tourist activities on the beach and the litter they produce (original photos).

Conclusions. Agriculture, aquaculture, coastal infrastructure, fisheries, power stations, shipping, and tourism are the sectors in CPUGG that have the potential to put pressure on the coastal environment. Each sector has activity-related causes that influence pressure generation on the CPUGG coast. In CPUGG, agriculture uses river water that flows into the coast, allowing agricultural waste such as pesticides or fertilisers to accumulate on the coast. The agricultural sector is responsible for seven pressures. Shrimp farming and seaweed cultivation are fishery activities at CPUGG that have an impact on increasing the nitrogen concentration levels in some waters and causing marine litter. There are ten pressure results from the aquaculture sector in total. Coastal infrastructure in CPUGG can cause abrasion, which leads to coastal shallowing. Aside from that, there are other pressures due to coastal infrastructure, for a total of nine pressures. The fishing sector generates eleven pressures, the majority of which are caused by operational activities in the fishing industry. Meanwhile, the power station sector only generates two types of activity, but each activity can generate ten pressures, and the only pressure generated by this sector is thermal changes in the surrounding waters. There are eight pressures due to the shipping sector in total, with the introduction of non-synthetic compounds as a risk from coal shipping activities being a significant pressure. The tourism sector is the one that generates the most pressure, with fourteen different types of pressure, with beach tourism being the most dominant activity in this sector. The top three pressures affecting the CPUGG ecosystem are marine litter, siltation changes, and the introduction of synthetic compounds. These three pressures have a significant impact because they originate in different sectors and affect all ecosystem components. The most pressure is placed on sublittoral rock, sublittoral sediment, littoral sediment, and littoral rock ecosystems that have an important role in regulating ecological conditions on the CPUGG coast. According to the decision table, tourism is the sector that causes the most pressure on CPUGG. Furthermore, the decision table demonstrates that some pressures originate in just one or two sectors but have a significant impact on the entire ecosystem. In fact, solutions to environmental problems on the CPUGG coast must be integrated and comprehensive across various sectors, activities, pressures, and affected ecosystems; however, given limited human and financial resources, the priority scale in dealing with environmental problems is the most likely option. The ODEMM linkage framework and TOPSIS approaches serve as initial tools for recognising the underlying factors contributing to environmental issues at CPUGG.

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