http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 9 No 4 2024

RESEARCH ARTICLE

Mapping of Basin Substrate and Vulnerability Index of Shallow Waters of Combol and Citlim Island, Moro District, Karimun Regency, Riau Islands Province, Indonesia

Aunurrahman[1*] Irfan Hanifa[2] Lilik Setiyaningsih[2]

[1]*Master of Environmental Science, Terbuka University,Yogyakarta, 55142, Indonesia*
[2]*Fishery and Marine Sciene Faculty, Jenderal Soedirman University, Purwokerto, 53122, Indonesia*

* Corresponding author: annurahmandoctor@gmail.com
Tel.: +62 813-9209-8622
Received: Dec 3, 2024; Accepted: Dec 24, 2024.
DOI: 10.25299/jgeet.2024.9.04.19951

Abstract
Mapping basin substrates and vulnerability indexes in shallow waters is crucial for understanding the ecological health and resilience of marine ecosystems. Given the increasing threats from climate change and human activities, this research provides essential insights for effectively managing and conserving these vital coastal environments. Our study discusses mapping the bottom substrate and the vulnerability index of shallow waters in the Combol and Citlim Island clusters, Moro District, Karimun Regency, Riau Islands Province. Shallow waters have rich ecosystems, including coral reefs and seagrass beds, which function as fish habitats and coastal protection. However, these ecosystems are vulnerable to climate change and pollution disturbances. Using the water column correction method, this study used Sentinel-2A multispectral satellite imagery to map the shallow water bottom habitat. The analysis showed that open substrates and dead corals dominated the habitat, with an area of ± 766.8 Ha and ± 682.5 Ha, respectively. The vulnerability index revealed that a total area of approximately 393 ha fell into the moderate vulnerability category. Our mapping result is essential for understanding ecosystem dynamics and formulating appropriate conservation strategies. We anticipate that these findings will offer valuable insights for managing aquatic resources and safeguarding coastal ecosystems in the region.

Keywords: Basin Substrate, vulnerability index, shallow waters, sentinel-2A, ecosystem conservation

1. Introduction

Shallow sea waters are dynamic ecosystems that play crucial roles in biodiversity and coastal protection. These areas support various marine life and contribute significantly to local economies through fisheries and tourism (Barbier et al., 2011; Lubis et al., 2018; Aunurrahman et al., 2024). The ecological functions provided by coral reefs and seagrass beds are essential for maintaining the health of marine environments, as they offer habitat and nursery grounds for numerous fish species (Duarte, 2002; Kausarian et al., 2017). Furthermore, these ecosystems are increasingly threatened by anthropogenic activities, including pollution and climate change, which can lead to habitat degradation and loss of biodiversity (Halpern et al., 2008; McLeod et al., 2011). Therefore, effective management and conservation strategies are critical to preserving these vital coastal resources for future generations.

Shallow sea waters are one of the areas that have high dynamics and important roles both economically and ecologically. These sea waters are shiny with various ecosystems such as coral reefs, seagrass beds, algae, fish and so on. Due to its diversity, this ecosystem is vulnerable to external disturbances. Coral reefs and seagrass as the main components of the ecosystem function as fish habitats, tourism spots, coastal protectors from wave impacts and mixing of suspended materials (McClanahan et al., 2002; Lubis et al., 2018). This was also conveyed by Riniatsih et al., (2017) who stated that mangroves, coral reefs, seaweed and seagrass have a role as supporters of the sustainability and preservation of coastal ecosystems.

Natural factors (sea temperature changes, global climate change, earthquakes and sea level rise) and the threat of pollution caused by human activities such as domestic waste pollution, industrial waste, oil spills make shallow marine habitats and ecosystems vulnerable to damage. According to SOPAC (2005), vulnerability is the tendency of an entity to experience damage. Entities can be physical conditions or concepts. The entity studied is shallow marine habitats. The physical vulnerability of shallow marine habitats is a condition that can increase the process of damage in coastal areas such as abrasion, erosion and sedimentation. The physical vulnerability of shallow marine habitats can trigger damage processes in coastal areas such as abrasion, erosion, and sedimentation (Anton et al., 2019; Dolan and Walker, 2006). Natural factors and the impact of human pollution contribute to the degradation of these sensitive ecosystems (Suaria et al., 2016; Lu et al., 2018).

Vulnerability is characterized by the exposure of the system to a disaster, physical events/incidents of social phenomena that cause exposure to risk and limited community capacity in responding to natural disasters that arise (Dolan and Walker, 2006; Vanderhorst et al., 2021; Piegorsch et al., 2007). The higher the level of vulnerability of a habitat or ecosystem in shallow sea waters, the easier it is for the habitat or ecosystem to be damaged. Therefore, monitoring these changes is quite important and can be approached through the use of remote sensing technology. So far, one of the best approaches in creating a map of shallow sea water habitats is to use remote sensing data. Remote sensing technology is one source of information in collecting marine data effectively and efficiently. This was also conveyed by Setyawan et al., (2014) who stated that remote sensing data in the form of satellite imagery has been successfully used for mapping shallow sea water habitats, coral reef cover, and the distribution of macro algae.

Remote sensing satellite sensors have different shallow water detection capabilities according to the characteristics of their sensors. In the scope of remote sensing, shallow sea waters refer to the ability of satellite imagery to penetrate the water column (Jawak et al., 2015; McCarthy et al., 2017). Mapping of shallow waters (coral reefs) is carried out to the depth limit that can be detected by satellite sensors. Especially for relatively clear shallow waters, the optical remote sensing method is able to penetrate a maximum water depth of 25 m and will decrease as the water becomes increasingly turbid. This was also conveyed by Green et al., (2000) who stated that shallow sea waters in the scope of remote sensing refer to the ability of visible light to penetrate the water column, and reach the bottom of the water to a depth of 25 m. Some habitats on the seabed that can be detected by satellite sensors include seagrass, coral reefs, substrates, and algae.

Our research is crucial for understanding the ecological dynamics of the shallow waters surrounding Combol and Citlim Islands, as it highlights the condition and distribution of critical habitats such as coral reefs and seagrass beds. Our findings reveal that the dominant substrates are open areas and dead corals, covering significant expanses, underscoring the need for targeted conservation efforts. Furthermore, the identified vulnerability index indicates a substantial portion of the area is moderately vulnerable, emphasizing the urgency of implementing effective management strategies to protect these vital ecosystems from ongoing threats posed by climate change and human activities.

2. Methods

Our research location is in the Combol Island and Citlim Island clusters (Combol Island, Citlim Island, Badas Island, Parang Island, Duku Island, Semangka Island, Separi Island, Anaksaoma Island, Samo Island, Merottok Besar Island, Merottok Kecil Island, Menibung Island, Pandan Island, Seraujau Island, Resam Island, Sebaik Island, Kolawa Island, Sekatip Island, Kelelawar Kecil Island, Moro District, Karimun Regency, Riau Islands Province. In this study, shallow water habitat mapping was processed using Sentinel-2A multispectral satellite imagery with a spatial resolution of 10 meters. The method used for shallow water habitat mapping is the water column correction method developed by Lyzenga (1981). The basic assumption for the water column correction is that the light entering the water column decreases exponentially with increasing water depth (attenuation). In visible light, red light attenuates faster than blue and green light. There are two ways to do water column correction, especially in find the value (ki/kj) that represents the ratio of attenuation coefficients. First, through the gradient value on the linear line formed by a pair of visible spectrum bands. Second, it can also be obtained based on the following formula:

$$\frac{Ki}{Kj} = a + \sqrt{(a^2 + 1)}$$

$$a = (\sigma_{ii} - \sigma_{ij})/2\sigma_{ij}$$

$$Depth\ Invariant\ Index = \ln(Li) - [\left(\frac{Ki}{Kj}\right).\ln(Lj)]$$

Information:

Li	=	Digital values on the i band
Lj	=	Digital values on j band
Ki/Kj	=	The ratio of attenuation coefficients in the band pair i and j
$\sigma_{ii,jj}$	=	Variant of band i, or band j
σ_{ij}	=	Covariance band i j

Depth Invariant Index is a corrected image of the water column with a digital value in the form of an index of shallow water bottom habitat objects.

2. Results and Discussion

Based on the analysis of shallow seabed habitat mapping in the Combol Island and Citlim Island clusters using Sentinel-2A satellite imagery, it is known that the dominant shallow seabed habitat is open substrate and dead coral. The total area of shallow seabed habitat for open substrate in the Combol Island and Citlim Island clusters is ± 766.8 Ha. The total area of shallow seabed habitat for dead coral in the Combol Island and Citlim Island clusters is ± 682.5 Ha. The total area of shallow seabed habitat for live coral in the Combol Island and Citlim Island clusters is ± 294 Ha, while for seagrass habitat in the Combol Island and Citlim Island clusters it is ± 259 Ha.

Table 1. Area of shallow marine habitat of the Combol and Citlim Islands clusters

Shallow Water Habitat	Area (Ha)		Total
	Combol Island	Citlim Island	
Open Substrate	236,7	530,1	766,8
Living Coral	67,6	226,6	294,2
Seagrass	149,0	110,5	259,5
Dead Coral	233,4	449,1	682,5
Total	686,7	1316,3	2003,1

Based on the table above, it shows that the shallow sea water habitat in the Combol Island and Citlim Island clusters is dominated by open substrates and dead corals. The area of open substrate habitat in the Combol Island cluster is ± 236.7 Ha and the area of dead coral habitat in the Combol Island cluster is ± 233.4 Ha. The area of open substrate habitat in the Citlim Island cluster is ± 530.1 Ha and the area of dead coral habitat in the Citlim Island cluster is ± 449.1 Ha. This has the potential to cause a high level of vulnerability of shallow sea water habitats in the Combol Island and Citlim Island clusters.

While the area of live coral habitat in the Combol Island cluster is ± 67 Ha and the area of seagrass habitat in the Combol Island cluster is ± 149 Ha. While the area of live coral habitat in the Citlim Island cluster is ± 226 Ha and the area of seagrass habitat in the Citlim Island cluster is ± 110 Ha. A picture of the shallow seabed habitat in the Combol Island and Citlim Island clusters (Figure 1).

The predominance of open substrates and dead corals in the shallow sea water habitats of the Combol and Citlim Island clusters raises significant concerns regarding the ecological stability and resilience of these ecosystems. The substantial areas of dead coral, measuring ± 233.4 Ha in Combol and ± 449.1 Ha in Citlim, indicate potential stressors affecting coral health, such as climate change, pollution, and overfishing. In contrast, the relatively small areas of live coral (± 67 Ha in Combol and ± 226 Ha in Citlim) and seagrass (± 149 Ha in Combol and ± 110 Ha in Citlim) suggest that these critical habitats are under pressure and may struggle to recover. The imbalance between the areas of dead and live coral habitats highlights the urgent need for targeted conservation efforts to enhance the resilience of these marine ecosystems and mitigate the risk of further degradation. Understanding these dynamics is essential for developing effective management strategies that can protect and restore the ecological integrity of the Combol and Citlim Island clusters.

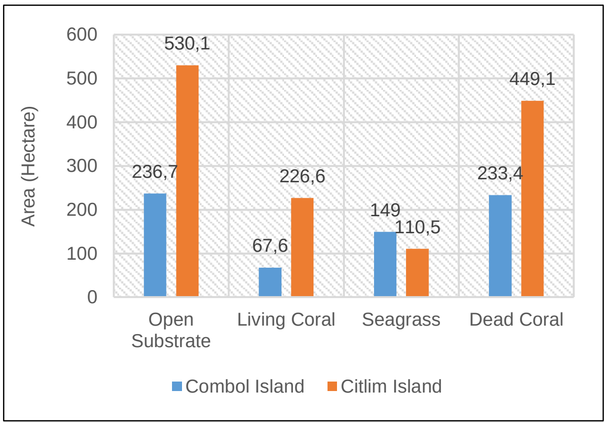

Fig 1. Area diagram of shallow seabed habitat classification in the Combol and Citlim Island clusters.

Based on the analysis of the shallow sea water vulnerability index using a scoring system and overlay between parameters in the Combol Island and Citlim Island clusters, it is known that the dominant vulnerability index is the medium vulnerability category. The area of the vulnerability index with a medium category is ± 393 Ha. The shallow sea water vulnerability index in the Combol Island cluster is predominantly included in the moderate vulnerability index category with an area of ± 198 Ha. While the shallow sea water vulnerability index in the Citlim Island cluster is predominantly included in the moderate category with an area of ± 195 Ha, however the shallow sea water vulnerability index in the Citlim Island cluster from each category does not have a significant difference, while the shallow sea water vulnerability index in the Combol Island cluster from each category has a significant difference. The area of the shallow sea water vulnerability index in the Combol Island and Citlim Island clusters is presented in the following table.

Table 2. Area of shallow sea water vulnerability index in the Combol and Citlim Islands clusters

Shallow sea waters vulnerability index	Area (Ha)		
	Combol Island	Citlim Island	Total
Very Low	71,5	178,4	249,9
Low	17,9	134,5	152,4
Middle	198,0	195,3	393,3
High	59,7	154,7	214,4
Very high	46,2	142,3	188,5
Total	393,3	805,2	1.198,5

The assessment of vulnerability indices in marine ecosystems is critical for understanding the impacts of environmental stressors and guiding conservation efforts (Leenhardt et al., 2015). Furthermore, the use of scoring systems and parameter overlays provides a robust framework for evaluating the resilience of coastal habitats (McCay and Jones, 2011).

The high level of vulnerability has the potential for changes in coastal areas where live coral and seagrass are considered less than dead coral habitats and open substrates. The distribution map of the shallow sea water vulnerability index from the combined Combol Island and Citlim Island clusters is presented in Figure 3-5.

A broad overview of the vulnerability index of shallow sea waters in the Combol and Citlim Islands (Figure 2).

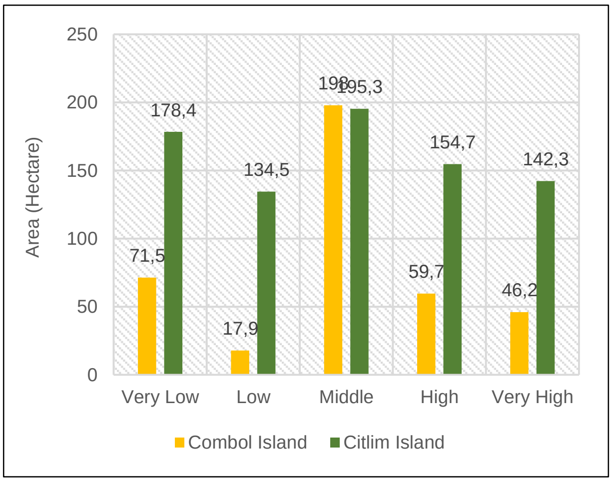

Fig 2. Vulnerability index of shallow sea waters in the Combol and Citlim Islands clusters.

The analysis of the shallow sea water vulnerability index in the Combol and Citlim Islands highlights the pressing need for targeted conservation strategies. The predominance of medium vulnerability in both clusters, with a total area of approximately 393 hectares, underscores the critical state of these marine ecosystems. Given that the Combol Island cluster exhibits significant differences among vulnerability categories, it is essential to prioritize monitoring and management efforts in this area. The variation in vulnerability levels can be attributed to factors such as local environmental conditions, anthropogenic influences, and the inherent resilience of the marine habitats (Blauhut et al., 2016). For instance, the presence of live coral and seagrass is crucial for maintaining ecosystem health, as these habitats provide essential services, including coastal protection, biodiversity support, and carbon sequestration. The data suggests that areas classified under the high and very high vulnerability categories, particularly in the Combol Island cluster, may be at an increased risk of degradation due to environmental stressors, necessitating immediate action to mitigate potential losses.

Furthermore, the identification of medium vulnerability across both the Combol and Citlim Islands serves as a clarion call for collaborative conservation efforts involving local communities, governmental agencies, and environmental organizations. Engaging stakeholders in the development and implementation of sustainable management practices can enhance the resilience of these ecosystems. Community-based initiatives, such as habitat restoration projects and sustainable fishing practices, can play a pivotal role in reducing anthropogenic pressures and fostering a sense of stewardship among local populations.

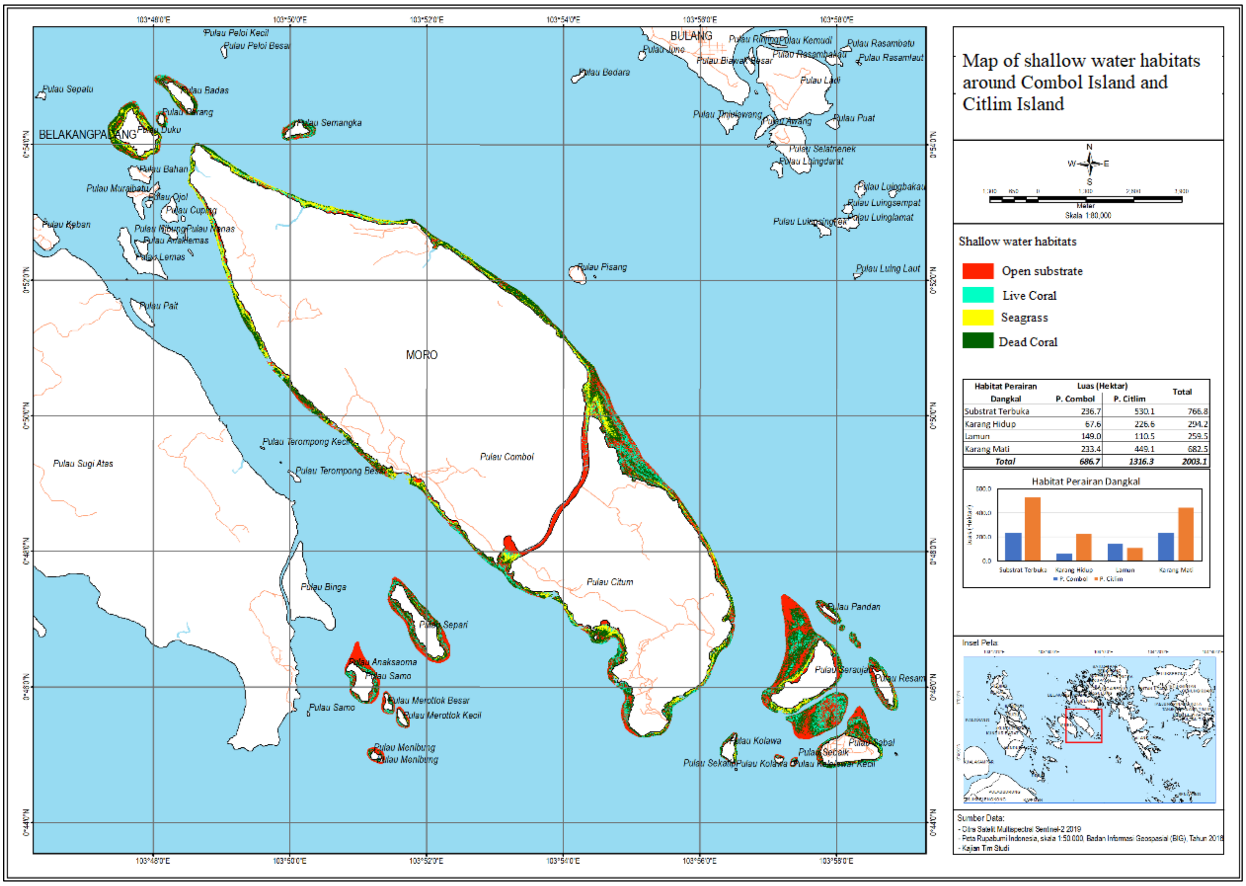

Fig 3. Map of shallow water habitats around Combol Island and Citlim Island.

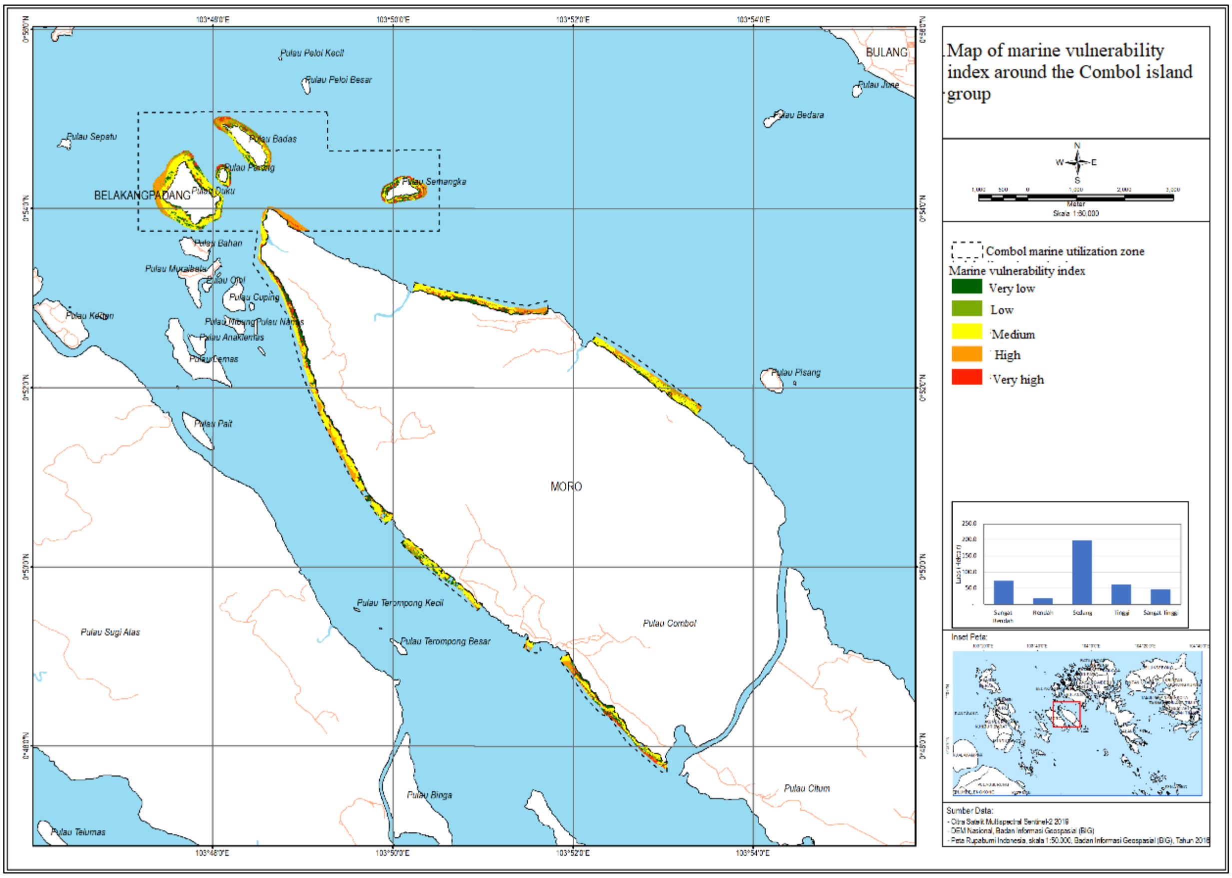

Fig 4. Map of marine vulnerability index around the Combol island group.

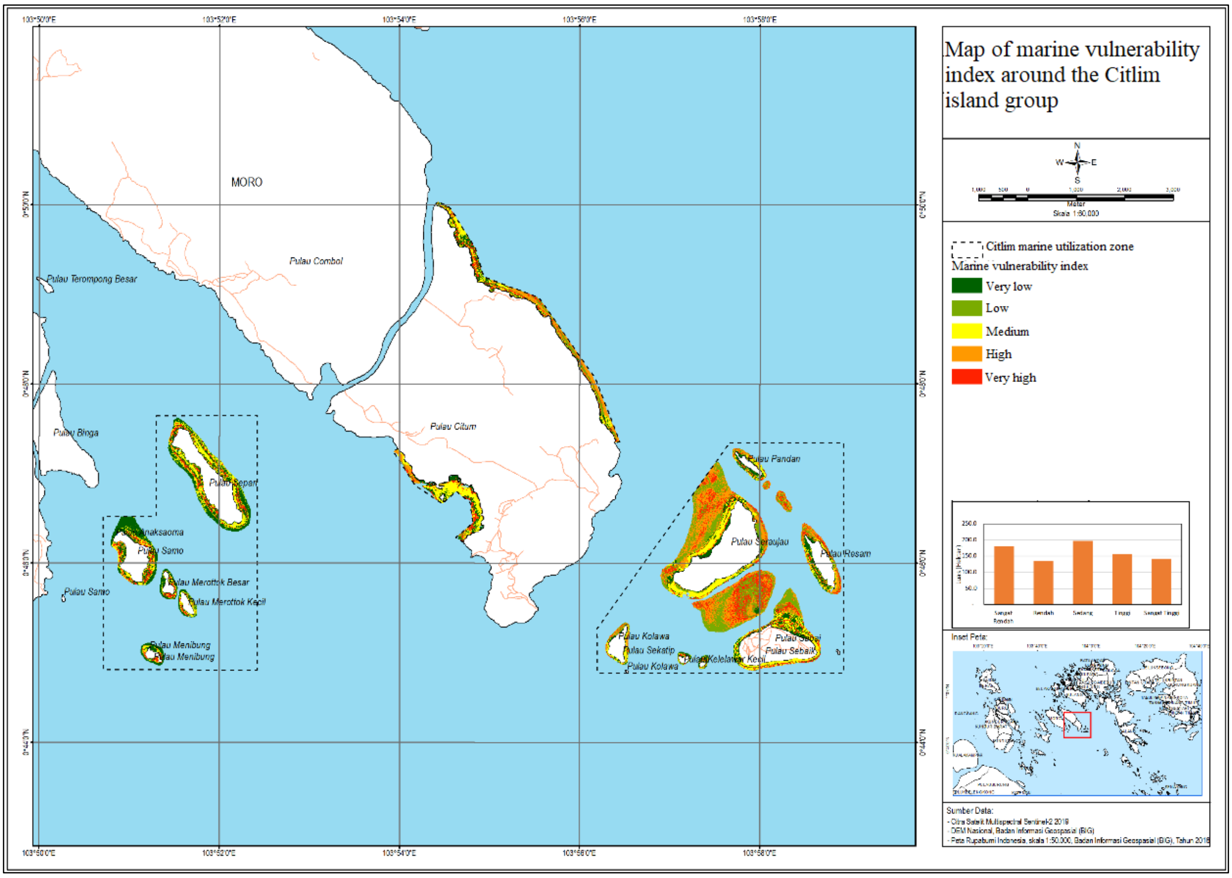

Fig 5. Map of marine vulnerability index around the Citlim island group.

The comprehensive analysis of shallow seabed habitats and vulnerability indices in the Combol and Citlim Islands reveals critical insights into the ecological health of these marine ecosystems (Figure 3). The mapping conducted using Sentinel-2A satellite imagery indicates a dominance of open substrates and dead coral, with a total area of approximately 766.8 hectares for open substrates and 682.5 hectares for dead coral across both clusters. This alarming prevalence of dead coral suggests significant environmental stressors impacting coral health, such as climate change, pollution, and overfishing. In contrast, the areas of live coral and seagrass are notably smaller, totaling only 294 hectares and 259 hectares, respectively. This imbalance raises concerns about the resilience of these habitats, which are vital for maintaining biodiversity and providing essential ecosystem services.

The analysis of the shallow sea water habitats in the Combol and Citlim Island clusters reveals a concerning trend characterized by a significant predominance of open substrates and dead corals. These findings underscore the vulnerability of these ecosystems, as extensive areas of dead coral, measuring ± 233.4 Ha in Combol and ± 449.1 Ha in Citlim, indicate a decline in coral health and vitality (Figure 3). Factors such as rising sea temperatures, ocean acidification, and increased sedimentation due to coastal development are likely contributors to this degradation. The limited presence of live coral (± 67 Ha in Combol and ± 226 Ha in Citlim) suggests that these habitats are not only under stress but may also lack the capacity for natural recovery. This situation calls for immediate attention to mitigate the impacts of anthropogenic activities and to initiate restoration efforts aimed at enhancing coral resilience.

Additionally, the presence of seagrass habitats, although more substantial in Combol (± 149 Ha) compared to Citlim (± 110 Ha), further complicates the ecological dynamics of these shallow waters. Seagrasses play a vital role in coastal ecosystems by stabilizing sediments, improving water quality, and providing critical habitat for various marine species (Figure 4). The relatively small areas of seagrass in both clusters indicate that these ecosystems are also under threat, potentially exacerbating the vulnerability of associated coral habitats. Therefore, comprehensive management strategies that integrate habitat protection, pollution control, and community engagement are essential for fostering the recovery and sustainability of these marine environments. Such strategies should prioritize the restoration of live coral and seagrass populations to enhance the overall resilience of the Combol and Citlim Island clusters against future environmental challenges (Figure 5).

4. Conclusion

The vulnerability index assessment further underscores the precarious state of these marine environments. With approximately 393 hectares categorized as medium vulnerability, it is evident that both the Combol and Citlim Island clusters face considerable ecological challenges. Notably, the Combol Island cluster displays significant differences among vulnerability categories, necessitating focused conservation efforts to address the unique pressures it faces. In contrast, the Citlim Island cluster exhibits a more uniform vulnerability across categories, suggesting that management strategies may benefit from a more generalized approach. The identification of high and very high vulnerability areas necessitates immediate action to enhance the resilience of these ecosystems and mitigate the risk of further degradation.

To effectively protect and restore the ecological integrity of the Combol and Citlim Islands, it is essential to implement targeted conservation strategies that consider both the ecological dynamics and socio-economic factors at play. Collaborative efforts among local communities, governmental bodies, and environmental organizations will be crucial in fostering sustainable practices and engaging stakeholders in conservation initiatives. Moreover, integrating local ecological knowledge into management strategies can enhance the effectiveness of restoration projects and promote a sense of stewardship among the communities that depend on these marine resources. Ultimately, addressing the vulnerabilities identified in this study is vital for ensuring the long-term sustainability of the shallow sea waters in the Combol and Citlim Islands, thereby safeguarding their ecological health for future generations.

To effectively address the vulnerabilities identified in the shallow seabed habitats of the Combol and Citlim Islands, it is imperative to implement a multifaceted approach that includes rigorous monitoring and assessment of environmental conditions. Regular data collection through remote sensing technologies, such as Sentinel-2A satellite imagery, can provide valuable insights into habitat changes over time, enabling timely interventions. Furthermore, engaging local communities in conservation efforts is crucial, as their traditional knowledge and practices can enhance the effectiveness of management strategies. Educational programs aimed at raising awareness about the importance of coral and seagrass ecosystems can foster a sense of stewardship among residents. Collaborative initiatives that involve stakeholders, including government agencies, non-governmental organizations, and local fishers, can facilitate the development of sustainable fishing practices and reduce pollution inputs. By prioritizing these integrated efforts, the resilience of the Combol and Citlim Island clusters can be strengthened, ensuring the preservation of their ecological integrity for future generations.

Acknowledgments

The author would first like to thank the entire team who helped in the research process, both secondary and primary data collection.

References

Anton, I. A., Panaitescu, M., Panaitescu, F. V., & Ghiţă, S. (2019). Impact of coastal protection systems on marine ecosystems. In *E3S Web of Conferences* (Vol. 85, p. 07011). EDP Sciences.

AUNURRAHMAN, A., ANGGORO, S., SAPUTRA, S. W., & MUSKANANFOLA, M. R. (2024). Coral reef condition Kepala Jeri Island, Batam, Riau Islands, Indonesia. *Biodiversitas Journal of Biological Diversity*, *25*(7).

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological monographs*, *81*(2), 169-193.

Blauhut, V., Stahl, K., Stagge, J. H., Tallaksen, L. M., De Stefano, L., & Vogt, J. (2016). Estimating drought risk across Europe from reported drought impacts, drought indices, and vulnerability factors. *Hydrology and Earth System Sciences*, *20*(7), 2779-2800.

Deudero, S., & Alomar, C. (2015). Mediterranean marine biodiversity under threat: reviewing influence of marine litter on species. *Marine pollution bulletin*, *98*(1-2), 58-68.

Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal research*, 1316-1323.

Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal research*, 1316-1323.

Duarte, C. M. (2002). The future of seagrass meadows. *Environmental conservation*, *29*(2), 192-206.

Green, E. P., Mumby, P. J., Edwards, A. J., & Clark, C. D. (2000). Remote sensing handbook for tropical coastal management.

Häder, D. P., Banaszak, A. T., Villafañe, V. E., Narvarte, M. A., González, R. A., & Helbling, E. W. (2020). Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. *Science of the Total environment*, *713*, 136586.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., d'Agrosa, C., ... & Watson, R. (2008). A global map of human impact on marine ecosystems. *science*, *319*(5865), 948-952.

Jawak, S. D., Vadlamani, S. S., & Luis, A. J. (2015). A synoptic review on deriving bathymetry information using remote sensing technologies: models, methods and comparisons. *Advances in remote Sensing*, *4*(2), 147-162.

Kausarian, H., Sri Sumantyo, J. T., Kuze, H., Aminuddin, J., & Waqar, M. M. (2017). Analysis of polarimetric decomposition, backscattering coefficient, and sample properties for identification and layer thickness estimation of silica sand distribution using L-band synthetic aperture radar. *Canadian Journal of Remote Sensing*, *43*(2), 95-108.

Leenhardt, P., Low, N., Pascal, N., Micheli, F., & Claudet, J. (2015). The role of marine protected areas in providing ecosystem services. In *Aquatic functional biodiversity* (pp. 211-239). Academic Press.

Lu, Y., Yuan, J., Lu, X., Su, C., Zhang, Y., Wang, C., ... & Sweijd, N. (2018). Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability. *Environmental Pollution*, *239*, 670-680.

LUBIS, M. Z., Anurogo, W. E. N. A. N. G., Hanafi, A. D. I. T. Y. A., Kausarian, H. U. S. N. U. L., TAKI, H. M., & Antoni, S. A. T. R. I. A. (2018). Distribution of benthic habitat using Landsat-7 Imagery in shallow waters of Sekupang, Batam Island, Indonesia. *Biodiversitas Journal of Biological Diversity*, *19*(3), 1117-1122.

LUBIS, M. Z., Pujiyati, S. R. I., PAMUNGKAS, D. S., TAUHID, M., ANUROGO, W., & KAUSARIAN, H. (2018). Coral reefs recruitment in stone substrate on Gosong Pramuka, Seribu Islands, Indonesia. *Biodiversitas Journal of Biological Diversity*, *19*(4), 1451-1458.

Lyzenga, D. R. (1981). Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. *International journal of remote sensing*, *2*(1), 71-82.

McCarthy, M. J., Colna, K. E., El-Mezayen, M. M., Laureano-Rosario, A. E., Méndez-Lázaro, P., Otis, D. B., ... & Muller-Karger, F. E. (2017). Satellite remote sensing for coastal management: A review of successful applications. *Environmental management*, *60*, 323-

339.
McCay, B. J., & Jones, P. J. (2011). Marine protected areas and the governance of marine ecosystems and fisheries. *Conservation biology*, *25*(6), 1130-1133.
McClanahan, T., Polunin, N., & Done, T. (2002). Ecological states and the resilience of coral reefs. *Conservation ecology*, *6*(2).
Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., ... & Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, *9*(10), 552-560.
Piegorsch, W. W., Cutter, S. L., & Hardisty, F. (2007). Benchmark analysis for quantifying urban vulnerability to terrorist incidents. *Risk Analysis: An International Journal*, *27*(6), 1411-1425.
Riniatsih, I., Munasik, M., Adhi Suryono, C., AzizahTN, R., Hartati, R., Pribadi, R., & Subagiyo, S. (2017). Komposisi Makroalga Yang Berasosiasi Di Ekosistem Padang Lamun Pulau Tumpul Lunik, Pulau Rimau Balak Dan Pulau Kandang Balak Selatan, Perairan Lampung Selatan.
South of Pacific Islands Applied Geoscience Commission. (2005). Environmental Vulnerability Index: EVI: Description of Indicators.
Suaria, G., Avio, C. G., Mineo, A., Lattin, G. L., Magaldi, M. G., Belmonte, G., ... & Aliani, S. (2016). The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. *Scientific reports*, *6*(1), 37551.
Vanderhorst, H. R., Suresh, S., Renukappa, S., & Heesom, D. (2021). Strategic framework of Unmanned Aerial Systems integration in the disaster management public organisations of the Dominican Republic. *International Journal of Disaster Risk Reduction*, *56*, 102088.