Diversity and Abundance of Mangrove Gastropods in Setiu Wetlands and Matang Mangrove Forest Reserve, Peninsular Malaysia

Nursalwa Baharuddin[1,2]* and Behara Satyanarayana[2]

[1]Faculty of Science and Marine Environment, Universiti Malaysia Terengganu
[2]Mangrove Research Unit (MARU), Institute of Oceanography and Environment, Universiti Malaysia Terengganu
21030 Kuala Nerus, Terengganu, Malaysia
Email: nursalwa@umt.edu.my

Abstract

Mangrove gastropods, a highly diverse group of mollusks, play a critical yet often overlooked role in mangrove ecosystems. This study investigates the distribution and abundance of mangrove gastropods in two study sites with distinct management regimes: Matang Mangrove Forest Reserve (MMFR) and Setiu Wetlands (SW) in Peninsular Malaysia. Gastropod sampling was conducted over two days in April 2023, with one-hour visual encounter surveys performed at each study site per day. A total of 3,717 individuals, representing 26 species, were collected across both study sites. The family Ellobiidae was predominant in MMFR, while the family Littorinidae dominated in SW. Despite the higher biodiversity of both mud-dwelling and tree-dwelling species observed in MMFR, the overall low abundance of gastropods indicates negative impacts from greenwood exploitation and the widespread monoculture of Rhizophora *spp. In contrast, the reduced diversity of mud-dwelling species in SW may be attributed to suboptimal sediment conditions caused by a shifted Setiu River mouth, low freshwater discharge, and increased sedimentation. This study provides precise assessments of species distribution across various microhabitats, offering essential baseline data for future ecological monitoring. Improved management practices, including habitat restoration, protection of biodiversity hotspots, and community engagement, are critical for sustaining gastropod populations and ensuring the long-term health and resilience of these vital coastal ecosystems. The findings highlight the sensitivity of gastropods to environmental changes and emphasize the need for adaptive conservation strategies to mitigate human impacts on mangrove ecosystems. This study serves as a foundation for developing effective conservation strategies to protect mangrove ecosystems, crucial for maintaining gastropod populations and the overall health of coastal ecosystems.*

Keywords: *Mangrove, gastropods, exploitation, microhabitat, conservation*

Introduction

Mangrove ecosystems are globally recognized for their ecological, environmental, and socioeconomic value. They provide vital services, including carbon storage, coastal protection, and food and livelihood support for millions of coastal residents (Brander *et al*., 2012; Vo *et al*., 2012; Mohamed *et al*., 2024). However, these ecosystems face severe threats from deforestation, climate change, and land conversion—particularly in Southeast Asian hotspots like Myanmar, the Philippines, Malaysia, Cambodia, and Indonesia (Primavera, 2008; Gandhi and Jones, 2019; Samanta *et al*., 2023; Parkinson and Wdowinski, 2022). Encouragingly, recent conservation efforts have slowed the rate of mangrove loss. These efforts demonstrate how sustainable management and restoration can protect these essential ecosystems (Friess *et al*., 2016, 2020).

Mangrove gastropods—a highly diverse class of molluscs—are a critical yet often overlooked part of mangrove ecosystems. They perform essential ecological functions, such as nutrient recycling, litter decomposition, and energy transfer within food webs. These functions directly influence ecosystem productivity and health (Strong *et al*., 2007). More than 300 species of gastropods are associated with mangroves (Brown and Lydeard, 2010). They serve various ecological roles, including filter feeding, scavenging, herbivory, and predation, all contributing to the complex functioning of these habitats (Proffitt and Devlin, 2005). The diversity and abundance of these gastropods are key indicators of ecosystem health and resilience.

Gastropods also act as valuable bioindicators due to their sensitivity to environmental changes and pollutants, such as heavy metals (Wolswijk *et al*., 2020). These pollutants can accumulate in mangrove ecosystems, threatening both ecosystem health and public safety (Oehlmann and Oehlmann, 2003; Kottè-Mapoko *et al*., 2017, 2021). Thus, understanding gastropod distribution and abundance is crucial for managing and conserving mangrove ecosystems. Monitoring gastropod populations allows for better assessment of ecosystem dynamics and aids in

*) Corresponding author

https://ejournal.undip.ac.id/index.php/ijms
DOI: 10.14710/ik.ijms.29.4.425-432
Received : 17-09-2024
Accepted : 29-11-2024

preserving the ecological and socioeconomic benefits that mangroves provide.

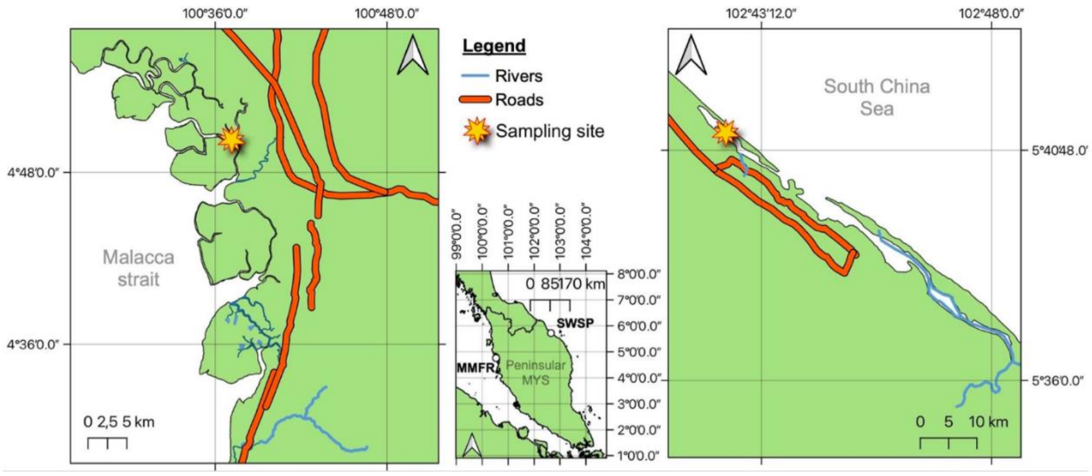
In Peninsular Malaysia, two key mangrove sites offer unique contexts for studying gastropod diversity and abundance: the Setiu Wetlands (SW) on the east coast and the Matang Mangrove Forest Reserve (MMFR) on the west coast. The MMFR, a globally renowned managed mangrove forest spanning over 40,000 ha, focuses on commercial activities—primarily charcoal production and construction pole harvesting from *Rhizophora apiculata* and *R. mucronata*—following a 30-year rotation cycle (Chong, 2006; Satyanarayana *et al*., 2021; Chen *et al*., 2024). This intensive resource extraction places significant pressure on the mangrove ecosystem, which may influence gastropod diversity and abundance. Monitoring these populations in this context is essential to understand how resource extraction affects ecosystem resilience.

In contrast, the Setiu Wetlands (SW) covers approximately 400 ha and faces different challenges. While less commercially exploited, it contends with natural hydrodynamic changes, including a shifted river mouth, and mollusc collection by local communities (Yahya *et al*., 2018). The SW has also been impacted by increased salinity and altered sedimentation patterns, which can affect gastropod populations. Since its designation as a State Park in 2018 (Wahab, 2024), the SW has become a vital fisheries hub, underscoring the need to understand gastropod dynamics in maintaining biodiversity and supporting sustainable livelihoods (Ling *et al*., 2013). By investigating gastropod diversity and abundance in these shifting environmental conditions, this study will contribute valuable insights for conservation and management efforts.

Community ecology theories emphasize that the diversity and abundance of mangrove gastropods serve as critical indicators of ecosystem resilience, productivity, and sustainability (Friess *et al*., 2016, 2020). This study focuses on examining the distribution and abundance of gastropods across distinct microhabitats in two key locations: the Setiu Wetlands (SW) and the Matang Mangrove Forest Reserve (MMFR). By investigating how environmental conditions and management practices differ between SW and MMFR, the study aims to elucidate their impact on gastropod diversity and abundance. This approach aligns with the primary research objective of evaluating the ecological role of gastropods and their contribution to ecosystem health and sustainability.

Materials and Methods

The study was carried out from Matang Mangrove Forest Reserve (MMFR) on the west coast and Setiu Wetlands (SW) on the east coast in Peninsular Malaysia (April 2023) (Figure 1.). The mangrove (live) gastropods were collected via random handpicking for one hour, which is categorised under visual encounter surveys (Cummings *et al*., 2016). All specimens on the ground, referred to as 'mud substratum species, ' as well as on the tree trunks, leaves and roots, referred to as ‘tree-dwelling species’, were collected. For the species with a higher abundance, only its representatives (10-15 individuals) were taken and released the rest after counting. All samples were placed in labelled zip-lock plastic bags, stored in an ice box and transferred to the laboratory for further analysis. The sample collection location was recorded using a handheld GPS (Garmin, GPSMAP 65s, USA).



Matang Mangrove Forest Reserve | Setiu Wetlands in Peninsular Malaysia

Figure 1. Map of study sites

Each specimen was meticulously cleaned in the laboratory with a brush under the tap water to eliminate any algal film, dirt, or other encrustations on the shells. Morphological features such as shape, colour, size, and other characteristics were considered for its taxonomic identification. Species-level identification was carried out based on the standard literature of Baharuddin and Marshall (2014) and Raven and Vermeulen (2006). Additionally, the books such as "Kekunci Siput dan Kerang-Kerangan Perairan Pantai Malaysia Timur" (Long and Ramli, 2010), and "The Molluscs of the Southern Gulf of Thailand" (Swennen *et al.,* 2001) were referred to during the identification process. The World Register of Marine Species (WoRMS) database was consulted for species name changes at the lowest taxonomic level and its authentication (https://www.marinespecies.org/).

The Shannon Index (H') is a measure of biodiversity that considers both species richness and evenness. It was calculated using the formula $H' = -\Sigma (Pi*\ln(Pi))$, where $Pi = ni/N$.Pi represents the proportion of the individuals in the total sample of N species collected, ni is the number of individuals within the species, and N is the total number of individuals across all species within the samples. This index is particularly useful for assessing the diversity of snail species. The Shannon diversity index is classified into three levels: low ($H'<2$), moderate ($2< H'<4$), and high ($H'>4$) (Odum and Barret, 2004). The Simpson index, a widely used metric for assessing habitat biodiversity, also gauges the likelihood of randomly selecting two individuals from an infinitely large community. It offers an advantage by providing a more comprehensive insight into species abundance, surpassing the mere enumeration of species present. The Simpson diversity index (D) is calculated using the formula $D= 1 - \Sigma(Pi)^2$. A value of 1 for (D) indicates high diversity, while 0 indicates low biodiversity. The Pielou Index, also known as the Evenness Index or the J' Index, measures species evenness within a community (Hammer *et al*., 2001). Assessing the equitability of species distribution in a given habitat is useful. The index ranges from 0 to 1, with 0 indicating complete unevenness (one species dominates the community) and 1 indicating perfect evenness (all species are equally abundant). The formula for calculating the Pielou Index is: $J'= H'/\ln(S)$, where J' is the Pielou Index, H' is the Shannon Diversity Index, and S is the total number of species.

Results and Discussion

This study reveals significant differences in gastropod diversity and abundance between the Matang Mangrove Forest Reserve (MMFR) and the Setiu Wetlands (SW). A total of 3,717 gastropods, representing 26 species, were found across both study sites, with greater species richness observed at MMFR (15 species) compared to SW (13 species) (Table 1 and 2.). The family Ellobiidae, comprising species such as *Cassidula nucleus, C. aurisfelis, Auriculastra oparica, Ellobium aurisjudae, E. tornatelliforme, Pythia plicata,* and *P. pantherine*, was exclusively found in MMFR, whereas the family Littorinidae, including species like *Littoraria scabra, L. lutea, L. melanostoma, L. pallescens,* and *L. philippiana*, was confined to SW. Species from other families, such as Potamididae (six species), Neritidae (five species), Assimineidae (two species), and Muricidae (one species), were found in both study sites, exhibiting a mixed distribution (Table 1.). The taxonomic subclasses—Caenogastropoda, Heterobranchia, and Neritimorpha—appear to represent the diverse ecological niches occupied by gastropods within mangrove habitats.

In the Matang Mangrove Forest Reserve (MMFR), combination of mud and tree-dwelling substrates supports a higher number of gastropod species (15 species in total), with *Cassidula aurisfelis* (39% relative abundance) and *Neripteron auriculatum* (34% relative abundance) being the most abundant. Both species thrive in muddy, nutrient-rich environments (Ismail, 2019; Anggraini *et al*., 2021; Safe'i *et al*., 2021). The Pielou Index indicates that mud-dwelling species are more evenly distributed (J= 0.759) compared to tree-dwelling species in MMFR (J= 0.623) (Table 2.). For tree-dwelling species, the MMFR supports eleven species, with *Ellobium aurisjudae* (48% relative abundance) representing nearly half of the total population. This species is typically found above the tide level, under logs, and occasionally on the lower trunks of mangroves (Harzhauser *et al*., 2023), which aligns with the present findings. *Cassidula nucleus* follows with 22% relative abundance (Figure 2.). The Shannon Index further confirms a greater diversity of tree-dwelling species than mud-dwelling species in MMFR (H= 1.598) (Table 2.). Although the diversity indices are higher for MMFR, the overall abundance of gastropods remains low, with only 799 individuals recorded (Table 2.). This relatively low abundance may be attributed to ongoing management activities, such as the production of mangrove poles and charcoal (Chong, 2006; Satyanarayana *et al*., 2021; Chen *et al*., 2024). While some areas of MMFR are considered protective forests or undisturbed, such as virgin jungle, the exploitation of greenwood, along with the extensive monoculture of *Rhizophora* spp., likely impacts gastropod populations. According to Macintosh *et al.* (2002), dense and diverse mangrove forests are positively correlated with greater invertebrate diversity. Their research suggests that mature mangrove stands support higher invertebrate abundance and biomass, while newly planted stands tend to have lower species abundance and biomass.

Table 1. Mangrove gastropods recorded the following subclass, family and species at different microhabitats and sites, where MD= mud substratum species, TD= Tree-dwelling species, MMFR= Matang Mangrove Forest Reserve, and SW= Setiu Wetlands.

Subclass	Family	Species	Microhabitat	Site
Caenogastropoda	Assimineidae	*Assiminea grayana*	MD	MMFR
		Assiminea sp.	MD	SW
	Littorinidae	*Littoraria scabra*	TD	SW
		Littoraria lutea	TD	SW
		Littoraria melanostoma	TD	SW
		Littoraria pallescens	TD	SW
		Littoraria philippiana	TD	SW
	Muricidae	*Chicoreus capucinus*	MD, TD	MMFR
	Potamididae	*Cerithidea obtusa*	MD	MMFR
		Cerithidea quoyii	TD	MMFR, SW
		Pirenella cingulata	MD, TD	SW
		Pirenella alata	MD	SW
		Telescopium telescopium	MD	SW
		Terebralia palustris	MD	MMFR
Heterobranchia	Ellobiidae	*Cassidula nucleus*	TD	MMFR
		Cassidula aurisfelis	MD, TD	MMFR
		Auriculastra oparica	TD	MMFR
		Ellobium aurisjudae	TD	MMFR
		Ellobium tornatelliforme	TD	MMFR
		Pythia plicata	TD	MMFR
		Pythia pantherina	TD	MMFR
Neritimorpha	Neritidae	*Neripteron auriculatum*	MD	MMFR
		Neripteron violaceum	MD, TD	MMFR, SW
		Neritina cornucopia	TD	MMFR
		Nerita balteata	TD	SW
		Clithon oualaniense	MD	SW
Total species		26	12(MD), 18(TD)	15(MMFR), 13(SW)

Table 2. Abundance (total number of individuals) and ecological indices of mangrove gastropods recorded at different microhabitats and sites, where MD= mud substratum species, TD= Tree-dwelling species, MMFR= Matang Mangrove Forest Reserve and SW= Setiu Wetlands.

Microhabitat / Site	Abundance (ind.)	Indices		
		Shannon H'	Simpson D	Pielou J'
MD/MMFR	246	1.478	0.716	0.759
MD/SW	2890	1.017	0.590	0.567
TD/MMFR	553	1.598	0.705	0.623
TD/SW	28	1.864	0.798	0.809
Total abundance	3717			

In the Setiu Wetlands (SW), six out of the 13 gastropod species were found on mud substratum. Notably, *Pirenella alata* (48% relative abundance) and *Clithon oualaniense* (41% relative abundance) constituted a significant portion of the population, totalling 2,890 individuals, which represents nearly three-quarters of the total gastropod collection (Table 2, Figure 2.). The occurrence of *P. alata* in mangrove and brackish fishponds and on bare mud in outer to mid-estuarine mangroves (Lozouet and Plaziat, 2008) is well documented. This species is typically found on mud substrates in the shade of trees in the seaward zones of mangrove forests beneath *Rhizophora* spp. In contrast, *C. oualaniense*, a eurybiotic species known to thrive in soft substrates of intertidal habitats, has been observed in high population densities in Vietnamese mangroves (Zvonareva and Kantor, 2016). This species is

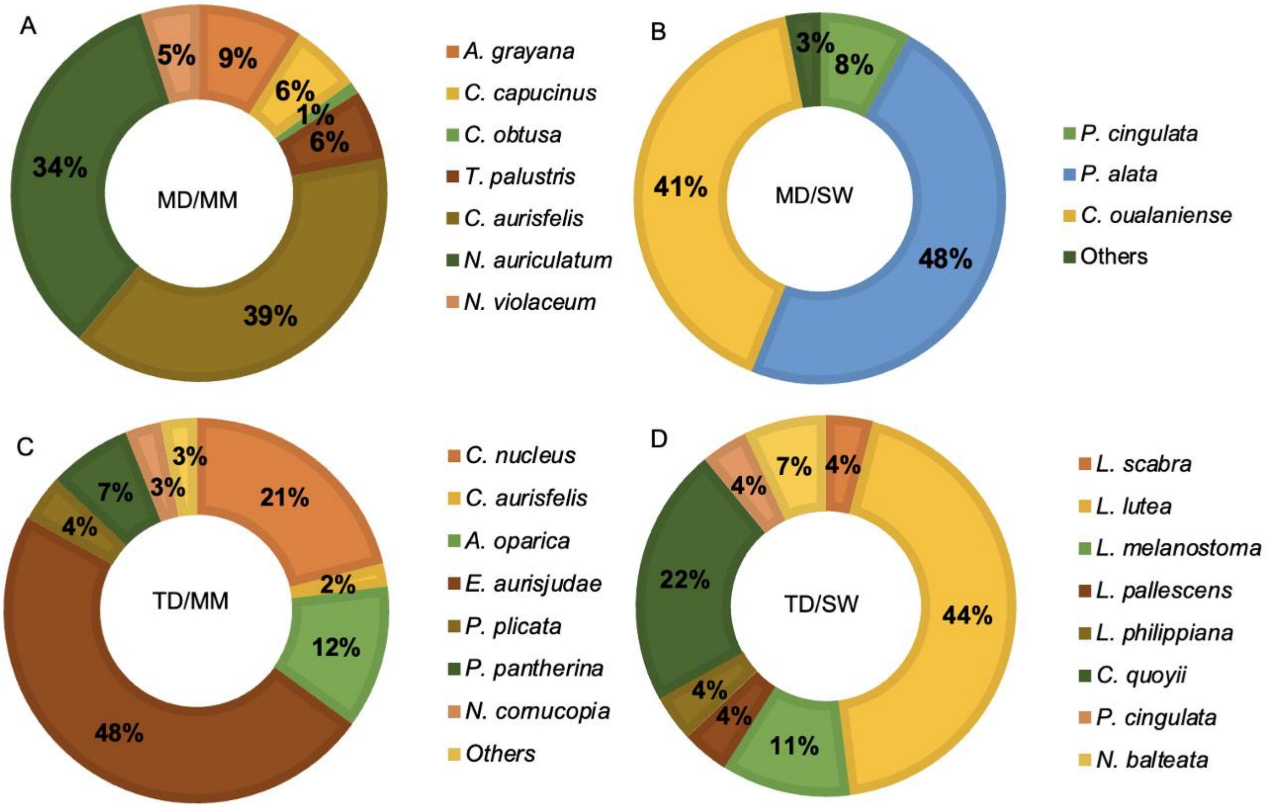


Figure 2. Relative abundance of mangrove gastropods at different microhabitats in Setiu Wetlands (SW) and Matang Mangrove Forest Reserve (MMFR). MD/MM = mud substratum species at Matang mangrove; MD/SW = mud subsratum species at Setiu Wetlands; TD/MM = tree-dwelling species at Matang mangrove; TD/SW = tree-dwelling species at Setiu Wetlands.

considered opportunistic within the mangrove ecosystem, benefiting from detritus enrichment and favourable conditions for micro-algal growth, which are essential for its sustenance (Zvonareva and Kantor, 2016).

The Shannon and Simpson indices reveal the lowest diversity among species inhabiting mud substratum in the SW (H = 1.017, D = 0.590) (Table 2.). For tree-dwelling species, *Littoraria lutea* and *Cerithidea quoyii* contributed 22–44% of the total population. The arboreal behavior of *C. quoyii* was observed at 1.5 m above ground level on the trunks of *Rhizophora* and *Nypa* mangroves (Reid, 2014). While the tree-dwelling community in SW appears relatively robust, the mud substratum shows signs of disturbance.

Recent hydrodynamic changes, including low freshwater discharge and a shifted Setiu River mouth, have led to poor water circulation and exchange mechanisms in the area (Zainol and Akhir 2019; Zainol *et al*., 2022). As a result, much of the sand brought in by tidal movements is deposited in the lagoon and mangrove areas. The SW is home to rich mangrove biodiversity, providing various ecosystem services to local communities. However, these recent changes in hydrodynamics are starting to impact both flora and fauna (personal observation). The low diversity of gastropods in this study may be linked to the degraded sedimentological conditions caused by these changes (Poh *et al*., 2018). Additionally, pollution from adjacent agricultural and aquacultural activities exacerbates these issues, altering the composition and distribution of mollusks. Setiyowati (2018) notes that the shift in sediment composition toward a predominantly sand-based substrate may render it less conducive for gastropod populations. The limited diversity of gastropods in the SW is likely associated with these suboptimal conditions, underscoring the need for continuous monitoring and management to ensure the sustainability of the area's gastropod community.

Conclusion

Our survey of mangrove gastropod biodiversity in the MMFR and the SW revealed significant insights into the ecosystem complexities. Both sites exhibited diverse gastropod species, with MMFR hosting a higher species richness. Variations in the habitat characteristics, including sediment composition and human impacts, likely account for the observed differences between the two study sites. Our findings emphasise the resilience of certain gastropod species in degraded environments and underscore the need for conservation efforts to prioritise preserving diverse microhabitats within mangrove ecosystems. Further research is essential to understand the mechanisms driving species distribution patterns and to develop effective strategies for mitigating anthropogenic disturbances. By integrating scientific knowledge with conservation initiatives, we can safeguard these coastal ecosystems and their diverse species for future generations.

Acknowledgement

This study was supported by the Higher Institution Centre of Excellence (HICoE) research grant (Vote 66928) awarded to the Institute of Oceanography and Environment, Universiti Malaysia Terengganu, by the Ministry of Higher Education (Malaysia). Authors extend their gratitude to the postgraduate students for their help in fieldwork/sample collection. Special thanks to the State Forest Department of Perak and Setiu Wetlands State Park authorities for their kind permission to work in the both areas.

References

Anggraini, R., Syahrial., Karlina, I., Mariati, W., Saleky, D. & Leni, Y. 2021. Gastropoda test family of Neritidae as bioindicator to health status of mangrove forest Pulau Tunda Serang Banten, Indonesia. *Acta Aquatica: Aquatic Sci. J.*, 8(1): 49-55. https://doi.org/10.29103/aa.v8i1.382 9

Baharuddin, N. & Marshall, D.J. 2014. Common aquatic gastropods of Brunei. Education and Technology Centre, Universiti Brunei Darussalam, Brunei. 19 pp.

Brander, L.M., Wagtendonk, A.J., Hussain, S.S., McVittie, A., Verburg, P.H., Groot, R.S.D. & Ploeg, S.V.D. 2012. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. *Ecosyst. Serv.,* 1: 62-69. https://doi.org/10.1016/j.ecoser.2012. 06.003

Brown, K.M. & Lydeard, C. 2010. Mollusca: Gastropoda. *In* Thorpe, JH & Covich, AP. (Eds). Ecology and classification of North American freshwater invertebrates. Academic Press. London, UK. p: 277-306. https://doi.org/10. 1016/B978-0-12-374855-3.00010-8

Chen, D., Satyanarayana, B., Wolswijk, G., Rahim, N. H. A., Amir, A.A., Huge, J. & Guebas, F. D. 2024. Historical ecological monitoring and appraisal for extractive uses and other values in Malaysia unveils consequences of regime shifts in 120 years of mangrove management. *J. Nat. Conserv.,* 79(1): p.126582. https://doi.org/10. 1016/j.jnc.2024.126582

Chong, V.C. 2006. Sustainable utilization and management of mangrove ecosystems of Malaysia. *Aquat. Ecosyst. Health Manag.,* 9(2): 249-260. https://doi.org/10.1080/14634980 600717084

Cummings, K. S., Jones, H. A. & Lopes-Lima, M. 2016. Rapid bioassessment methods for freshwater molluscs. *In* Larsen, TH. (Ed). Core standardized methods for rapid biological field assessment. Conservation International. Arlington VA, USA. p: 185-207.

Friess, D.A., Yando, E.S., Abuchahla, G.O., Adams, J. B., Cannicci, S., Canty, S.W.J., Cavanaugh, K. C., Connolly, R M., Cormier, N., Guebas, F. D., Diele, K., Feller, I.C., Fratini, S., Jennerjahn, T. C., Lee, S.Y., Ogurcak, D.E., Ouyang, X., Rogers, K., Rowntree, J.K., Sharma, S. & Wee, A.K.S. 2020. Mangroves give cause for conservation optimism, for now. *Curr. Biol.,* 30(4): 153-154. https://doi.org/10.1016/j.cub.2019.12. 054

Friess, D.A., Lee, S.Y. & Primavera, J.H. 2016. Turning the tide on mangrove loss. *Mar. Pollut. Bull.,* 109(2): 673-675. https://doi.org/10.1016/ j.marpolbul.2016.06.085

Gandhi, S. & Jones, T.G. 2019. Identifying mangrove deforestation hotspots in South Asia, Southeast Asia and Asia-Pacific. *Remote Sens.*, 11(6): 728-755. https://doi.org/10.3390/rs11060728

Hammer, O., Harper D.A.T. & Ryan P.D. 2001. PAST: paleontological statistics software package for education and data analysis. *Palaeontol Electronica,* 4(1): 1-9.

Harzhauser, M., Pacaud, J.M. & Landau, B.M. 2023. The origin of the mangrove and saltmarsh snail *Ellobium* (Eupulmonata, Ellobiidae). *Taxonomy,* 3(1): 68-84. https://doi.org/10.3390/taxonomy 3010007

Ismail, M.H. 2019. Diversity and distribution of molluscs in the high shore mangroves of Peninsular Malaysia with emphasis on the

Family Ellobiidae. Thesis. University of Malaya. Malaysia. 133 pp.

Kottè-Mapoko, E.F., Ngo-Massou, V.M., Essome-Koum, G.L., Emane, J.M., Nyamsi-Moussian, L., Tchoffo, R. & Din, N. 2017. Molluscs' composition and distribution in mangroves of the Cameroon Central Coast. *Int. J. Res. Stud. Biosci.,* 5(5): 4-13. http://doi.org/10.20431/2349-0365.0505002

Kottè-Mapoko, E.F., Ngo-Massou, V.M., Essome-Koum, G.L., Emane, J.M., Nyamsi-Moussian, L., Konango-Same, A. & Din, B.N. 2021. Dynamic of mangrove associated mollusk in anthropized areas of the Cameroon coastline. *Open J. Ecol.,* 11(8): 565-579. https://doi.org/10.4236/oje.2021.118036

Ling, S.M., Ramachandran, S., Shuib, S., Nair, M., Afandi, S.H.M. & Prabhakaran, S. 2013. Rural resources as tourism capital: The case of Setiu Wetlands, Terengganu, Malaysia. *The Malaysian Forester,* 76(1): 27-39.

Long, S.M. & Ramli, R. 2010. Kekunci siput dan kerang-kerangan perairan Pantai Malaysia Timur. Penerbit UMT, Malaysia. 167 pp.

Lozouet, P. & Plaziat, J.C. 2008. Mangrove environments and molluscs: Abatan River, Bohol and Panglao Islands, Central Philippines. ConchBooks, Germany. 149 pp.

Macintosh, D.J., Ashton, E.C. & Havanon, S. 2002. Mangrove rehabilitation and intertidal biodiversity: a study in the Ranong mangrove ecosystem, Thailand. *Estuar. Coast. Shelf Sci.,* 55(3): 331-345. https://doi.org/10.1006/ecss.2001.0896

Mohamed, M.K., Adam, E. & Jackson, C.M. 2024. Assessing the perception and contribution of mangrove ecosystem services to the well-being of coastal communities of Chwaka and Menai Bays, Zanzibar. *Resour*ces, 13(7): 1-23. https://doi.org/10.3390/resources13010007

Odum, E.P. & Barret G.W. 2004. Fundamentals of ecology. Thomson Brooks Cole Publishing, Belmont, USA. 624 pp

Oehlmann, J. & Oehlmann, U.S. 2003. Molluscs as bioindicators. *In* Markert, BA., Breure, AM. & Zechmeister, HG. (Eds). Bioindicators and Biomonitors. Elsevier. p: 577-635.

Parkinson, R.W. & Wdowinski, S. 2022. Accelerating sea-level rise and the fate of mangrove plant communities in South Florida, USA. *Geomorphology*, 412(1): 108329. https://doi.org/10.1016/j.geomorph.2022.108329

Poh, S.C., Ng, N.C.W., Suratman, S., Mathew, D. & Tahir, N.M. 2019. Nutrient availability in the Setiu Wetland Lagoon, Malaysia: trends, possible causes and environmental impacts. *Environ. Monit. Assess.,* 19: 3-13. https://doi.org/ 10.1007/s10661-018-7128-y

Primavera, J.H. 2008. Socio-economic impacts of shrimp culture. *Aquac. Res.*, 28(10): 815-827. https://doi.org/10.1046/j.1365-2109.1997.00946.x

Proffitt, C.E. & Devlin, D.J. 2005. Grazing by the intertidal gastropod *Melampus coffeus* greatly increases mangrove leaf litter degradation rates. *Mar. Ecol. Prog. Ser.,* 296: 209-218. https://doi.org/10.3354/meps296209

Raven, H. & Vermeulen, J.J. 2006. Notes on molluscs from NW Borneo and Singapore. 2. A synopsis of the Ellobiidae (Gastropoda, Pulmonata). *Vita Malacologica*, 4: 29-62.

Reid, D.G. 2014. The genus *Cerithidea* Swainson, 1840 (Gastropoda: Potamididae) in the Indo-West Pacific region. *Zootaxa*, 3775(1): 1-65. http://doi.org/10.11646/zootaxa.3775.1.1

Samanta, S., Hazra, S., French, J.R., Nicholls, R.J. & Mondal, P.P. 2023. Exploratory modelling of the impacts of sea-level rise on the Sundarbans mangrove forest, West Bengal, India. *Sci. Total Environ.,* 903: p.166624. https://doi.org/10.1016/j.scitotenv.2023.166624

Safe'i, R., Sari, R N., Iswandaru, D., Latumahina, F. S., Taskirawati, I. & Kaskoyo, H. 2021. Biodiversity and site quality as indicators of mangrove forest health Pasir Sakti, Indonesia. *Ann. Rom. Soc. Cell. Biol.,* 25(2): 4400–4410.

Satyanarayana, B., Zuniga, M.R.Q., Huge, J., Sulong, I., Lokman, H.M. & Guebas, F.D. 2021. Mangroves fuelling livelihoods: a socio-economic stakeholder analysis of the charcoal and pole production systems in the world's longest managed mangrove forest. *Front. Ecol. Evol.,* 9: 621721. https://doi.org/10.3389/fevo.2021.621721

Setiyowati, D. 2018. Abundance and distribution pattern of gastropods in Blebak Beach Jepara. *Acta Aquatica: Aquatic Sci. J.*, 5(1): 8–13.

Strong, E.E., Gargominy, O., Ponder, W.F. & Bouchet, P. 2007. Global diversity of gastropods (Gastropoda; Mollusca) in freshwater. *In:* Balian, EV., Lévêque, C., Segers, H., Martens, K. (Eds). Freshwater Animal Diversity Assessment. Developments in Hydrobiology, vol 198. Springer, Dordrecht. p:149-166. https://doi.org/10.1007/978-1-4020-8259-7_17

Swennen, C., Mollenbeek, R.G., Ruttanadakul, N., Hobbelink, H., Dekker, H. & Hajisamae, S. 2001. The molluscs of the Southern Gulf of Thailand. The Biodiversity Research Training Bangkok, Thailand. 210 pp.

Vo, Q.T., Kuenzer, C., Vo, Q.M., Moder, F. & Oppelt, N. 2012. Review of valuation methods for mangrove ecosystem services. *Ecol. Indic.,* 23: 431-446. https://doi.org/10.1016/j.ecolind.2012.0 4.022

Wahab, F. 2024. Preserving Setiu Wetlands for future generations. Available at: https://www.thestar.com.my/metro/metro-news/2024/08/06/preserving-setiu-wetlands-for-future-generations. Accessed 10 May 2024.

Wolswijk, G., Satyanarayana, B., Dung, L.Q., Siau, Y.F., Ali, A.N.B., Saliu, I.S., Fisol, M.A.B., Gonnelli, C. & Dahdouh-Guebas, F. 2020. Distribution of mercury in sediments, plant and animal tissues in Matang Mangrove Forest Reserve, Malaysia. *J. Hazard. Mater.,* 387: p.121665. https://doi.org/10.1016/j.jhazmat.2019.121665

Yahya, N., Idris, I. Rosli, N.S. & Bachok, Z. 2018. Population dynamics of mangrove clam, *Geloina expansa* (Mousson, 1849) (Mollusca, Bivalvia) in a Malaysian mangrove system of South China Sea. *J. Sustain. Sci. Manag.*, 13(5): 203-216.

Zainol, Z., Peris, A.D., Akhir, M.F., Rahim, N.H.A., Satyanarayana, B. & Dahdouh-Guebas, F. 2022. Mangrove propagule dispersal in a shallow and narrow coastal lagoon: A simulation-based assessment of the Setiu Wetlands, Malaysia. *Forests,* 13(9): 1525-1541. https://doi.org/10.3390/f13091525

Zainol, Z. & Akhir, M.F. 2019. Temporal variability of phytoplankton biomass in relation to salinity and nutrients in a shallow coastal lagoon. *Malay. J. Anal. Sci.,* 23(6): 1090-1106. https://doi.org/10.17576/mjas-2019-2306-16

Zvonareva, S. & Kantor, Y. 2016. Checklist of gastropod molluscs in mangroves of Khanh Hoa province, Vietnam. *Zootaxa*. 4162(3): 401-437. http://doi.org/10.11646/zootaxa.4162.3.1