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Revealing macrozoobenthos diversity of Java coral reefs, Indonesia: a review on research trends and species assemblages

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Macrozoobenthos communities play significant ecological roles in coral reef ecosystems. However, they are frequently overlooked due to their cryptic appearance, and their diversity remains undiscovered, particularly in Indonesia. This comprehensive review of publications on the macrozoobenthos in the coral reef ecosystems of Java - the most populated island in Indonesia, was conducted to compile a species list and gain an overview of its community composition. We also assessed the existence of species that are frequently reported, endemic, protected, and threatened. Data analysis was performed with data from 53 publications appearing from the 1980s to 2022. In total, 482 species belonging to 4 phyla and 9 classes have been recorded. Mollusca is the most speciose phylum (n = 321), followed by Echinodermata (n = 106), Arthropoda (n = 49), and Platyhelminthes (n = 6). Generally, the northern part of Java is well studied and has larger numbers of recorded phyla and species. The highest species number (n = 266) has been recorded off the northern coast of West Java, while there are around 25–99 species in other regions. Echinoderms species such as *Culcita novaeguineae*, *Diadema setosum*, *Echinothrix calamaris*, and *Holothuria atra* had relatively higher occurrences than other taxa. We also noted the occurrence of giant clam *Hippopus hippopus*, which is protected by Indonesian law. This review provides fundamental knowledge of macrozoobenthic diversity in the coral reefs of Java, making it available to global audiences. However, it revealed a lack of research on benthic fauna in several areas with moderate to good coral cover conditions. Further research is needed to explore macrozoobenthic species richness in this region thoroughly, and periodic monitoring is essential to provide early warnings of possible changes and biodiversity loss.

KEYWORDS
coral reefs, Indonesian biodiversity, Java, macrofauna benthos, marine invertebrates

1 Introduction

Coral reefs are considered to be among the most complex and diverse marine ecosystems on the planet (Fisher et al., 2015; Hoeksema, 2017). Large proportions of this biodiversity are invertebrates, particularly the macrozoobenthos – the community of benthic invertebrates retained on a 1-mm mesh sieve (Glynn and Enochs, 2011; Stella et al., 2011; Ruiz-Abierno and Armenteros, 2017). Crustacea and Mollusca are the most speciose invertebrate taxa in the marine ecosystem (Costello et al., 2010). More than 66,000 crustacean species are currently recognized globally (Zhang, 2011), and roughly one-third to half inhabit benthic ecosystems (Saeedi et al., 2019; Knauber et al., 2023). Furthermore, about 6,000 molluscan species are predicted to inhabit shallow water of the tropical shelves, generally at depths less than 200 m (Briggs, 1995; Wells, 2000). Other taxa, such as marine worms and echinoderms, also contribute to species richness in coral reefs (Colin and Arneson, 1995; Miloslavich et al., 2010; Richards and Day, 2018).

As the community related most closely to coral reefs, the macrozoobenthos plays important ecological roles (Glynn and Enochs, 2011; Chen, 2021). Suspension feeders such as ascidians and mussels contribute to water clarity, reducing high particle concentrations in the environment (Petersen, 2007). As deposit feeders, Holothurians play roles in surface sediments' regeneration, mineralization, and nutrient cycling (Purcell et al., 2016; Shabana et al., 2018). Corallivores such as *Acanthaster planci* and some gastropod species serve as indicators of reef health (Glynn and Enochs, 2011; Giyanto et al., 2017). Besides, marine benthic fauna in coral reefs have long served as food resources for humans. Those include sea cucumbers, shellfish, and crustaceans, providing important sustenance for communities living near or depending on the ocean (Szabó and Amesbury, 2011; Setyastuti and Purwati, 2015; Pratiwi, 2018). In addition, macrozoobenthos holds significant value as a tourist attraction. Its great diversity and tropical uniqueness are among the most important motivations for scuba divers and snorkelers, fostering economic growth in the region (Coghlan, 2012; Giglio et al., 2015; Tegar and Gurning, 2018).

The Indonesian archipelago spans the Coral Triangle, an area of the tropical western Pacific with the world's greatest marine biodiversity (Asian Development Bank, 2014; Gray, 1997). Its estimated 51,000 km^2 of coral reef accounts for more than 17% of the global total reef area and is home to a huge range of marine biota (Asian Development Bank, 2014; Hoeksema, 2017). Up until now, comprehensive evidence to understand the Indonesian or even the western Pacific marine diversity remains unavailable (Costello et al., 2010; Hoeksema, 2017; Madduppa et al., 2021). Research is ongoing in this region, but little attention has been paid to invertebrate groups (Hutomo and Moosa, 2005; Cox and Bright, 2017; Pamungkas and Glasby, 2019). The well-documented species richness in the Indonesian coral reef ecosystem has been based on corals, reef fishes, and stomatopods (Huffard et al., 2012). Madduppa et al. (2021) noted that more than half of environmental DNA reads for invertebrate species from Indonesian coral reefs remain unidentified. Furthermore, many studies have focused on specific locations, primarily in eastern Indonesia, and/or specific taxa (Oedjoe and Eoh, 2015; Situmeang et al., 2017; Anzani et al., 2019; Alwi et al., 2020; Papu et al., 2020; Pratiwi and Elfidasari, 2020). Palomares et al. (2007) reviewed the historical ecology of the Raja Ampat Archipelago, including the documented number of invertebrate species. Other studies have focused on taxonomic groups such as benthic amphipod crustaceans in eastern Indonesia (Arfianti and Costello, 2021), sea slugs around the reef area of Bunaken National Park (Eisenbarth et al., 2018), and echinoderms in North Sulawesi (Supono et al., 2015).

Java (Figure 1), a major island in Indonesia, has an estimated 950 km^2 of coral reef area along its coast and offshore islands

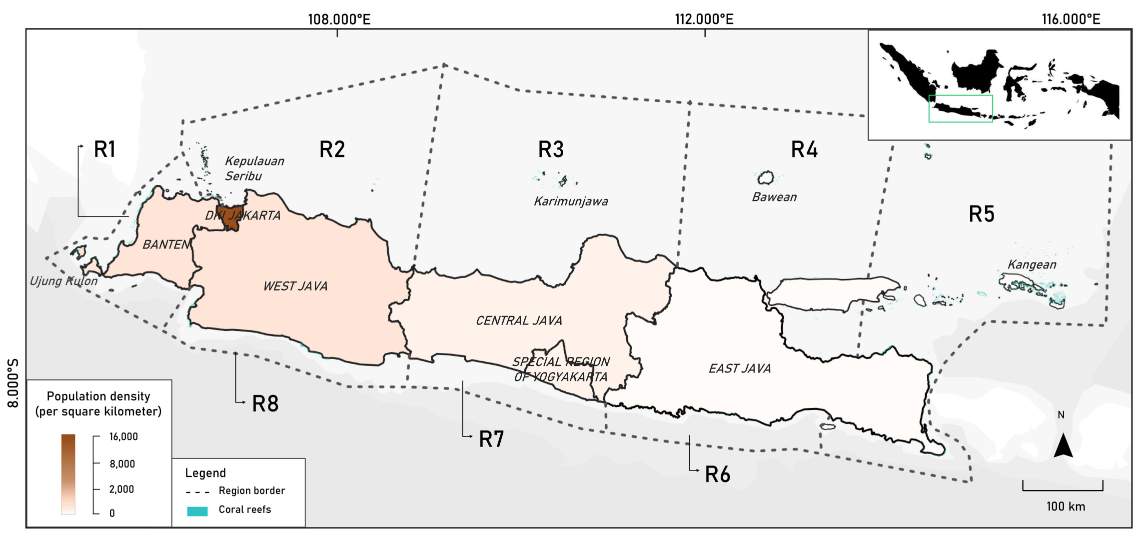

FIGURE 1
Java Islands with the regional divisions (R1-R8) for this study. Population density (people per square kilometer area) in each province is displayed based on the 2021 report data (BPS, 2022a).

(UNEP-WCMC, 2021), which accounts for about 2.5% of the total Indonesian coral reefs (Burke et al., 2012; Dsikowitzky et al., 2018). The reefs along the coast of Java (e.g., in Banten Bay, Jakarta Bay, Jepara, Pasir Putih, Baluran, Nusa Kambangan, Wediombo, and Prigi Bay) are typically patchy (Hadi et al., 2020). Most inshore fringing reefs are found on the western and eastern sides of the island, on the Ujung Kulon Peninsula, and in particular on the Blambangan Peninsula (Dsikowitzky et al., 2018; Hadi et al., 2020). Although Java is not within the Coral Triangle, the conditions of the reefs surrounding its offshore islands are favorable, including Kepulauan Seribu (Thousand Islands), Karimunjawa, Bawean, and the Kangean Islands (Hadi et al., 2020).

Java is inhabited by more than 50% of the Indonesian population (BPS, 2022a), and human activities have directly and indirectly caused the degradation of its coral reefs. Declines in reef health and diversity have been reported in Jakarta Bay and Thousand Islands (Baum et al., 2016; Yonvitner et al., 2022), Karimunjawa and Central Java reefs (Edinger and Risk, 2000; Kennedy et al., 2020), and Gili Ketapang, East Java (Krisnawati and Hidayah, 2020). The macrozoobenthic community response to these declines has not been studied extensively, except in Jakarta Bay–Kepulauan Seribu, where van der Meij et al. (2009) and Cleary et al. (2008) reported the disappearance of reef-associated molluscan species and differences in echinoderm community structures. Surveys of the diversity and the presence of benthic macrofauna have been carried out, but are dispersed (Aziz, 1981; Brown and Muskanofola, 1985; Pertiwi et al., 2015; Cleary et al., 2016; Siddiqi et al., 2017; Yusri et al., 2017; Andrimida and Hermawan, 2019; Setiawan et al., 2019b; Fitriyah et al., 2020; Faricha et al., 2021; Sabdono et al., 2021; Siringoringo et al., 2021). No review of such studies conducted throughout the Java regions has been performed. This review attempts to fill this gap in our current knowledge by gathering available data on macrozoobenthos species richness and making it accessible to global audiences. We compiled macrozoobenthos studies of Java's coral reefs, providing an updated valid macrozoobenthos species inventory and its community composition. We also assessed the existence of species that are frequently reported, endemic, protected, threatened, and distributed only in Java or Indonesia. Finally, the potential implications of our findings and suggestions for future research were discussed.

2 Methods

Data for this review were obtained through a detailed examination of the published literature. A literature search was done using the main online scientific repositories, including Scopus (https://www.scopus.com/), Science Direct (http://www.sciencedirect.com/), Springer Link (https://link.springer.com/), Research Gate (https://www.researchgate.net/), and Google Scholar (https://scholar.google.com/). The following terms and possible combinations were used: 'macrobenthic', 'macrobenthos', 'macroinvertebrate(s)', 'marine invertebrate(s)', 'macrofauna benthos', 'macrozoobenthos', 'Java coral reefs', which further lead us to the specific place or region in Java and specific taxa. We assessed the community of mobile macrobenthic fauna, whether included in multiple or specifically examined in studies that record at the phylum, class, genus, or species level. Additionally, we contacted research institutes, marine protected areas, and terrestrial reserves containing coastal marine habitats around Java through their official email channels. This outreach facilitated access to further information including reports, articles, and books on coral reefs and macrozoobenthos published by the office, as well as research conducted by other parties in the region. For subsequent analysis, we selected references that stated the sampling was carried out in coral reefs or areas with live corals. Very early descriptions of invertebrate species in Jakarta (Sluiter, 1887; Sluiter, 1889; Sluiter, 1890) were not included in our dataset due to uncertainty about habitats. Only literature published by a publisher with an ISSN/ISBN number and government-related reports were included in the review.

The geographical scope of this study was defined as the coral reef ecosystems of Java's coastal waters, including its smaller islands, encompassing the governmental administrative areas of Banten, Special Capital Region of Jakarta, West Java, Central Java, Special Region of Yogyakarta, and East Java. Eight study regions were defined according to administrative area and geomorphological and hydrological characteristics (Figure 1). Geologically, Java is a young island formed with the continuous subduction of the Indian-Australian Plate into the Sunda Plate along the Java Trench (Whittaker et al., 2007). To the north of the island (Figure 1, R2–R4) is the Java Sea, part of the Sunda Shelf/Java Sea ecoregion (Spalding et al., 2007). This sea is shallow (average depth, 46 m) and is formally part of the Pacific Ocean. To the south of Java (Figure 1, R6–R8) is the open Indian Ocean and a narrow shelf with an average sill depth of 400 m that increases quickly to more than 7000 m along 350 km of the ridge. This area is part of the Southern Java ecoregion (Spalding et al., 2007). The two ecoregions are connected by the Sunda Strait in the west (Figure 1, R1) and the Bali Strait in the east (Figure 1, R5), which are very shallow with limited water exchange (Dsikowitzky et al., 2018).

The assessment of reported species was carried out by checking their updated status and taxonomic name as indicated in the World Register of Marine Species (WoRMS) and recent relevant literature. Species not recorded in the WoRMS were re-identified based on appropriate literature sources or expert knowledge. Species identified to the genus level (e.g., *Diadema* sp. and *Drupella* spp.) were not included unless they constituted the solitary current record of the genus in a location. In such cases, their inclusion provided valuable additional information at the genus level without excessively increasing species numbers. Common species were determined based on their reported occurrence in multiple locations throughout Java. We noted protected species in accordance with the Indonesian law on protected fauna and flora (Permen LHK No.P.106, 2018) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2023). Species under threat of extinction were identified with reference to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2024) and the Ministry of Marine Affairs and Fisheries of Indonesia (Ubaidillah et al., 2013). The mapping of coral reef areas

(Allen Coral Atlas, 2022), marine protected areas (UNEP-WCPC, 2020), and recording of sampling locations were carried out using QGIS 3.28.0 software.

3 Results

3.1 Records of research on the macrozoobenthos in Java coral reefs

We compiled 53 publications (34 journal articles, 13 proceedings, and 6 reports) published from the 1980s to 2022 (Figure 2A; Supplementary Table S1). Prior to the 2000s and even into the beginning of the 21st century, few studies of benthic fauna in the region were published. Most studies were published in the past 10 years, although relatively few were published in 2012–2016. The most frequent topic of study was echinoderm diversity (22 publications), followed by mollusk diversity (15 publications). Nine publications discussed the macrozoobenthos overall. Some macrozoobenthic species lists were also found in reports on coral reef ecosystem studies (Figure 2B). This review encompasses research spanning approximately four decades, covering different study focuses, and acknowledges that variations in sampling methods are unavoidable. Furthermore, 58% of publications appeared in Indonesian in domestic journals and reports. The remaining 42% of articles were published in international journals and proceedings in English (Figure 2C).

Most early research was performed in the coral reef area of the Kepulauan Seribu Archipelago (R2), in the northern part of the capital city of Jakarta. Kepulauan Seribu was the first area in Indonesia to be designated a marine national park (Kementerian Pertanian, 1982). Researchers from the RCO BRIN reported on echinoderm diversity in the coral reefs of Pari Island (Aziz, 1981). The samples they used had been collected from a study of coral reef formation conducted by a Pulau Pari research group in 1964–1976, which also led to the observation of the living habits of *A. planci* (Aziz and Sukarno, 1977) and *Archaster typicus* (Darsono et al., 1978) populations. Furthermore, The Kepulauan Seribu Expedition, organized by the RCO BRIN in 2005 to explore the coral reef area, led to the publication of two articles in international journals with notes that the expedition was a joint project with foreign authors (van der Meij et al., 2009; Cleary et al., 2016). Mollusk sampling was carried out on the expedition and compared with that performed in 1937/38 to assess community changes (van der Meij et al., 2009). Concurrently, a macrozoobenthic species checklist was compiled and reported as part of coral reef monitoring from 2005 to 2009 by the Yayasan Terangi in coordination with the local government (Setyawan et al., 2011). Whereas in other regions, only the survey of the giant clam stock as a resource for "teraso" floor tile production in Karimunjawa (R3) was reported before the 2000s (Brown and Muskanofola, 1985).

Following a long gap in time, we found that marine macrobenthic fauna studies undertaken and published since 2011. The RCO BRIN conducted marine biodiversity research in Bawean

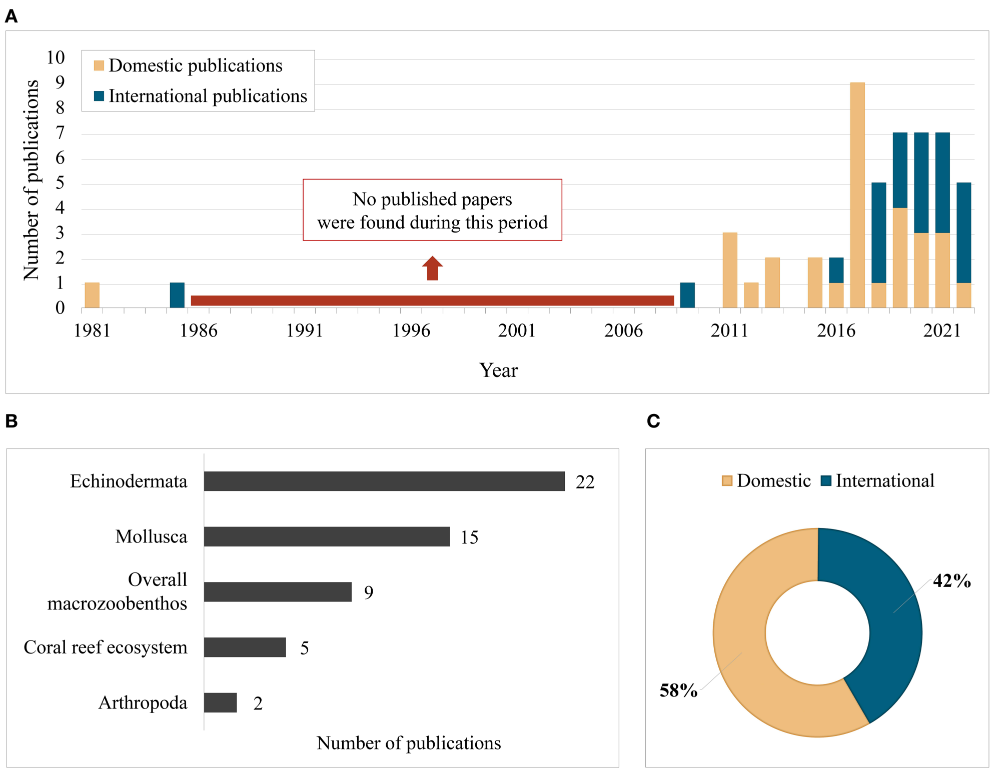

FIGURE 2
Overview of publications on the macrozoobenthos of Java coral reef by **(A)** year, **(B)** research subject, and **(C)** publication scope.

(R4); the benthic fauna surveyed included echinoderms and mollusks (Sihaloho, 2011; Vimono and Sihaloho, 2011). Echinoderm diversity has also been examined at other locations in the Kepulauan Seribu (Supono and Arbi, 2012; Komala, 2015; Triana et al., 2015). A species inventory and several articles discussing ecological aspects such as macrozoobenthos structure in different habitats (Cleary et al., 2016) and relationships of nudibranch communities to other benthic fauna (Kusuma et al., 2013; Sari and Aunurohim, 2013) have been published. Most of these studies were published in domestic journals, limiting access to global audiences.

Since 2017, the number of studies has increased significantly, with about five to nine domestic and international publications appearing annually through the present. Species inventories for the offshore islands still predominate, as those areas are better known for having remarkable coral reefs than the coastal areas of the main island. In the western coast of Java (R1), a baseline coral reef ecosystem study was conducted off Sangiang Island (Yusri et al., 2017). Other works describe further explorations of macrozoobenthic diversity and community structure (Ali et al., 2017; Mustagfirin and Hartati, 2017; Panggarbesi et al., 2017; Siddiqi et al., 2017; Amfa et al., 2020; Sasongko et al., 2020; Hartati et al., 2021; Alamsyah et al., 2022), its potential utilization (Sulardiono, 2016; Ernawati et al., 2019), and responses to environmental conditions (Setyowati et al., 2017; Suryanti et al., 2018b, 2018a; Pratiwi, 2019; Fitriyah et al., 2020). Additionally, nudibranch species sampled from Karimunjawa and Bali were listed in bioactive compound research (Kristiana et al., 2020). In 2021, monitoring reports of Coral Reef Rehabilitation and Management Program–Coral Triangle Initiative (COREMAP–CTI) program in Kepulauan Seribu and Karimunjawa listed the presence of target benthic organisms (*A. planci*, Echinoidea, Holothuroidea, *Linckia laevigata*, Giant clams, *Drupella* spp., Trochidae, and Paniluridae) (Faricha et al., 2021; Siringoringo et al., 2021).

Few papers describe research on the macrozoobenthos of the main island of Java. Five publications describe echinoderms, mollusks, and benthic invertebrate diversity off the island's northern coast (Putri et al., 2019; Rahayu et al., 2019; Elfahmi and Efendy, 2020; Sabdono et al., 2021; Atlanta et al., 2022). Other reports describe mainly echinoderms and mollusks in Baluran National Park (Huda et al., 2017; Setiawan et al., 2019a, Setiawan et al., 2019b, 2021) and in the Situbondo (Sari and Aunurohim, 2013; Somma et al., 2017), of the island's eastern coast (R5). All reported studies conducted off the southern coast of East Java (R6) were conducted around Sempu Island, Malang. Sea slug diversity in this area is well recorded (Andrimida and Hermawan, 2019; Andrimida, 2022), and a survey of the biodiversity of cryptic marine fauna diversity has also been studied (Andrimida and Hermawan, 2020). Meanwhile, research published off the southern coast of Java were scattered, including in Yogyakarta (R7) (Suwartimah et al., 2017; Febiansi et al., 2018; Triatmojo et al., 2018; Cahyadi et al., 2021; Wulandari and Mardiana, 2022), Pangandaran and Sukabumi (R8) (Sahidin et al., 2018, 2021; Nasrudin et al., 2020; Salsabilla et al., 2022).

Despite considerable recent attention to the macrozoobenthos of Java, this review revealed an imbalance in research among locations, particularly across marine protected areas and terrestrial reserves containing coral reef habitats. There was no macrozoobenthos diversity research carried out in the coral reefs ecosystem of Ujung Kulon National Park (R1), which has around 14.85% to 60.7% hard coral cover (Fahlevy et al., 2019). The same result was found in the coastal area of Sumenep or Kangean District (R5) which has good conditions with the widest coral reef area in the region (Arisandi et al., 2018; Allen Coral Atlas, 2022). Moreover, limited published research describes a macrozoobenthic study in the Bawean reef area (R3); observational reports assembled by RCO BRIN in 2011 were obtained through a request from the BRIN library office, as they were not available in digital form. Publications on studies conducted in other good coral reef locations, such as Situbondo, Baluran National Park, and Alas Purwo National Park, are also limited.

3.2 Macrozoobenthic species richness and composition

After carefully checking each reported species, 121 species have been curated based on valid nomenclature in the WoRMS and recent relevant literature (Supplementary Table S2, 2 Arthropoda, 24 Echinodermata, and 95 Mollusca). At least 482 macrozoobenthic species belonging to 4 phyla and 9 classes occurring in the coral reef ecosystem of Java have been recorded (Figure 3; Supplementary Table S3). The largest proportion of species belongs to the phylum Mollusca (n = 321) and Echinodermata (n = 106; total, ~88.4% of species). Phyla represented by fewer species are Arthropoda (n = 49) and Platyhelminthes (n = 6). In addition, the validity of some species reports was considered erroneous because the species are known to have restricted geographic distributions or to not inhabit marine waters (Table 1), and were excluded from the species list.

The numbers of reported macrozoobenthic species per region are presented in Figure 4, while their taxa composition is provided in Figure 5. In general, the numbers of reported phyla and species were relatively higher in the northern part of Java (R2–R4). The highest number of phyla and species were reported in R2, off the northern coast of West Java (4 phyla, 266 species). All studies in this region were conducted at Kepulauan Seribu; Mollusca predominated (161 species), followed by Echinodermata (74 species), Arthropoda (30 species), and Platyhelminthes (1 species). Four phyla and 99 species were reported to occur off the northern coast of East Java (R4), with the largest contribution derived from the biodiversity research conducted by Rahayu et al. (2019) in the Lamongan coastal area. The most diverse taxa were Mollusca (69 species), followed by Echinodermata (15 species), Crustacea (11 species), and Platyhelminthes (4 species). Fewer taxa have been recorded in R3 (3 phyla, 52 species), although a large number of studies have been conducted there (Figure 4). Echinodermata and Mollusca are represented by the largest numbers of species (29 and 22 species, respectively), followed by one lobster (Arthropoda) species.

For other regions, 25–65 species have been recorded. In R1, three phyla consisting of 25 species, the fewest number of species among regions (17 Echinodermata, 7 Mollusca, and 1 Arthropod),

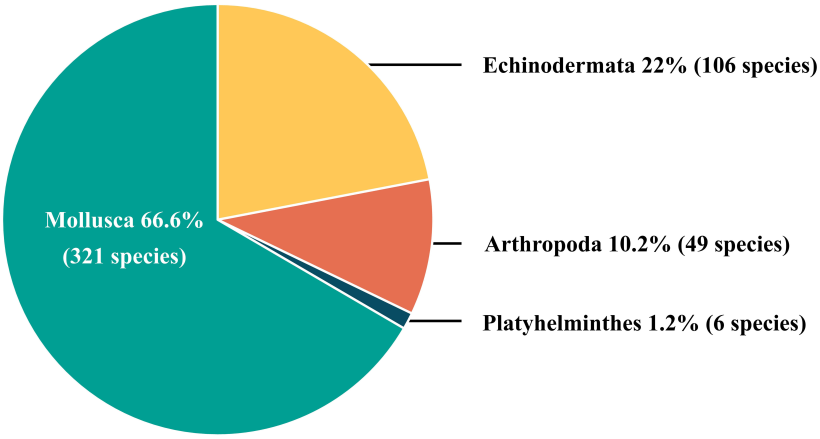

FIGURE 3
Overall macrozoobenthos species richness and composition in Java coral reef.

TABLE 1 Species recorded in the World Register of Marine Species for which confirmation of their presence in the coral reefs of Java is required.

Phylum	Species mentioned in the original papers	Notes	Remark
Echinodermata	*Aquilonastra burtoni*	Distributions: Eastern Mediterranean, Red Sea, Arabian Gulf, NW Indian Ocean	(O'Loughlin and Rowe, 2006)
	Patiria miniata	Distributions: Northeast Pacific (Alaska to Gulf of California)	WoRMS
	Diadema antillarum	Distributions: Caribbean	(Moore et al., 2019)
	Echinometra lucunter	Distributions: Atlantic - Caribbean	(McClanahan and Muthiga, 2020)
	Echinometra viridis	Distributions: Atlantic - Caribbean	(McClanahan and Muthiga, 2020)
Mollusca	*Isognomon alatus*	Distributions: Western Atlantic	(Mikkelsen and Bieler, 2021)
	Tellina radiata	Distributions: North America	WoRMS
	Acanthinucella punctulata	Distributions: West Coast of North America	WoRMS
	Cerithium muscarum	Distributions: Western Atlantic, North America	WoRMS
	Clithon oualaniense	Habitat: brackish, freshwater	WoRMS
	Cominella glandiformis	Endemic species in New Zeland	(Donald et al., 2020; Vafidis et al., 2020)
	Conus fergusoni	Distributions: Eastern Pacific, Panama	WoRMS
	Cypraea pantherina	Distributions: Eritrea, Somalia, Red Sea, Tanzania	WoRMS
	Melanoides tuberculata	Habitat: freshwater	WoRMS
	Palmadusta ziczac	Subtropical species. Distributions: Mediterranean	WoRMS
	Patella caerulea	Distributions: East Atlantic and Mediterranean	(Vafidis et al., 2020)
	Urosalpinx cinerea	Distributions: North American East Coast	WoRMS

were recorded. Furthermore, a relatively small species number [n = 34 species (18 Mollusca and 16 Echinodermata)] has been recorded in R5, although the coral reef area is the largest of any other region (Figure 4). In R6, a total of 65 species across three phyla were documented. Among these, over 80% were Mollusca (55 sea slug species); followed by Arthropoda (n = 8) and Platyhelminthes (n = 2). Similarly, large proportions of Mollusca have been recorded in R7 (23 of 31 species) and R8 (23 of 27 species), followed in R7 by 8

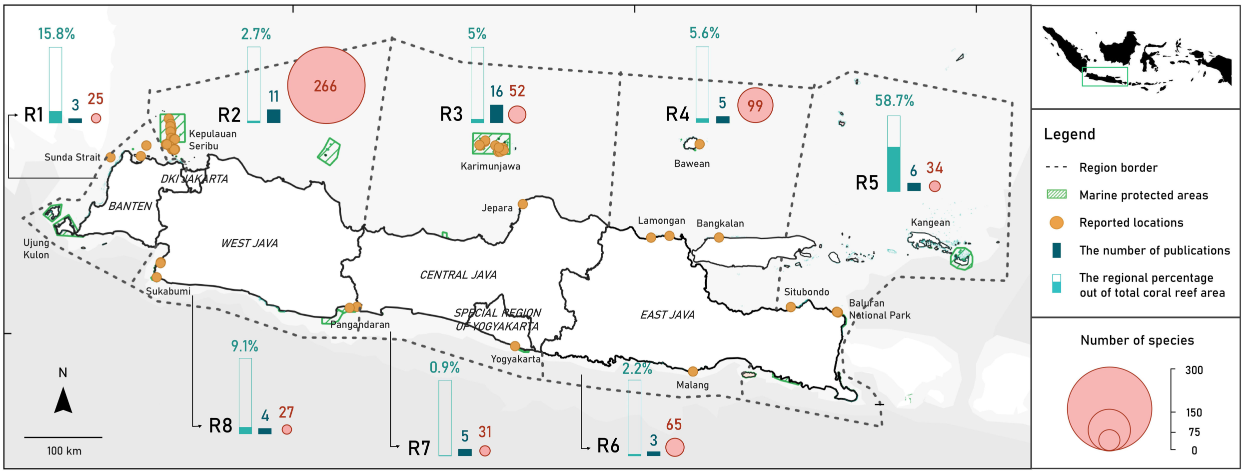

FIGURE 4
The number of publications and reported macrozoobenthos species based on regional divisions in Java coral reefs, with the regional percentage out of Java's total coral reef areas (km^2).

Echinodermata and in R8 by 2 Echinodermata and 2 Arthropoda species.

3.3 Frequently reported and endemic macrozoobenthos reported in the coral reefs of Java

Macrozoobenthos species list that commonly occurs in Java's coral reefs is provided in Table 2. Four Echinodermata were reported in five locations: *Culcita novaeguineae*, *Diadema setosum*, *Echinothrix calamaris*, and *Holothuria atra*. Additionally, species reported to occur in four locations include five Echinodermata (*Acanthaster planci*, *Linckia laevigata*, *Echinometra mathaei*, *H. leucospilota*, and *Ophiocoma scolopendrina*) and one Mollusca (*Monetaria annulus*). While other phyla have not shown notable occurrences, the frequently reported species relatively within their phylum are also listed (Table 2). As for endemic species, we did not find species known to have limited distributions in Java or Indonesian waters.

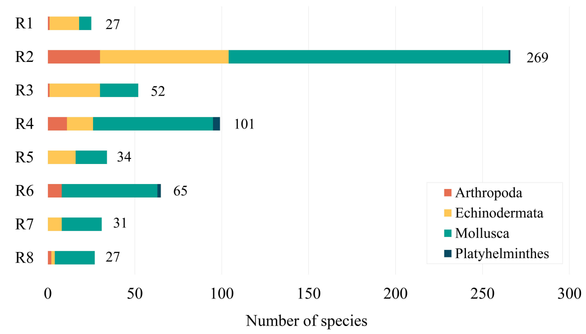

FIGURE 5
The species composition of macrozoobenthos in each region of Java coral reefs.

3.4 Protected and threatened macrozoobenthos reported in the coral reefs of Java

Of the protected species listed in Indonesian law (Permen LHK No.P.106, 2018), we noted one species of giant clam, *Hippopus hippopus*, documented only in Baluran National Park (Setiawan et al., 2019a, 2021). Additionally, *H. hippopus* together with other five giant clams in the Tridacninae family (*Tridacna crocea*, *T. derasa*, *T. gigas*, *T. maxima*, and *T. squamosa*), are protected under Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). These species have primarily been reported in Kepulauan Seribu and Karimunjawa, where they are included in reef health monitoring programs. Furthermore, three commercially valuable sea cucumber species (*Holothuria nobilis*, *Thelenota ananas*, and *Thelenota anax*), also protected by CITES, have been found in the coral reef of Java. Some of those species are listed as endangered species by the International Union for Conservation of Nature (IUCN) and are threatened in Indonesia due to overfishing. Additional details regarding population trends and remarks on threatened species (Ubaidillah et al., 2013) are presented in Table 3.

4 Discussion

Research on coral reefs biodiversity is fundamental not only to obtain information on species richness, but also for the analysis of the stability and sustainability of these ecosystems (Rogers, 2013). Java's coral reefs are adjacent to the coral triangle region which is recognized as a biodiversity hotspot. While some studies have explored macrobenthic fauna in the coral triangle prior to the 21st century (Wells, 2000; Mazlan et al., 2005; Palomares et al., 2007; Pamungkas and Glasby, 2019), our review focusing on Java coral reefs uncovered a notable scarcity of published findings, which

TABLE 2 Frequently reported macrozoobenthos species among locations in Java coral reefs.

Phylum	Class/Order	Species	Total occurrence (locations)	References*
Arthropoda	Crustacea	*Chlorodiella nigra*	2	12,31
		Panulirus versicolor	2	24,43
		Platypodia granulosa	2	12,31
		Xanthias lamarckii	2	12,31
Echinodermata	Asteroidea	*Acanthaster planci*	4	1,2,4,6,7,10,13,23,27
		Culcita novaeguineae	5	1,3,4,6,9,10,14,20,35
		Linckia laevigata	4	3,4,6,9,10,18,20,23,25,35
	Echinoidea	*Diadema setosum*	5	2,3,4,7,6,9,10,14,18,22,25,37,38
		Echinometra mathaei	4	3,4,10,38,45,47,49
		Echinothrix calamaris	5	2,6,7,10,22,37,38
	Holothuroidea	*Holothuria atra*	5	3,4,8,17,21,25,29,35,37
		Holothuria leucospilota	4	3,9,8,14,29,31
	Ophiuroidea	*Ophiocoma scolopendrina*	4	4,9,29,39,45,47,51
Mollusca	Bivalvia	*Atrina vexillum*	3	2,6,33
		Isognomon isognomum	3	6,31,40
		Tridacna crocea	3	6,13,15,27,40,41
		Tridacna maxima	3	6,13,15,27,40,41
		Tridacna squamosa	3	6,15,27,40,44
	Gastropoda	*Cypraea tigris*	3	1,6
		Monetaria annulus	4	5,33,46,48,50
		Phyllidia varicosa	3	6,16,26,42,43
		Phyllidiella pustulosa	3	6,36,42,43
Platyhelminthes	Polycladida	*Thysanozoon nigropapillosum*	2	6,31

*References listed in the Supplementary Material (Supplementary Table S1).

underscores the limited understanding of this subject. However, this review also revealed a significant recent increase in macrozoobenthos research, reflecting substantial progress. Large bodies of data from the Kepulauan Seribu and Karimunjawa have increased our knowledge of the taxonomy, ecology, and species composition of macrozoobenthic. Of note, both locations are tourist destinations, and several types of benthic fauna are local fishery commodities (Rositasari et al., 2017; Marfai et al., 2019). This situation highlights the importance of management strategies that balance economic benefits with conservation efforts to ensure the sustainable use of these resources. Future periodic monitoring would provide researchers and managers with early warnings about changes and biodiversity loss in these locations (Pereira & Cooper, 2006; Mellin et al., 2020).

Reliable baseline data are lacking for other locations in Java with good coral cover, most in terrestrial-based reserves, presumably due to limitations of expertise and funding that have prevented marine observation from being a priority (Pamungkas and Glasby, 2019). Most research conducted in these areas has focused on iconic fauna and their ecosystems, such as the Javan rhinoceros (*Rhinoceros sondaicus*) at Ujung Kulon National Park and the banteng (*Bos javanicus*) at Baluran National Park. The information from the Ujung Kulon National Park office is consistent with our findings, that no survey has been conducted on macrozoobenthos in the coral reefs there (H. Juanda, personal communication, October 19th, 2022). In addition, some surveys have been conducted but have not yet been published or have been published only as gray literature. The Baluran National Park office informed us that the park has archives of reports on macrozoobenthic research, but primarily in the form of undergraduate thesis (A. Pratiwi, personal communication, October 21st, 2022). Furthermore, we found news and interim reports on the diversity of marine resources, including the macrozoobenthos, produced as part of a survey for marine conservation area mapping conducted in 2019–2021 by the East Java Marine and Fisheries Office at Bawean Island (Arisandy, 2021). Issues with the bureaucratic system, human resources, and the coordination of management institutions may result in the obstruction of research programs (Negoro et al., 2020). Thus,

TABLE 3 List of protected (by Indonesian law and CITES) and threatened (by IUCN red list and the Ministry of Marine Affairs and Fisheries) macrozoobenthos species in Java coral reefs.

Phylum	Species	Conservation status		IUCN Red List (population trend)	Species under threat of extinction[2]
		Indonesian law[1]	CITES		
Arthropoda	*Panulirus versicolor*			Least concern (unknown)	Commercially important lobster species, threatened due to the possibility of overfishing
Echinodermata	*Actinopyga echinites*			Vulnerable (decreasing)	
	Actinopyga miliaris			Vulnerable (decreasing)	
	Bohadschia argus			Least concern (stable)	Threatened due to the possibility of overfishing.
	Holothuria nobilis		Appendix II	Endangered (unknown)	Threatened due to overfishing.
	Holothuria scabra			Endangered (decreasing)	Threatened due to overfishing
	Stichopus herrmanni			Vulnerable (decreasing)	
	Thelenota ananas		Appendix II	Endangered (decreasing)	Vulnerable to extinction due to overfishing
	Thelenota anax		Appendix II	Data deficient (unknown)	
Mollusca	*Hippopus hippopus*	Protected	Appendix II	Conservation dependent	
	Tridacna crocea		Appendix II	Least concern (unknown)	
	Tridacna derasa		Appendix II	Vulnerable (unknown)	
	Tridacna gigas		Appendix II	Vulnerable (unknown)	
	Tridacna maxima		Appendix II	Conservation Dependent	
	Tridacna squamosa		Appendix II	Conservation Dependent	
	Conus marmoreus			Least concern (unknown)	Harvested for food and accessories (the shells), need to be protected for sustainable utilization
	Conus textile			Least concern (unknown)	Harvested for food and accessories (the shells), need to be protected for sustainable utilization
	Tectus pyramis			Not evaluated	Vulnerable to extinction due to overfishing
	Turbo petholatus			Not evaluated	Harvested for accessories (the shells), need to be protected for sustainable utilization

[1](Permen LHK No.P.106, 2018); [2](Ubaidillah et al., 2013).

greater collaboration is needed. In parallel, efforts to increase research capacity should focus on dissemination to international peer-reviewed publishers so that the data obtained could reach wider audiences.

With the compilation of a species inventory, the present review has made an initial step toward identifying the knowledge gaps regarding macrozoobenthos diversity in the Indonesian coral reef ecosystem, particularly at the island scale. Besides that, species curation due to changes in taxonomic orders or misspelled, is important to do in providing the proper species inventory data (Hammond, 1992; Park et al., 2014). Moreover, as we found some species whose presence in Java coral reefs was uncertain (Table 1), there is a possibility of misidentification without taking into account species' geographic distributions. Notably, several macrozoobenthos studies in Java coral reefs refer to guidebooks from disparate geographical regions, such as North America, the

Caribbean, or the Mediterranean seas. In such cases, it does not seem unique to Indonesian researchers as the number of key identification papers or books for marine species is relatively limited (Siallagan et al., 2023). Several methods have been developed to be effective and accurate in identifying species, such as the integrative approach of molecular and morphological data (Kunal et al., 2021; Pereira et al., 2021) and deep learning applications (Lin et al., 2021; Sun et al., 2021; Goodwin et al., 2022). However, those methods also require researchers to possess expertise in taxonomy and consider ecological factors (Goodwin et al., 2022). In parallel, several approaches that can be taken are research collaboration with taxonomists (local or foreign researchers) and fostering marine taxonomy studies with careful identification processes. Looking towards the long-term, the establishment of Indonesian marine reference collections, databases, and identification keys by esteemed research institutions, as suggested by Siallagan et al. (2023), assumes paramount importance in addressing this knowledge gap effectively.

Concerning the macrozoobenthic diversity among regions in this study, the natural habitat and geographic conditions may explain the pattern (Stella et al., 2011; Jimenez et al., 2012; Graham and Nash, 2013; Bahamonde et al., 2022; Knauber et al., 2023). These conditions include biotic (i.e., coral cover and food availability) and abiotic (i.e., substrate heterogeneity, salinity, sedimentation, light, and current) factors. For instance, the shallow water with slow currents and sufficient light exposure in the Java Sea is more favorable for coral and the macrozoobenthos than the strong tidal wave and marked depths off the southern part of Java Island (Dsikowitzky et al., 2018). However, there might be data biases for the regions with good coral reef conditions, in the western (R1) and eastern (R5) part. The limited number of studies on these regions must be considered as a contributing factor. Thus, additional research and taxonomic efforts could greatly augment the information we have about marine biodiversity in Java (Costello et al., 2010; Hernan et al., 2022).

The high occurrence of Echinodermata in this review might be due to a high number of studies focusing on this phylum. While Mollusca seems to exhibit the highest species richness, it is noteworthy that the majority of these species are reported from a single location. Nevertheless, we found that *Drupella* spp., a genus that is included in coral reef health monitoring (Giyanto et al., 2014), are reported in several publications and locations (Setyawan et al., 2011; Panggarbesi et al., 2017; Yusri et al., 2017; Faricha et al., 2021; Siringoringo et al., 2021), but omitted in the dataset due to unclear designated species. Furthermore, although no endemic species were discovered, we found one sea slug species (*Thuridilla lineolata*) that was previously considered to be geographically limited to Indonesian waters (Gosliner, 1995) has been reported to occur in the Philippines (Martín-Hervás et al., 2021) and potentially on Andaman Island, India (Jeeva et al., 2019), and is now considered to be common in the western Indo-Pacific. In the latter case (Jeeva et al., 2019), we recommend further identification, as the study did not mention the bright blue color on the body and parapodia of *T. lineolata*. Two species first recorded in Java (with type localities limited to Java; *Nassarius javanus* and *Phyllidiella nigra*) are known to occur commonly in the western Indo-Pacific and eastern Indian Ocean (Stoffels et al., 2016; Yang et al., 2019; Dharmawan et al., 2021). *Nassarius javanus*, recorded from Kepulauan Seribu (van der Meij et al., 2009; Cleary et al., 2016), is rarely mentioned in other publications describing samples from Java or Indonesia; rather, an *N. javanus* sample was recently collected for mitochondrial genomic analysis in China (Yang et al., 2019) and was recorded for the first time in India (Ravinesh et al., 2021). As suggested by Costello et al. (2010), the number of species considered to be endemic will likely diminish as marine research proceeds.

In comparison with available data from taxon-specific studies conducted in Indonesia, Java's coral reefs are also relatively diverse (Table 4). Reported numbers of Echinodermata and Mollusca species in North Sulawesi are similar to those documented in Java (Burghardt et al., 2006; Supono et al., 2015). Given the lack of inventories for other taxonomic groups, further research is needed to broaden our knowledge of Indonesian marine biodiversity. The total numbers of certain macrozoobenthic groups in Java appear to

TABLE 4 The comparison of recorded macrozoobenthos species in Java coral reefs and other locations.

Region/Country	Coastline Length[1-2] (km)	Reef Area[2-5] (sq km)	Arthropoda	Echinodermata	Mollusca	Total species
Java coral reef (this study)	6,905	657	49	106	321	476
North Sulawesi[6-8]	2,395	2,894	37 (stomatopods)	114	323	474
Papuan Bird's Head Seascape[6,9]	12,445	1,529	57 (stomatopods)	NA	699	756
PANAMA[10]	5,637	770	21 (amphipods)	155	587	763
COSTA RICA[11]	2,069	970	128 (amphipods)	124	441	701
West coast of KOREA[12]	2,450	NA (tidal flats)	135	16	196	347

[1]World Resources Institute, 2000; [2]BPS, 2021; [3]BPS, 2022b; [4]Asian Development Bank, 2014; [5]Burke et al., 2012; [6]Huffard et al., 2012; [7]Supono et al., 2015; [8]Burghardt et al., 2006; [9]McKenna et al., 2002; [10]Miloslavich et al., 2010; [11]Wehrtmann et al., 2009; [12]Park et al., 2014.

be comparable to those reported for Panama (Miloslavich et al., 2010) and Costa Rica (Wehrtmann et al., 2009), which have similar coastline lengths or reef areas. The reported diversities in Malaysia (Mazlan et al., 2005) and Madagascar (Miloslavich et al., 2010) exceed those documented in this review, probably because these countries have larger reef areas. In addition, the overall number of species in Java is comparable to those in another ecosystem, such as the tidal flat on the western coast of Korea (Park et al., 2014). Still, differences in taxon composition must be recognized. Such comparisons suggest that the number of species recorded in publications included in this review is the lower bound of species occurring in such a complex coral reef ecosystem as that of Java.

To conclude, this review would be the basis of data on macrozoobenthos in the coral reefs of Java, providing a comprehensive updated species list of Arthropoda, Echinodermata, Mollusca, and Platyhelminthes. Additionally, the species occurrence dataset following the Darwin Core (DwC) standards is provided to enhance the accessibility of our data to a broader audience (Supplementary Table S4). Our findings suggest that the variation in macrozoobenthic species richness and composition among different regions is likely biased due to uneven study efforts across taxonomic groups and geographic areas, particularly in regions with good coral reef conditions. The coral reef areas of Java potentially harbor more biodiversity than currently documented. Additional taxonomic studies conducted with advanced biodiversity survey methods would be useful to fill the current knowledge gap. Given the large population of Java, which could threaten its natural habitats, periodic monitoring is essential to provide early warnings of changes and the possible loss of biodiversity in the future.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

EA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. JP: Conceptualization, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing. S-KL: Data curation, Investigation, Supervision, Validation, Writing – review & editing. JK: Funding acquisition, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2024.1387984/full#supplementary-material

References

Alamsyah, M., Marhento, G., and Siburian, M. F. (2022). Keanekaragaman jenis Echinodermata pada zona intertidal di pesisir selatan Pulau Tidung Kecil Kepulauan Seribu DKI Jakarta. *EduBiologia: Biol. Sci. Educ. J.* 2, 41. doi: 10.30998/edubiologia.v2i1.11277

Ali, A. I., Suryanti, S., and Sulardiono, B. (2017). "Kelimpahan dan pola sebaran Echinodermata di Pulau Karimunjawa Jepara," in *Prosiding Seminar Nasional Hasil-Hasil Penelitian Perikanan dan Kelautan ke-VI*. (Semarang: Fakultas Perikanan dan Ilmu Kelautan Universitas Diponegoro), 159–172.

Allen Coral Atlas (2022). *Imagery, maps and monitoring of the world's tropical coral reefs* (Accessed March 10, 2023).

Alwi, D., Muhammad, S., and Tae, I. (2020). Morphological characteristics and ecological index sea urchins (Echinoidea) in Wawama Village Water Morotai Island District. *Jurnal Sumberdaya Akuatik Indopasifik* 4, 23. doi: 10.46252/jsai-fpik-unipa.2020.vol.4.no.1.95

Amfa, M. O., Abdurrahman, M. I., Hidayat, S. A., Situmeang, G. L., Farwati, N., and Yudha, F. K. (2020). Macrobenthos community structure in coral reef ecosystem around Pramuka Island, Jakarta. *IOP Conf. Ser. Earth Environ. Sci.* 420. doi: 10.1088/1755-1315/420/1/012003

Andrimida, A. (2022). New records of nudibranchs and a sacoglossan (Gastropoda: Heterobranchia) from Sempu Strait, Indonesia. *Indo Pacific J. Ocean Life* 6, 1–9. doi: 10.13057/oceanlife/o060101

Andrimida, A., and Hermawan, R. (2019). Diversity and distribution of sea slugs (Gastropods: Heterobranchia) in Sempu Strait, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 391. doi: 10.1088/1755-1315/391/1/012073

Andrimida, A., and Hermawan, R. (2020). Assessing cryptic marine fauna diversity as underwater macrophotography (UMP) objects in Sempu Strait, Indonesia. *E3S Web Conf.* 153, 1–13. doi: 10.1051/e3sconf/202015301001

Anzani, L., Madduppa, H. H., Nurjaya, I. W., and Dias, P. J. (2019). Short communication: Molecular identification of white sea squirt Didemnum sp. (tunicata, ascidiacea) colonies growing over corals in raja ampat Islands, Indonesia. *Biodiversitas* 20, 636–642. doi: 10.13057/biodiv/d200304

Arfianti, T., and Costello, M. J. (2021). The distribution of benthic amphipod crustaceans in Indonesian seas. *PeerJ* 9. doi: 10.7717/peerj.12054

Arisandi, A., Tamam, B., and Fauzan, A. (2018). Coral reef profile of Kangean Island, Sumenep District, Indonesia. *Jurnal Ilmiah Perikanan dan Kelautan* 10, 76–83. doi: 10.20473/jipk.v10i2.10516

Arisandy, K. R. (2021). *Public Consultation on Discussion of Zoning Plans and Management of Conservation Areas in Bawean Island Waters, Gresik Regency*. Available online at: https://kkp.go.id/djprl/bpspldenpasar/artikel/36844-konsultasi-publik-pembahasan-rencana-zonasi-dan-pengelolaan-kawasan-konservasi-di-perairan-pulau-bawean-kabupaten-gresik (Accessed December 2, 2022).

Asian Development Bank (2014). *State of the Coral Triangle: Indonesia* (Mandaluyong: Asian Development Bank).

Atlanta, V., Ambarwati, R., Rahayu, D. A., and Mujiono, N. (2022). Diversity of bivalves on the north coast of Lamongan, East Java, Indonesia. *Biodiversitas* 23, 4263–4271. doi: 10.13057/biodiv/d230850

Aziz, A. (1981). Fauna Echinodermata dari terumbu karang Pulau Pari, Pulau-pulau Seribu. *Oseanologi di Indonesia* 14, 41–50.

Aziz, A., and Sukarno, (1977). Preliminary observation on living habits of Acanthaster planci (Linnaeus) at Pulau Tikus, Seribu Islands. *Mar. Res. Indonesia* 17, 121–132. doi: 10.14203/mri.v17i0.355

Bahamonde, F., Pablo Rodríguez, J., Rosenfeld, S., Méndez, F., López, Z., Gerard, K., et al. (2022). Variability at multiple spatial scales in intertidal and subtidal macrobenthic communities in a fjord with glaciers, Magellanic Subantarctic ecoregion, Chile. *Prog. Oceanogr.* 208. doi: 10.1016/j.pocean.2022.102879

Baum, G., Kusumanti, I., Breckwoldt, A., Ferse, S. C. A., Glaser, M., Dwiyitno,, et al. (2016). Under pressure: Investigating marine resource-based livelihoods in Jakarta Bay and the Thousand Islands. *Mar. pollut. Bull.* 110, 778–789. doi: 10.1016/j.marpolbul.2016.05.032

BPS (2021). *Statistik sumber daya laut dan pesisir 2021* (Jakarta: Badan Pusat Statistik Republik Indonesia).

BPS (2022a). *Statistical Yearbook of Indonesia 2022* (Jakarta: Badan Pusat Statistik Republik Indonesia).

BPS (2022b). *Statistik lingkungan hidup Indonesia 2022*. Eds. C. Widya, D. Aryanti and Krismawati, (Jakarta: Badan Pusat Statistik Republik Indonesia).

Briggs, J. C. (1995). *Global Biogeography* (Amsterdam: Elsevier).

Brown, J. H., and Muskanofola, M. R. (1985). An investigation of stocks of giant clams (family Tridacnidae) in Java and of their utilization and potential. *Aquac. Res.* 16, 25–39. doi: 10.1111/j.1365-2109.1985.tb00294.x

Burghardt, I., Carvalho, R., Eheberg, D., Gerung, G., Kaligis, F., Mamangkey, G., et al. (2006). Molluscan diversity at Bunaken National Park, Sulawesi. *J. Zoological Soc. Wallacea* 2, 29–43.

Burke, L., Reytar, K., Spalding, M., and Perry, A. (2012). *Reefs at risk revisited in the coral triangle* (Washington, DC, USA: World Resources Institute).

Cahyadi, G. A. B. Y. P., Pinasti, R., Salwa, A., Devi, M. A., Fajriana, L. R., Qudsiyati, N., et al. (2021). Biodiversity of gastropods in intertidal zone of Krakal Beach, Gunungkidul, Yogyakarta. *Nusantara Sci. Technol. Proc.* 1, 16–24. doi: 10.11594/nstp.2021.0703

Chen, E. Y. S. (2021). Often overlooked: Understanding and meeting the current challenges of marine invertebrate conservation. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.690704

CITES (2023). *The Convention on International Trade in Endangered Species of Wild Fauna and Flora Appendices I, II and III*. Available online at: https://cites.org/eng/app/appendices.php (Accessed April 30, 2024).

Cleary, D. F. R., De Vantier, L., Giyanto,, Vail, L., Manto, P., De Voogd, N. J., et al. (2008). Relating variation in species composition to environmental variables: A multi-taxon study in an Indonesian coral reef complex. *Aquat. Sci.* 70, 419–431. doi: 10.1007/s00027-008-8077-2

Cleary, D. F. R., Polónia, A. R. M., Renema, W., Hoeksema, B. W., Rachello-Dolmen, P. G., Moolenbeek, R. G., et al. (2016). Variation in the composition of corals, fishes, sponges, echinoderms, ascidians, molluscs, foraminifera and macroalgae across a pronounced in-to-offshore environmental gradient in the Jakarta Bay–Thousand Islands coral reef complex. *Mar. pollut. Bull.* 110, 701–717. doi: 10.1016/j.marpolbul.2016.04.042

Coghlan, A. (2012). Facilitating reef tourism management through an innovative importance-performance analysis method. *Tour Manag.* 33, 767–775. doi: 10.1016/j.tourman.2011.08.010

Colin, P. L., and Arneson, C. (1995). *Tropical pacific invertebrates: A field guide to the marine invertebrates*. (California: Coral Reef Press).

Costello, M. J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., and Miloslavich, P. (2010). A census of marine biodiversity knowledge, resources, and future challenges. *PloS One* 5. doi: 10.1371/journal.pone.0012110

Cox, K., and Bright, J. (2017). Raja Ampat: A biodiversity hot spot and the future of marine conservation. *Fish. (Bethesda)* 42, 462–467. doi: 10.1080/03632415.2017.1356119

Darsono, P., Aziz, A., and Djamali, A. (1978). Pengamatan terhadap populasi bintang laut Archaster typicus, di daerah rataan gugus Pulau Pari, Pulau-pulau Seribu, Jakarta. *Oseanologi di Indonesia* 10, 33–41.

Dharmawan, I. G. W. D., Bengen, D. G., Setyobudiandi, I., Subhan, B., Verawati, I., Sani, L. M. I., et al. (2021). Illuminating species diversity of nudibranch in Indonesian coral reef ecosystem using molecular identification. *IOP Conf. Ser. Earth Environ. Sci.* 944. doi: 10.1088/1755-1315/944/1/012033

Donald, K. M., Mcculloch, G. A., Dutoit, L., and Spencer, H. G. (2020). Population structure of the New Zealand whelk, Cominella glandiformis (Gastropoda: Buccinidae), suggests sporadic dispersal of a direct developer. *Biol. J. Linn. Soc.* 130, 49–60. doi: 10.1093/biolinnean/blaa033

Dsikowitzky, L., Damar, A., Ferse, S. C. A., Irianto, H. E., Jennerjahn, T. C., Lukas, M. C., et al. (2018). "Java Island, Indonesia". In: *World Seas: an Environmental Evaluation (Second Edition)*. (London: Elsevier Academic Press). p. 459–490. doi: 10.1016/B978-0-08-100853-9.00029-4

Edinger, E. N., and Risk, M. J. (2000). Effects of land-based pollution on Central Java coral reefs. *J. Coast. Dev.* 3, 593–613.

Eisenbarth, J. H., Undap, N., Papu, A., Schillo, D., Dialao, J., Reumschüssel, S., et al. (2018). Marine Heterobranchia (Gastropoda, Mollusca) in Bunaken National Park, North Sulawesi, Indonesia-A follow-up diversity study. *Diversity (Basel)* 10. doi: 10.3390/d10040127

Elfahmi, M. R., and Efendy, M. (2020). Struktur komunitas makrozoobentos epifauna pada ekosistem lamun, mangrove dan terumbu karang di Desa Labuhan Kecamatan Sepulu Bangkalan. *Juvenil: Jurnal Ilmiah Kelautan dan Perikanan* 1, 260–268. doi: 10.21107/juvenil.v1i2.8446

Ernawati, T., Priatna, A., and Satria, F. (2019). Biological reference points of painted spiny lobster Panulirus versicolor (Latreille 1804) in Karimunjawa Waters, Indonesia. *Indones Fish Res. J.* 25, 91–101. doi: 10.15578/ifrj.25.2.2019.91-101

Fahlevy, K., Khodijah, S., Prasetia, M. F., Nasrullah, I. A., Yudha, F. K., Subhan, B., et al. (2019). Live hard coral coverage and coral diseases distribution in the ujung kulon national park, banten, Indonesia. *AACL Bioflux* 12, 1234–1249.

Faricha, A., Munasik,, Kusnadi, A., Renyaan, J., Alifatri, L. O., Arbanto, B., et al. (2021). *Studi baseline terumbu karang dan ekosistem terkait di Taman Nasional Karimunjawa, Jawa Tengah, tahun 2021* (Indonesia: Research Center for Oceanography, National Research and Innovation Agency). Unpublished report.

Febiansi, D., Rahmayanti, F., Kurnia, R. N., Silmi, M. A., Dewi, A. K., Millaty, I. N. K., et al. (2018). Species diversity of gastropods (Cypraeidae and Conidae) at Krakal Beach, Gunungkidul, Yogyakarta, Indonesia. *Ocean Life* 2, 27–32. doi: 10.13057/oceanlife/o020104

Fisher, R., O'Leary, R. A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, R. E., et al. (2015). Species richness on coral reefs and the pursuit of convergent global estimates. *Curr. Biol.* 25, 500–505. doi: 10.1016/j.cub.2014.12.022

Fitriyah, A., Suryanti, S., and Rudiyanti, S. (2020). Hubungan tutupan karang dengan keanekaragaman Echinodermata di Pulau Karimunjawa, Jepara. *Jurnal Pasir Laut* 4, 52–59. doi: 10.14710/jpl.2020.30527

Giglio, V. J., Luiz, O. J., and Schiavetti, A. (2015). Marine life preferences and perceptions among recreational divers in Brazilian coral reefs. *Tour Manag.* 51, 49–57. doi: 10.1016/j.tourman.2015.04.006

Giyanto, G., Abrar, M., Manuputty, A. E. W., Siringoringo, R. M., Tuti, Y., and Zulfianita, D. (2017). *Panduan pemantauan kesehatan terumbu karang, edisi 2*. Jakarta: COREMAP CTI LIPI.

Giyanto, G., Manuputty, A. E. W., Abrar, M., Siringoringo, R. M., Suharti, S. R., Wibowo, K., et al. (2014). *Panduan monitoring kesehatan terumbu karang*. Eds. Suharsono, and O. K. Sumadhiharga (Jakarta: COREMAP CTI LIPI).

Glynn, P. W., and Enochs, I. C. (2011). "Coral reefs: An ecosystem in transition," in *Coral Reefs: An Ecosystem in Transition* (Dordrecht: Springer), 273–325. doi: 10.1007/978-94-007-0114-4

Goodwin, M., Halvorsen, K. T., Jiao, L., Knausgård, K. M., Martin, A. H., Moyano, M., et al. (2022). Unlocking the potential of deep learning for marine ecology: Overview, applications, and outlook. *ICES J. Mar. Sci.* 79, 319–336. doi: 10.1093/icesjms/fsab255

Gosliner, T. M. (1995). The genus Thuridilla (Opisthobranchia: Elysiidae) from the tropical Indo-Pacific, with a revision of their phylogeny and systematics of the Elysiidae. *Proc. California Acad. Sci.* 49, 1–54.

Graham, N. A. J., and Nash, K. L. (2013). The importance of structural complexity in coral reef ecosystems. *Coral Reefs* 32, 315–326. doi: 10.1007/s00338-012-0984-y

Gray, J. S. (1997). Marine biodiversity: Patterns, threats and conservation needs. *Biodivers Conserv* 6, 153–175. doi: 10.1023/A:1018335901847

Hadi, T. A., Abrar, M., Giyanto, B. P., Johan, O., Budiyanto, A., Dzumalek, A. R., et al. (2020). *The status of Indonesian coral reefs 2019*. Jakarta: Puslit Oseanografi LIPI.

Hammond, P. (1992). "Species inventory," in B. Groombridge ed. *Global Biodiversity*. Dordrecht: Springer.

Hartati, R., Ambariyanto, A., Widianingsih, W., Mahendrajaya, R. T., Mustagfirin, M., and Prihatinningsih, P. (2021). Stichopodidae (Holothuroidea: Echinodermata) from Nyamuk Island, Karimunjawa National Park, Central of Java, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 919. doi: 10.1088/1755-1315/919/1/012024

Hernan, G., Dubel, A. K., Caselle, J. E., Kushner, D. J., Miller, R. J., Reed, D. C., et al. (2022). Measuring the efficiency of alternative biodiversity monitoring sampling strategies. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.820790

Hoeksema, B. W. (2017). The hidden biodiversity of tropical coral reefs. *Biodiversity* 18, 8–12. doi: 10.1080/14888386.2017.1307787

Huda, M. A. I., Sudarmadji, S., and Fajariyah, S. (2017). Keanekaragaman jenis Echinoidea di zona intertidal pantai Jeding Taman Nasional Baluran. *Berkala Sainstek* 5, 61. doi: 10.19184/bst.v5i2.5531

Huffard, C. L., Erdmann, M. v., and Gunawan, T. (2012). *Geographic Priorities for Marine Biodiversity Conservation in Indonesia*. Jakarta: Ministry of Marine Affairs and Fisheries and Marine Protected Areas Governance Program.

Hutomo, M., and Moosa, M. K. (2005). Indonesian marine and coastal biodiversity: Present status. *Indian J. Mar. Sci.* 34, 88–97.

IUCN (2024). *The IUCN Red List of Threatened Species. Version 2023-1*. Available online at: https://www.iucnredlist.org (Accessed May 1, 2024).

Jeeva, C., Muruganantham, M., and Mohan, P. M. (2019). New reports on ophisthobranch fauna from the intertidal environment of Port Blair, Andaman Island India. *Curr. Trends Oceanogr. Mar. Sci.* 2. doi: 10.29011/CTOMS-110.100010

Jimenez, H., Dumas, P., Ponton, D., and Ferraris, J. (2012). Predicting invertebrate assemblage composition from harvesting pressure and environmental characteristics on tropical reef flats. *Coral Reefs* 31, 89–100. doi: 10.1007/s00338-011-0820-9

Kementerian Pertanian (1982). *Keputusan Menteri Pertanian Nomor 527/KPTS/UM/7/1982 tentang Areal Perairan Kepulauan Seribu Ditetapkan Sebagai Cagar Alam Laut dengan Luas Lebih Kurang 108.000 Ha*. Jakarta.

Kennedy, E. V., Vercelloni, J., Neal, B. P., Ambariyanto,, Bryant, D. E. P., Ganase, A., et al. (2020). Coral reef community changes in Karimunjawa National Park, Indonesia: Assessing the efficacy of management in the face of local and global stressors. *J. Mar. Sci. Eng.* 8, 1–27. doi: 10.3390/jmse8100760

Knauber, H., Kohlenbach, K., Brandt, A., and Saeedi, H. (2023). Crustaceans of the Northwest Pacific Ocean: Species richness and distribution patterns. *J. Sea Res.* 191. doi: 10.1016/j.seares.2022.102332

Komala, R. (2015). Keanekaragaman teripang pada ekosistem lamun dan terumbu karang di Pulau Bira Besar, Kepulauan Seribu, Jakarta. *Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia* 1, 222–226. doi: 10.13057/psnmbi/m010209

Krisnawati, S., and Hidayah, Z. (2020). Pemetaan terumbu karang Pulau Gili Ketapang Probolinggo. *Juvenil: Jurnal Ilmiah Kelautan dan Perikanan* 1, 437–450. doi: 10.21107/juvenil.v1i4.8933

Kristiana, R., Bedoux, G., Pals, G., Wayan Mudianta, I., Taupin, L., Marty, C., et al. (2020). Bioactivity of compounds secreted by symbiont bacteria of Nudibranchs from Indonesia. *PeerJ* 2020, 1–23. doi: 10.7717/peerj.8093

Kunal, A., Mahadevegowda, L., Melichar, T., and Boregowda, M. H. (2021). "DNA barcoding: nucleotide signature for identification and authentication of livestock". In *Advances in Animal Genomics*. (London: Elsevier Academic Press). P. 299–308. doi: 10.1016/B978-0-12-820595-2.00018-7

Kusuma, R. C., Ruswahyuni, R., and Subiyanto, S. (2013). Kelimpahan Nudibranchia pada karang bercabang dan karang batu di Pantai Pancuran Belakang Pulau Karimunjawa Jepara. *Manage. Aquat. Resour. J. (MAQUARES)* 2, 273–281. doi: 10.14710/marj.v2i3.4224

Lin, C., Huang, X., Wang, J., Xi, T., and Ji, L. (2021). Learning niche features to improve image-based species identification. *Ecol. Inform* 61. doi: 10.1016/j.ecoinf.2021.101217

Madduppa, H., Cahyani, N. K. D., Anggoro, A. W., Subhan, B., Jefri, E., Sani, L. M. I., et al. (2021). eDNA metabarcoding illuminates species diversity and composition of three phyla (chordata, mollusca and echinodermata) across Indonesian coral reefs. *Biodivers Conserv.* 30, 3087–3114. doi: 10.1007/s10531-021-02237-0

Marfai, M. A., Mardianto, D., Suriadi,, Wibowo, A. A., Utami, N. D., Jihad, A., et al. (2019). *Kajian pengelolaan pesisir berbasis ekowisata di Kepulauan Karimunjawa*. Ed. Nanik, (Yogyakarta: Gadjah Mada University Press).

Martín-Hervás, M., del, R., Carmona, L., Malaquias, M. A. E., Krug, P. J., Gosliner, T. M., et al. (2021). A molecular phylogeny of Thuridilla Bergh 1872 sea slugs (Gastropoda, Sacoglossa) reveals a case of flamboyant and cryptic radiation in the marine realm. *Cladistics* 37, 647–676. doi: 10.1111/cla.12465

Mazlan, A. G., Zaidi, C. C., Wan-Lotfi, W. M., and Othman, B. H. R. (2005). On the current status of coastal marine biodiversity in Malaysia. *Indian J. Mar. Sci.* 34, 76–87.

McClanahan, T. R., and Muthiga, N. A. (2020). Echinometra. *Developments Aquaculture Fish. Sci.* 43, 497–517. doi: 10.1016/B978-0-12-819570-3.00028-7

McKenna, S. A., Allen, G. R., and Suryadi, S. (2002). *A marine rapid assessment of the Raja Ampat Islands, Papua Province, Indonesia*. Washington, DC: Conservation International.

Mellin, C., Peterson, E. E., Puotinen, M., and Schaffelke, B. (2020). Representation and complementarity of the long-term coral monitoring on the Great Barrier Reef. *Ecol. Appl.* 30. doi: 10.1002/eap.2122

Mikkelsen, P. M., and Bieler, R. (2021). *Seashells of southern Florida: living marine mollusks of the Florida Keys and adjacent regions: bivalves* (Princeton: Princeton University Press).

Miloslavich, P., Díaz, J. M., Klein, E., Alvarado, J. J., Díaz, C., Gobin, J., et al. (2010). Marine biodiversity in the caribbean: Regional estimates and distribution patterns. *PloS One* 5. doi: 10.1371/journal.pone.0011916

Moore, A. M., Tassakka, A. C. M., Ambo-Rappe, R., Yasir, I., Smith, D. J., and Jompa, J. (2019). Unexpected discovery of Diadema clarki in the Coral Triangle. *Mar. Biodivers.* 49, 2381–2399. doi: 10.1007/s12526-019-00978-4

Mustagfirin, M., and Hartati, R. (2017). "Keanekaragaman sumber daya teripang di perairan Pulau Nyamuk, Kepulauan Karimunjawa," in *Prosiding Seminar Nasional Hasil-hasil Penelitian Perikanan dan Kelautan ke-VI*. Semarang: Fakultas Perikanan dan Ilmu Kelautan Universitas Diponegoro, 529–535.

Nasrudin, C. A., Yuniarti,, Ihsan, Y. N., and Syamsudin, M. L. (2020). Influence of rainfall intensity towards macrozoobenthos community structure in Ciletuh Bay Regency of Sukabumi District, West Java, Indonesia. *World News Natural Sci.* 28, 142–154.

Negoro, A. H. S., Muhlisin,, Masyithoh, N., Kusumah, M., and Trihartono, A. (2020). Maritime policies in the era of regional autonomy: Identifying the challenges. *IOP Conf. Ser. Earth Environ. Sci.* 485. doi: 10.1088/1755-1315/485/1/012030

Oedjoe, M. D. R., and Eoh, C. B. (2015). Keanekaragaman timun laut (Echinodermata: Holothuroidea) di perairan Sabu Raijua, Pulau Sabu, Nusa Tenggara Timur. *Jurnal Ilmu Dan Teknologi Kelautan Tropis* 7, 309–320. doi: 10.29244/jitkt.v7i1.9815

O'Loughlin, P. M. , and Rowe, F. W. E. (2006). A systematic revision of the asterinid genus Aquilonastra O'Loughlin 2004 (Echinodermata: Asteroidea). *Mem Mus Vic* 63, 257–287. doi: 10.24199/j.mmv.2006.63.18

Palomares, M. L. D., Johana, H. J., and Pauly, D. (2007). Historical ecology of the Raja Ampat archipelago, Papua Province, Indonesia. *Hist Philos. Life Sci.* 29, 33–56.

Pamungkas, J., and Glasby, C. J. (2019). Status of polychaete (Annelida) taxonomy in Indonesia, including a checklist of Indonesian species. *Raffles Bull. Zool.* 67, 595–639. doi: 10.26107/RBZ-2019-0045

Panggarbesi, M. I., Khairudi, D., Santoso, P., Soedharma, D., Arafat, D., Tarigan, S. A. R., et al. (2017). "Kelimpahan makrobhentos di perairan Pulau Tunda dan Pulau Pamujan besar, Provinsi Banten," in *Prosiding Seminar Nasional Ekosistem Perairan Teluk Lada dan Pulau Tunda Tahun 2017 Kelimpahan*. Serang: LPSPL Serang, 97–106.

Papu, A., Undap, N., Martinez, N. A., Segre, M. R., Datang, I. G., Kuada, R. R., et al. (2020). First study on marine heterobranchia (Gastropoda, Mollusca) in Bangka Archipelago, North Sulawesi, Indonesia. *Diversity (Basel)* 12. doi: 10.3390/d12020052

Park, J., Song, S. J., Ryu, J., Kwon, B. O., Hong, S., Bae, H., et al. (2014). Macrozoobenthos of Korean tidal flats: A review on species assemblages and distribution. *Ocean Coast. Manag.* 102, 483–492. doi: 10.1016/j.ocecoaman.2014.07.019

Pereira, L. H. G., Castro, J. R. C., Vargas, P. M. H., Gomez, J. A. M., and Oliveira, C. (2021). The use of an integrative approach to improve accuracy of species identification and detection of new species in studies of stream fish diversity. *Genetica* 149, 103–116. doi: 10.1007/s10709-021-00118-6

Pereira, H. M., and Cooper, H. D. (2006). Towards the global monitoring of biodiversity change. *Trends Ecol. Evol.* 21, 123–129. doi: 10.1016/j.tree.2005.10.015

Permen LHK No.P.106 (2018). *Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor P.106/MENLHK/SETJEN/KUM.1/12/2018 tentang Perubahan Kedua atas Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor P.20/MENLHK/SETJEN/KUM.1/6/2018 tentang Jenis Tumbuhan dan Satwa yang Dilindungi*. Jakarta.

Pertiwi, N. P. D., Kurniasih, E. M., Rintiantoto, S. A., Dharmawan, G. W. D., Mustari, T. R., Basuki, F., et al. (2015). Revealing hidden diversity in Menjangan Besar Island, Karimunjawa: Reef-associated decapods as a proxy of biodiversity estimation. *Ilmu Kelaut* 19, 195. doi: 10.14710/ik.ijms.19.4.195-201

Petersen, J. K. (2007). Ascidian suspension feeding. *J. Exp. Mar. Biol. Ecol.* 342, 127–137. doi: 10.1016/j.jembe.2006.10.023

Pratiwi, R. (2018). Keanekaragaman dan Potensi Lobster (Malacostraca: Palinuridae) di Pantai Pameungpeuk, Garut Selatan, Jawa Barat. *Biosfera* 35, 10. doi: 10.20884/1.mib.2018.35.1.524

Pratiwi, R. (2019). Kepiting brachyura pulau tikus, Kepulauan Seribu. *Majalah Ilmiah Biologi Biosfera: A Sci. J.* 36, 63–70. doi: 10.20884/1.mib.2019.36.2.839

Pratiwi, R., and Elfidasari, D. (2020). Short communication: The crustaceans fauna from natuna islands (Indonesia) using three different sampling methods. *Biodiversitas* 21, 1215–1226. doi: 10.13057/biodiv/d210349

Purcell, S. W., Conand, C., Uthicke, S., and Byrne, M. (2016). "Ecological roles of exploited sea cucumbers," in *Oceanography and Marine Biology* (Boca Raton: CRC Press), 375–394.

Putri, A. E. M., Sunaryo, S., and Endrawati, H. (2019). Perbandingan jenis dan jumlah Echinodermata di perairan Pantai Krakal Gunung Kidul Yogyakarta dan Pantai Pailus Jepara, Jawa Tengah. *J. Mar. Res.* 8, 127–140. doi: 10.14710/jmr.v8i2.25090

Rahayu, D. A., Ambarwati, R., and Faizah, U. (2019). Biodiversity of invertebrates in Kemantren Coast, Lamongan. *Adv. Comput. Sci. Res.* 95, 34–40. doi: 10.2991/miseic-19.2019.8

Ravinesh, R., Biju Kumar, A., and Anjana, V. L. (2021). Diversity and distribution of molluscan fauna of Asthamudi estuary, Kerala, India. *Wetl. Ecol. Manag.* 29, 745–765. doi: 10.1007/s11273-021-09791-y

Richards, Z. T., and Day, J. C. (2018). Biodiversity of the Great Barrier Reef- how adequately is it protected? *PeerJ* 2018, 1–26. doi: 10.7717/peerj.4747

Rogers, C. S. (2013). Coral reef resilience through biodiversity. *ISRN Oceanogr.* 2013, 1–18. doi: 10.5402/2013/739034

Rositasari, R., Puspitasari, R., Nurhati, I. S., Purbonegoro, T., and Yogaswara, D. (2017). *5 Dekade LIPI di Teluk Jakarta* (Jakarta: Pusat Penelitian Oseanografi LIPI).

Ruiz-Abierno, A., and Armenteros, M. (2017). Coral reef habitats strongly influence the diversity of macro- and meiobenthos in the Caribbean. *Mar. Biodivers.* 47, 101–111. doi: 10.1007/s12526-016-0553-7

Sabdono, A., Radjasa, O. K., Trianto, A., Sibero, M. T., Martynov, A., and Kristiana, R. (2021). An ecological assessment of nudibranch diversity among habitats receiving different degrees of sedimentation in Jepara coastal waters, Indonesia. *Int. J. Conserv. Sci.* 12, 291–302.

Saeedi, H., Costello, M. J., Warren, D., and Brandt, A. (2019). Latitudinal and bathymetrical species richness patterns in the NW Pacific and adjacent Arctic Ocean. *Sci. Rep.* 9. doi: 10.1038/s41598-019-45813-9

Sahidin, A., Hamdani, H., Zahidah,, Herawati, H., Octavina, C., and Syawal, M. S. (2021). Diversity, distribution and decreasing factor of intertidal invertebrate communities in the Pangandaran Turism, Indonesia. *Int. J. Fish Aquat. Stud.* 9, 357–364. doi: 10.22271/fish.2021.v9.i1e.2421

Sahidin, A., Zahidah,, Hamdani, H., Riyantini, I., and Sewiko, R. (2018). The biodiversity of gastropods in Karapyak Rocky Shores, Pangandaran Region, West Java Province, Indonesia. *Omni-Akuatika* 14, 79–85. doi: 10.20884/1.oa.2018.14.2.547

Salsabilla, A., Yuniarti, M. S., Ihsan, Y. N., Syamsudin, M. L., and Yuliadi, L. P. (2022). Sedimentation rate implications to water quality and macrozoobenthos community structure in Ciletuh Bay, Sukabumi Regency, West Java, Indonesia. *AACL Bioflux* 15, 1–11.

Sari, L., and Aunurohim, A. (2013). Korelasi komunitas Nudibranchia dengan komunitas Porifera di perairan Pasir Putih, Situbondo. *Jurnal Sains dan Seni ITS* 2, 1–6. doi: 10.12962/j23373520.v2i2.4168

Sasongko, A. S., Tarigan, D. J., Cahyadi, F. D., Yonanto, L., Salim, M. N., Hasan, A. F., et al. (2020). Jenis-jenis bintang laut, bulu babi, dan teripang (Echinodermata) di perairan Pulau Tunda Kabupaten Serang. *Jurnal Teknologi Perikanan dan Kelautan* 11, 177–182. doi: 10.24319/jtpk.11.177-182

Setiawan, R., S, S., Mulyadi, B. P., and Hamdani, R. H. (2019a). Preferensi habitat spesies kerang laut (Moluska: Bivalvia) di ekosistem intertidal tanjung bilik taman nasional baluran. *Natural Sci.: J. Sci. Technol.* 8, 165–170. doi: 10.22487/25411969.2019.v8.i3.14601

Setiawan, R., Ula, F. A., and Sijabat, S. F. (2019b). Inventarisasi spesies bintang mengular (Ophiuroidea) di Pantai Bilik, Taman Nasional Baluran, Jawa Timur. *Jurnal Kelautan: Indonesian J. Mar. Sci. Technol.* 12, 192–200. doi: 10.21107/jk.v12i2.5838

Setiawan, R., Wimbaningrum, R., Siddiq, A. M., and Saputra, I. S. (2021). Keanekaragaman spesies dan karakteristik habitat kerang kima (Cardiidae: Tridacninae) di ekosistem intertidal Tanjung Bilik Taman Nasional Baluran. *Jurnal Kelautan: Indonesian J. Mar. Sci. Technol.* 14, 254–262. doi: 10.21107/jk.v14i3.9042

Setyastuti, A., and Purwati, P. (2015). Species list of Indonesian trepang. *SPC BECHE-DE-MER Inf. Bull.* 35, 19–25.

Setyawan, E., Yusri, S., and Timotius, S. (2011). *Terumbu karang Jakarta: Pengamatan jangka panjang terumbu karang Kepulauan Seribu, (2005-2009)* (Jakartra: Yayasan Terumbu Karang Indonesia (TERANGI)).

Setyowati, D. A., Supriharyono, S., and Taufani, W. T. (2017). Bioekologi bintang laut (Asteroidea) di perairan Pulau Menjangan Kecil, Kepulauan Karimunjawa. *Manage. Aquat. Resour. J. (MAQUARES)* 6, 393–400. doi: 10.14710/marj.v6i4.21328

Shabana, E. E., El Kazzaz, W., Dar, M., and Dewedar, A. (2018). The influence of Holothuria atra (Echinodermata: Holothuroidea) on organic matter assimilation, ammonification and nitrification rate of sediment Hurghada, Red Sea, Egypt. *J. Sci. Res. Sci.* 35, 1–15. doi: 10.21608/jsrs.2018.25515

Siallagan, Z. L., Sidabalok, C. M., Islami, M. M., Mujiono, N., Wilson, S. P., and Pamungkas, J. (2023). Why many Indonesian marine species remain undescribed: a case study using polychaete species discovery. *Raffles Bull. Zool.* 71, 337–365.

Siddiqi, A. A., Sulardiono, B., and Suryanti, S. (2017). "Struktur komunitas teripang (Holothuroidea) di perairan Pulau Karimunjawa Taman Nasional Karimunjawa, Jepara," in *Prosiding Seminar Nasional Hasil-hasil Penelitian Perikanan dan Kelautan ke-VI*. (Semarang: Fakultas Perikanan dan Ilmu Kelautan Universitas Diponegoro), 173–182.

Sihaloho, H. F. (2011). "Moluska di sekitar perairan Pulau Bawean," in *Biodiversitas di Kawasan Perairan Pulau Bawean* (LIPI Press, Jakarta), 78–86.

Siringoringo, R. M., Abrar, M., Sari, N. W. P., Nurdiansyah, D., Alivatri, L. O., Putra, R. D., et al. (2021). "Monitoring kesehatan terumbu karang dan ekosistem terkait di Kepulauan Seribu dan sekitarnya tahun 2021," (Jakarta: Research Center for Oceanography, National Research and Innovation Agency), 1–98. Unpublished report.

Situmeang, N. S., Purnama, D., and Hartono, D. (2017). Identifikasi spesies udang mantis (Stomatopoda) di perairan Kota Bengkulu. *Jurnal Enggano* 2, 239–248. doi: 10.31186/jenggano.2.2.239-248

Sluiter, C. P. (1887). *Die Evertebraten aus der Sammlung des Königlichen Naturwissenschaftlichen Vereins in Niederländisch Indien in Batavia. Die Echinodermen. 1. Holothuroidea*. Natuurkundig tijdschrift voor Nederlandsch Indië. 47, 18–220.

Sluiter, C. P. (1889). *Die Evertebraten aus der Sammlung des Königlichen Naturwissenschaftlichen Vereins in Niederländisch Indien in Batavia. Die Echinodermen 2. Echinoidea. 3. Asteroidea*. Natuurkundig tijdschrift voor Nederlandsch Indië. 48, 285–313.

Sluiter, C. P. (1890). *Die Evertebraten aus der Sammlung des Königlichen Naturwissenschaftlichen Vereins in Niederländisch Indien in Batavia*. Natuurkundig tijdschrift voor Nederlandsch Indië. 50, 329–348.

Somma, A., Zahida, F., and Yuda, P. (2017). Abundance and distribution of sea urchin (Echinoidea) in Pasir Putih reef, Situbondo, Indonesia. *Biota* 2, 111–115.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., et al. (2007). Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. *Bioscience* 57, 573–583. doi: 10.1641/B570707

Stella, J. S., Barrier, G., Marine, R., Authority, P., Hutchings, P., and Jones, G. P. (2011). Coral-associated invertebrates: Diversity, ecological importance and vulnerability to disturbance. *Oceanogr. Mar. Biol.: Annu. Rev.* 49, 43–104. doi: 10.1201/b11009-3

Stoffels, B. E. M. W., van der Meij, S. E. T., Hoeksema, B. W., Van Alphen, J., Van Alen, T., Meyers-Muñoz, M. A., et al. (2016). Phylogenetic relationships within the phyllidiidae (Opisthobranchia, Nudibranchia). *Zookeys* 2016, 1–35. doi: 10.3897/zookeys.605.7136

Sulardiono, B. (2016). Potensi pemanfaatan teripang (Holothurians) di perairan karimunjawa, Kabupaten Jepara, Provinsi Jawa. *Buletin Oseanografi Marina* 5, 64. doi: 10.14710/buloma.v5i1.11298

Sun, J., Futahashi, R., and Yamanaka, T. (2021). Improving the accuracy of species identification by combining deep learning with field occurrence records. *Front. Ecol. Evol.* 9. doi: 10.3389/fevo.2021.762173

Supono,, and Arbi, U. Y. (2012). Kelimpahan dan keragaman Echinodermata di Pulau Pari, Kepulauan Seribu. *Jurnal Ilmu dan Teknologi Kelautan Tropis* 4, 114–120.

Supono,, Lane, D. J. W., and Susetiono, (2015). Echinoderm fauna of the Lembeh Strait, North Sulawesi: Inventory and distibution review. *Mar. Res. Indonesia* 39, 51–61. doi: 10.14203/mri.v39i2.85

Suryanti, S., Ain, C., Endrawati, H., and Latifah, N. (2018a). Environmental factors that affect the biodiversity and color of starfish in Menjangan Besar Island, Karimunjawa. *Int. J. Agriculture Environ. Biores.* 3, 200–211.

Suryanti, S., Ain, C., and Latifah, N. (2018b). Relationships between of sea urchins abundance, macroalgae and coral closure on the Cemara Kecil Island. *J. Phys. Conf. Ser.* 1025. doi: 10.1088/1742-6596/1025/1/012038

Suwartimah, K., Wati, D. S., Endrawati, H., and Hartati, R. (2017). Komposisi Echinodermata di rataan litoral terumbu karang Pantai Krakal, Gunung Kidul, Yogyakarta. *Buletin Oseanografi Marina* 6, 53. doi: 10.14710/buloma.v6i1.15743

Szabó, K., and Amesbury, J. R. (2011). Molluscs in a world of islands: The use of shellfish as a food resource in the tropical island Asia-Pacific region. *Quaternary Int.* 239, 8–18. doi: 10.1016/j.quaint.2011.02.033

Tegar, D. R., and Gurning, S. R. O. (2018). Development of marine and coastal tourism based on blue economy. *Int. J. Mar. Eng. Innovation Res.* 2, 2548–1479. doi: 10.12962/j25481479.v2i2.3650

Triana, R., Elfidasari, D., and Vimono, I. B. (2015). Identifikasi Echinodermata di selatan Pulau Tikus, Gugusan Pulau Pari, Kepulauan Seribu, Jakarta. *Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia* 1, 455–459. doi: 10.13057/psnmbi/m010313

Triatmojo, A., Ario, R., and Widianingsih, (2018). Kelimpahan Echinodermata pada zona intertidal di Pantai Krakal dan Pantai Kukup, Gunungkidul Yogyakarta. *J. Mar. Res.* 7, 263–272.

Ubaidillah, R., Marwoto, R. M., Hadiaty, R. K., Fahmi, S., Wowor, D., Mumpuni,, et al. (2013). *Aquatic biota that are threatened with extinction in Indonesia*. Eds. D. Sadili, Sarmintohadi, and C. Mustika (Jakarta: Kementerian Kelautan dan Perikanan dan LIPI).

UNEP-WCMC, WorldFish Centre, WRI and TNC (2021). *Global distribution of coral reefs, compiled from multiple sources including the Millennium Coral Reef Mapping Project. Version 4.1, updated by UNEP-WCMC. Includes contributions from*

IMaRS-USF and IRD (2005), IMaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UN Environment Programme World Conservation Monitoring Centre. doi: 10.34892/t2wk-5t34

UNEP-WCPC (2020). *Protected Area Profile for Indonesia from the World Database on Protected Areas*. Available online at: www.protectedplanet.net (Accessed April 11, 2023).

Vafidis, D., Drosou, I., Dimitriou, K. , and Klaoudatos, D. (2020). Population characteristics of the limpet Patella caerulea (Linnaeus 1758) in Eastern Mediterranean (Central Greece). *Water (Switzerland)* 12. doi: 10.3390/W12041186

van der Meij, S. E. T., Moolenbeek, R. G., and Hoeksema, B. W. (2009). Decline of the Jakarta Bay molluscan fauna linked to human impact. *Mar. pollut. Bull.* 59, 101–107. doi: 10.1016/j.marpolbul.2009.02.021

Vimono, I. B., and Sihaloho, H. F. (2011). "Echinodermata di perairan Pulau Bawean," in *Biodiversitas di Kawasan Perairan Pulau Bawean* (LIPI Press, Jakarta), 91–97.

Wehrtmann, I. S., Cortés, J., and Echeverría-sáenz, S. (2009). *Marine biodiversity of Costa Rica, Central America*. Dordrecht: Springer. doi: 10.1007/978-1-4020-8278-8

Wells, F. E. (2000). "Centres of species richness and endemism of shallow water marine molluscs in the tropical Indo-West Pacific," in *Proceedings 9th International Coral Reef Symposium*, Bali, Indonesia.

Whittaker, J. M., Müller, R. D., Sdrolias, M., and Heine, C. (2007). Sunda-Java trench kinematics, slab window formation and overriding plate deformation since the Cretaceous. *Earth Planet Sci. Lett.* 255, 445–457. doi: 10.1016/j.epsl.2006.12.031

World Resources Institute (2000). *Coastal and marine ecosystems-marine jurisdiction: Coastline length*. Available online at: https://web.archive.org/web/20120419075053/http://earthtrends.wri.org/text/coastal-marine/variable-61.html (Accessed February 19, 2024).

Wulandari, A., and Mardiana, A. M. (2022). Invertebrate diversity at Gunung Kidul Beach Yogyakarta as an effort to conserve aquatic ecosystems. *AGARICUS: Adv. Agric. Sci. Farming* 2, 78–85.

Yang, Y., Li, Q., Kong, L., and Yu, H. (2019). Mitogenomic phylogeny of Nassarius (Gastropoda: Neogastropoda). *Zool. Scr.* 48, 302–312. doi: 10.1111/zsc.12343

Yonvitner, Agus, S. B., Lestari, D. F., Pasaribu, R., Supriyanto, E., Widodo, C., et al. (2022). Vulnerability status of the coral ecosystem in Kepulauan Seribu Marine National Park, Indonesia. *Coast. Manage.* 50, 251–261. doi: 10.1080/08920753.2022.2037388

Yusri, S., Prastowo Sw, M., Idris,, and Akrhari, H. (2017) (Kondisi ekosistem terumbu karang Pulau Sangiang). doi: 10.13140/RG.2.2.20816.25606

Zhang, Z.-Q. (2011). "Subphylum crustacea Brünnich 1772," in *Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness* (Auckland: Magnolia Press), 165–191.