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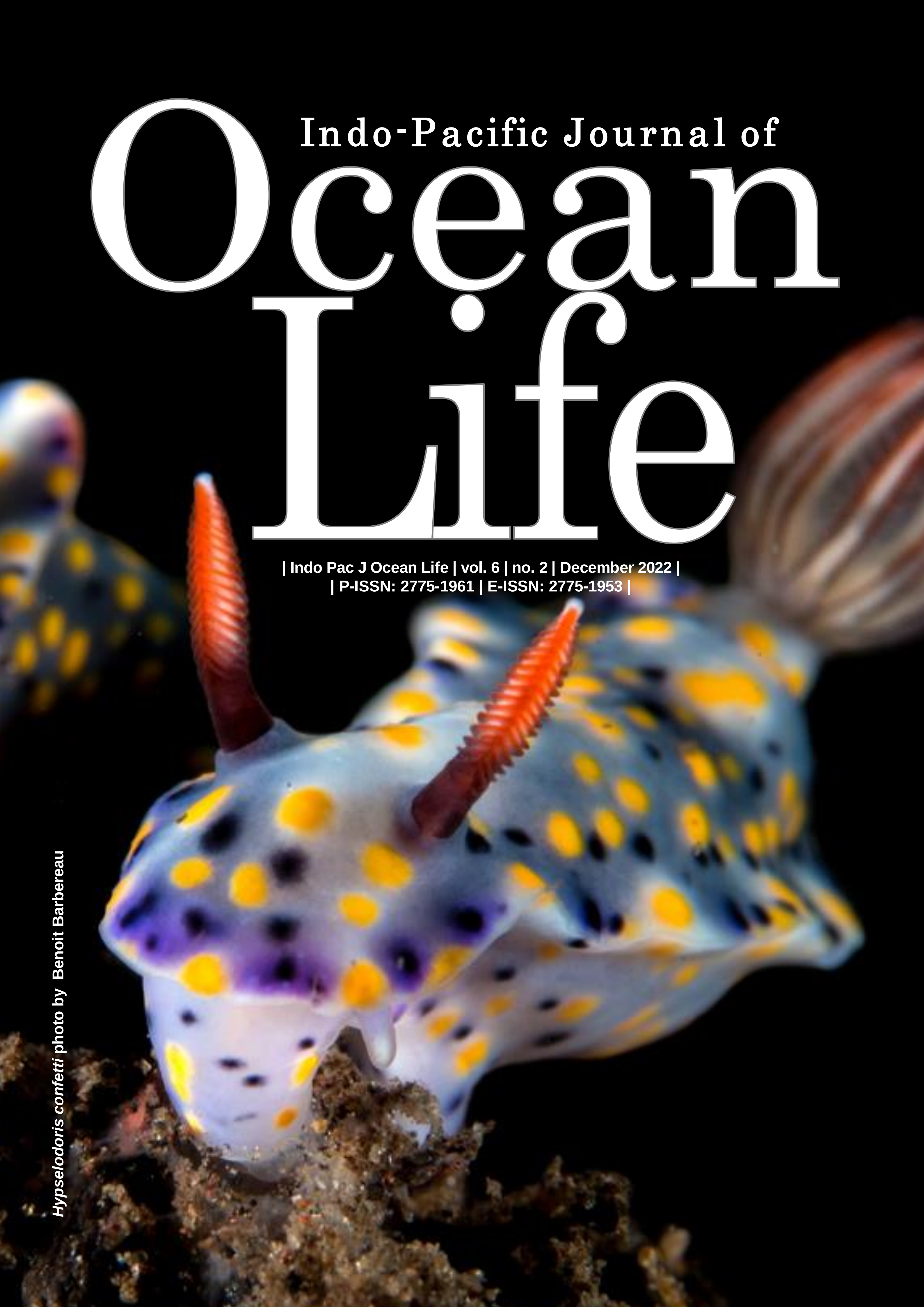

*Hypselodoris confetti* photo by Benoit Barbereau

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Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

**Proceeding:**

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**Thesis, Dissertation:**

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**Information from the internet:**

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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# Health monitoring status of corals in Gulf of Mannar and Palk Bay (India) with special reference to coral bleaching event

**KOUSHIK SADHUKHAN♥, RAMESH CHATRAGADDA, T SHUNMUGARAJ, M V RAMANA MURTHY**
National Centre for Coastal Research (NCCR), Ministry of Earth Sciences (MoES). Mandapam Field Office, Mandapam Camp, Tamil Nadu 623519, India. Tel.: +91-44-66783599, ♥email: sadhukhan.1985@gmail.com

Manuscript received: 1 September 2022. Revision accepted: 18 November 2022.

**Abstract.** *Sadhukhan K, Chatragadda E, Shunmugaraj T, Murthy MVR. 2022. Health monitoring status of corals in Gulf of Mannar and Palk Bay (India) with special reference to coral bleaching event. Indo Pac J Ocean Life 6: 61-73.* Coral reef ecosystems are highly important regarding ecological, cultural, and economic values. Unfortunately, these ecosystems are declining rapidly due to climate change and local anthropogenic threats. The present study assessed the coral reef health status in the Gulf of Mannar (GoM) and Palk Bay (PB), India, to understand the diversity and abundance of corals and the bleaching vulnerability of the reef areas. Extensive underwater surveys were conducted from August 2018 to August 2020. Line intercept transect (LIT) methods were employed in triplicates and estimated the bleaching-mediated reef threats. As a result, the average live coral cover of the Gulf of Mannar was 39.55±15.45% (Mean±SD), and Palk Bay was 28.40±14.60%, of which Mandapam Group of Islands has maximum live coral coverage (51.80±15.10%). Severe coral bleaching was also observed in the Gulf of Mannar and Palk Bay during the summer of two the consecutive year, 2019 and 2020, triggered by increased sea surface temperature (SST) of 4°C-5°C than the average temperature (28°C-31°C). The current study highlights the detailed distribution of the coral community with comparative analysis since 2000 and the adaptive response of native coral species to bleaching events that will help to implement management interventions like coral restoration of those native species to strengthen the reef resilience in the Gulf of Mannar and Palk Bay.

**Keywords:** Bleaching, coral cover, health monitoring, reef threats, Sea Surface Temperature (SST)

## INTRODUCTION

Coral reefs, considered rainforests of the sea, occupy less than 1% of the ocean floor but significantly provide shelter to 25% of all marine organisms. In addition, millions of the coastal population depend on reef fish resources for food, medicine, and tourism (Burke et al. 2015; Zhao et al. 2019; Machendiranathan et al. 2020). The reef ecosystem also protects the shoreline and coastal habitats. But unfortunately, over the past few decades, the world's tropical reef ecosystem, especially reef-building corals and the dependent coastal populations, are rapidly declined due to global climate change and anthropogenic stressors (Spalding and Brown 2015; Heron et al. 2016; Eakin et al. 2016; Hughes et al. 2017; Camp et al. 2018). As a result, many reef-building corals and reef habitats in Indo-Pacific regions are disappearing. Therefore, the collapses of these ecosystems contribute to shifts or changes in reef habitats, species distribution, and species interactions (de Vantier et al. 2020).

Furthermore, to encounter the positive and negative drive of the reef ecosystem, monitoring and assessment are the key components that provide essential information on the current health status and trend of increasing threats in the ecosystem. The reef monitoring method is essential to answer the following important questions - what is on our reefs (abundance, biodiversity), what species are special or important for the region, what changes are being seen over time, what is causing the decline of the reef health, and what is the current health status of the reef. Therefore, Ecosystem monitoring is a fundamental technique to increase coral reef resilience that delivers a detailed account of ecosystem states with an emphasis on the abundance of important biological species (Mumby and Steneck 2008; Lindenmayer and Likens 2010; Kupschus et al. 2016).

The sequential occurrence of mass global bleaching events from 1998, 2002, and then 2014-2017 due to global warming and thermal heat waves disrupt the physiological and symbiotic functions between corals and associated dinoflagellates (Skirving et al. 2019; Harrison et al. 2019; Bolanos et al. 2021). Ultimately this mass bleaching response is recognized as the primary global challenge to the existence of coral reefs as a prolonged condition of the bleached corals often leads to the mass mortality and permanent shifting of live reefs to macroalgal dominant dead reefs (Baker et al. 2008; Eakin et al. 2016, 2017; Darling and Cote 2018; Head et al. 2019). However, Coral reefs in the Gulf of Mannar (GoM) are comprised of 117 reef-building coral species distributed from Rameswaram to the Tuticorin coast. The region was declared as Gulf of Marine National Park in 1986 by Tamil Nadu Coast (Edward et al. 2007). Massive coral bleaching events in Indian coral reefs dramatically changed the reef ecology, species interactions, loss of shallow water reef-building corals, including live coral cover, habitat loss of reef fishes, and damaged shoreline operations (Edward et al. 2012; De et al. 2017). The health of coral reefs in the GoM and Palk Bay (PB) region is being declined to several natural and anthropogenic stressors, directly affecting the coastal population who depends on the reef resources (Ramesh et al. 2020). The primary cause of reef health damage in the GoM is coral bleaching, which now becomes an annual phenomenon due to increasing global warming. Post-bleaching stress in reefs is induced by the overgrowing macroalgal populations and increased microbial infections (Coral disease). This phase shift occurrence becomes a significant restraint for newly recruiting corals and may lead to coral species loss. Reef-building corals can tolerate the increase of 1°C - 2°C of their upper thermal threshold, but during summer in each year, SST range between 30°C-36̊ C in GoM, which eventually increase average of 3°C-4°C than its normal living temperature (Lough 2011; Edward et al. 2018). Therefore, to estimate the reef health condition of coral reefs in the GoM and PB, the present study assessed the total live and coral coverage, community structure of reef-building corals, abundant status of corals, anthropogenic interventions, the extent of annual bleaching vulnerability to coral species and emerging new threats to this ecosystem. This study also documented the bleaching resistance of coral species for reef management activities like reef restoration and artificial coral gardens.

## MATERIALS AND METHODS

Extensive field surveys were conducted at reef flats of 21 islands of the GoM (India) from August 2018 to August 2020. Field data acquisition was made by snorkeling and SCUBA diving. Line Intercept Transect (LIT) (English et al.1997; Hill and Wilkinson 2004) was employed to assess the distribution, abundance, and species diversity of corals in all the survey sites and used the internationally accepted corals' live form categories as mentioned by English et al. (1997). During the survey, field observations were made at 165 locations in all the 21 islands of GoM and 5 locations in PB (Figure 1). Locations were recorded using GARMIN e-Trex®30X handheld GPS device.

For detailed reef health assessment, a 20-meter-long flexible underwater tape was laid on selected reef areas, roughly parallel to the shoreline, with three replicates at each site in between 2-6 m depths, and every change in the benthic category is noted in underwater data sheets or underwater slates as described in English et al. (1997). Photographs and videos of benthic data in each transect were recorded as proof of underwater survey assessment in all the study areas. The identification of corals was made using standard coral identification keys (Veron, 2000; Huang et al. 2014). Observation of the sedimentation, coral disease, macroalgal proliferation, animal invasion, ghost nets, and anchor damage were considered to study the threats to the reefs. Sea Surface Temperature (SST), Dissolved oxygen, pH, and Salinity were estimated using Manta 2 water-quality multiprobe gadget. Furthermore, to evaluate the extent of bleaching, it has been categorized into partially bleached, completely bleached, and non-bleached (Sakai et al. 2019).

The descriptive statistical analysis measures the Relative Abundance (RA), linear regression curve, standard mean estimation, ANOVA, and Box Whisker analysis, calculated using SPSS software and MS Excel. Depending on the RA values, coral species are categorized into not recorded (RA=0), rare (0<RA<0.1), uncommon (RA=0.1-1), Common (RA=1-10), Abundant (RA=10-20), and dominant (RA>20) (Sukumaran and George 2012).

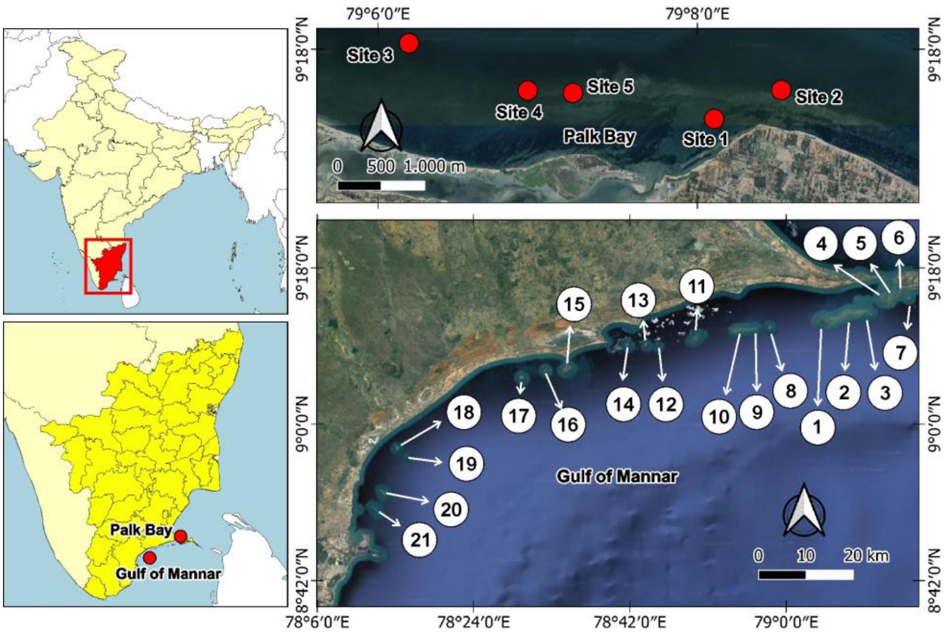


**Figure 1.** Study area Map – showing different islands of GoM and PB (India) [1. Hare Island (HAI); 2. Manoli Island (MAI); 3. Manoliputti Island (MPI); 4. Poomarichan Island (PCI); 5. Pullivasal Island (PVI); 6. Krusadai Island (KI); 7. Shingle Island (SHI); 8. Mulli Island (MUI); 9. Thalairi Island (THI);10. Valai Island (VAI); 11. Appa Island (API); 12. Poovarasanpatti Island (POI); 13. Anaipar Island (ANI); 14. Valimunai Island (VMI); 15. Nallathanni Island (NTI); 16. Pullivinichalli Island (PUI); 17. Upputhanni Island (UTI); 18. Karaichalli Island (KRI); 19. Vilanguchalli Islnd (VLI); 20. Kasuwar Island (KWI); 21. Vann Island (VNI)]

## RESULTS AND DISCUSSION

### Community structure

Community structure analysis revealed 75 species of hard corals and four species of soft corals belonging to 13 families and 22 genera of class Anthozoa. The family Acroporidae has the maximum representation of coral species (25), followed by Merulinidae (22) (Table 1). Mean live coral coverage in GoM was 39.55±15.45% and in PB was 28.40±14.60%. Among GoM, the Mandapam group of Islands has maximum live coral coverage, with 51.80±15.10%, followed by 48.60±15.30% in the Keezhakarai group of Islands, 26.30±14.20% in the Vembar group of islands and the live coral status found to be least in the Tuticorin group of Islands (26.30±14.20%) (Figure 2). The relative abundance of the investigated species was also categorized based on their abundance score as rare, uncommon, common, abundant, and dominant. Very few coral species were common, and *Montipora digitata* (10.66%) was the abundant coral species in GoM. *Acropora digitifera* (4.07%), *Acropora muricata* (5.03%), *Acropora hyacinthus* (4.19%), *Echinopora lamellose* (5.17%), and *Porites lutea* (7.30%) were commonly distributed in GoM and PB reefs (Table 1). Reefs of PB are abundant with massive and sub-massive corals, especially *P. lutea, P. solida, Dipsastraea speciosa, Dipsastraea favus,* and *Favites halicora*. Based on the relative abundance value, most coral species are uncommon to all islands of GoM. Few coral species, such as *Montipora tuberculosa* (0.05%), *Siderastrea savignyana* (0.05%), *Platygyra daedalea* (0.07%), *Pavona explanulata* (0.07%), *Goniopora columna* (0.05%) and *Porites nodifera* (0.02%) were rarely occurring in 21 islands of GoM (Table 1).

As compared to the earlier data of 2001 and 2015, it has been concluded that most of the islands have a significant recovery (F-7.14;df- 2; P<0.01) than the reef health condition existed 19 years back (Figure 3). The mean percentage of live coverage in the islands of Mandapam and Keezhakarai group increased substantially over time, while the live coral coverage in Vembar group of islands was found to be as degraded as 20 years back (Figure 3). Live coral coverage in Appa Island and Karaichalli Island has shown the highest increase in live coral coverage from 2% and 4% in 2001 to 54.5% and 48.4% in 2020 respectively (Figure 3). Island wise data on the different live and dead form categories has also been revealed during the study (Figure 4). Among the live form categories, branching *Acropora* corals (ACD, ACB & ACT) were found to be abundant in the islands of Mandapam Group and Appa Island of Keezhakarai range, whereas the live form CB found to be dominant in Tuticorin group of islands. Live-form categories called massive corals (CM) are generally found abundant at all islands of GoM and PB (Figure 4). Other live-form categories such as CS, CE, and CF are recorded from GoM and PB. Islands such as Poovarasanpatti, Valimunai, and Anaipar are the major contributor to the macroalgal assemblage (MA) in the reef. Among the dead form categories, DCA, R, RCK, and S has been revealed from both GoM and PB (Figure 4). The Vilanguchali island of the Tuticorin group of islands was found to be the most degraded coral coverage (11.7%) among all islands in which dead form categories were as follows - DCA - 57.9%, MA- 19.3%, R-3.2%, S-6.9%.

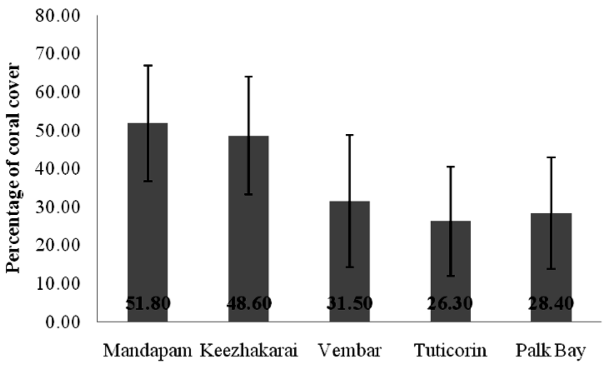


**Figure 2.** Average percentages of live coral cover in different areas of GoM and PB (India)

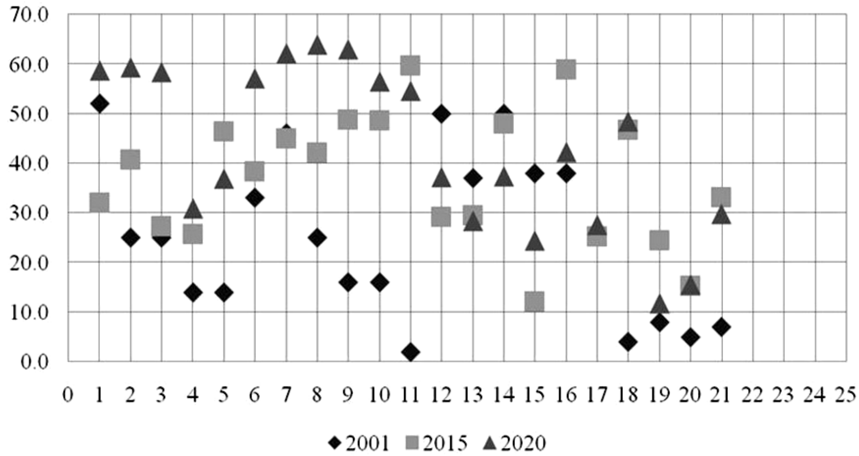


**Figure 3.** Comparative analysis of live coral coverage since 2001. Source: Shanmugaraj et al. (2013) and ENVIS (2015). [1-HAI; 2-MAI; 3-MPI; 4-PCI; 5-PVI; 6-KI; 7-SHI; 8-MUI; 9- THI;10- VAI; 11-API; 12-POI; 13-ANI; 14-VMI; 15-NTI; 16-PUI; 17-UTI; 18-KRI; 19-VLI; 20-KWI; 21-VNI]

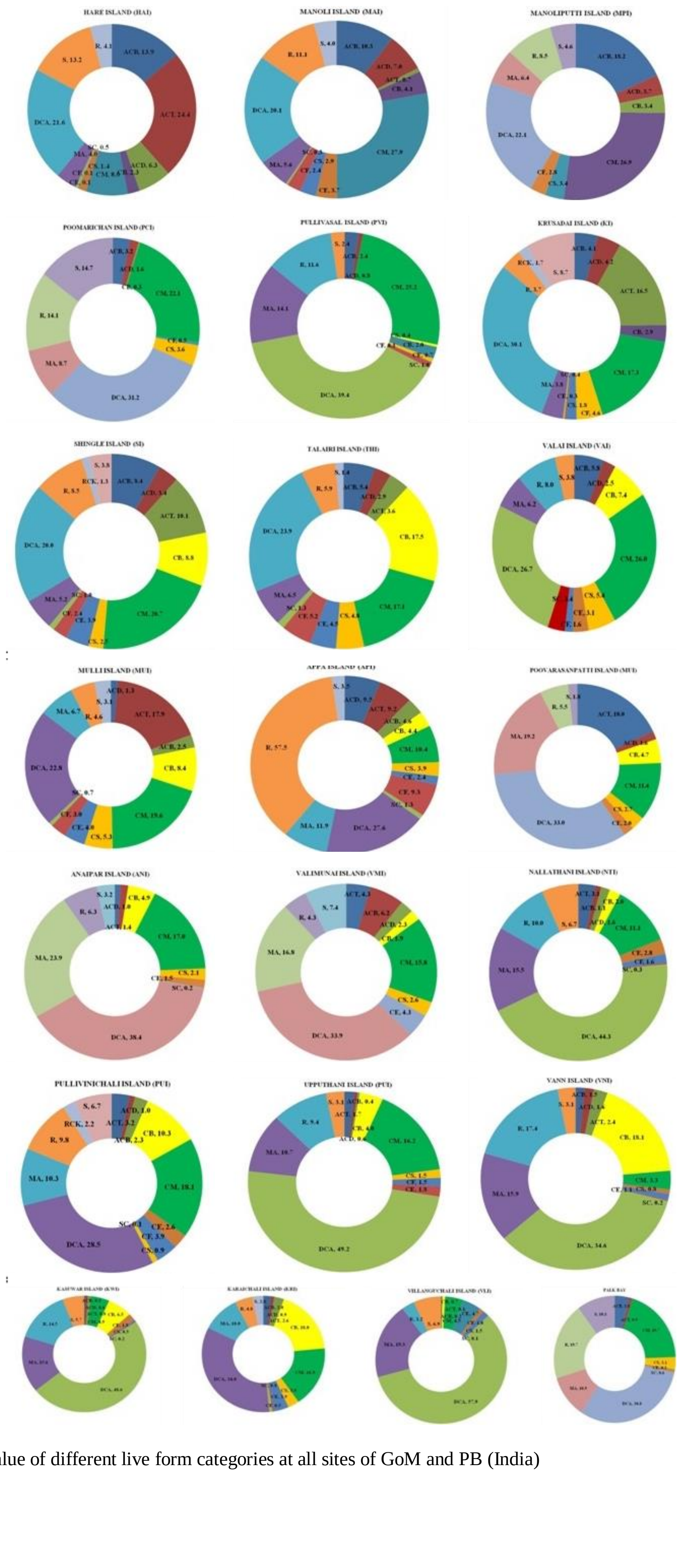


**Figure 4.** Percentage value of different live form categories at all sites of GoM and PB (India)

**Table 1.** Relative abundance and status of corals in GoM and PB (India)

| Hard coral species | RA | Status |
|---|---|---|
| *Acropora digitifera* (Dana, 1846) | 4.07 | C |
| *Acropora muricata* (Dana, 1846) | 5.73 | C |
| *Acropora millepora* (Ehrenberg, 1834) | 0.24 | UC |
| *Acropora gemmifera* (Brook, 1892) | 3.14 | C |
| *Acropora nasuta* (Dana, 1846) | 0.45 | UC |
| *Acropora tenuis* (Dana, 1846) | 1.21 | C |
| *Acropora nobilis* (Dana, 1846) | 0.50 | UC |
| *Acropora cyhterea* (Dana, 1846) | 1.76 | C |
| *Acropora hyacinthus* (Dana, 1846) | 4.19 | C |
| *Acropora humilis* (Dana, 1846) | 0.79 | UC |
| *Acropora microphthalma* (Verrill, 1869) | 0.64 | C |
| *Acropora intermedia* (Brook, 1891) | 0.50 | UC |
| *Acropora abrolhosensis* (Veron, 1985) | 0.98 | UC |
| *Acropora cervicornis* (Lamarck, 1816) | 0.29 | UC |
| *Acropora valenciennesi* (Milne Edwards, 1860) | 0.21 | UC |
| *Acropora valida* (Dana, 1846) | 0.29 | UC |
| *Montipora digitata* (Dana, 1846) | 10.66 | A |
| *Montipora foliosa* (Pallas, 1766) | 2.28 | C |
| *Montipora aequituberculata* (Bernard, 1897) | 1.52 | C |
| *Montipora verrilii* (Vaghan, 1907) | 1.48 | C |
| *Montipora hispida* (Dana, 1846) | 0.45 | UC |
| *Montipora tuberculosa* (Lamarck, 1816) | 0.05 | R |
| *Montipora verrucossa* (Lmarck, 1816) | 0.40 | UC |
| *Montipora* sp. (Unidentified, Blainville 1830) | 0.05 | R |
| *Montipora* sp. (Unidentified, Blainville 1830) | 0.05 | R |
| *Pocillopora damicornis* (Linneaus, 1758) | 3.52 | C |
| *Siderastrea savignyana* (Milne Edwards & Haime, 1850) | 0.05 | R |
| *Goniastrea edwardsi* (Chevalier, 1971) | 0.14 | UC |
| *Goniastrea retiformis* (Lamarck, 1816) | 3.59 | C |
| *Goniastrea pectinata* (Ehrenberg, 1834) | 0.98 | UC |
| *Favites abdita* (Ellis & Solander, 1786) | 0.88 | UC |
| *Favites halicora* (Ehrenberg, 1834) | 3.35 | C |
| *Favites flexuosa* (Dana, 1846) | 0.57 | UC |
| *Favites pentagona* (Esper, 1795) | 0.62 | UC |
| *Favites complanata* (Ehrenberg, 1834) | 0.98 | UC |
| *Favites colemani* (Veron, 2000) | 0.12 | UC |
| *Favites spinosa* (Klunzinger, 1879) | 0.17 | UC |
| *Phymastrea valenciennesi* (Milne Edwards & Haime, 1850) | 0.24 | UC |
| *Dipsastraea favus* (Forskal, 1775) | 3.90 | C |
| *Dipsastraea speciosa* (Dana, 1846) | 1.76 | C |
| *Dipsastraea pallida* (Dana, 1846) | 1.26 | C |
| *Dipsastrae astelligera* (Dana, 1846) | 0.38 | UC |
| *Astreosmilia maxima* (Veron, Pichon &Wijsman-Best 1977) | 0.05 | R |
| *Cyphastrea serailia* (Forskal, 1775) | 0.43 | UC |
| *Cyphastrea microphthalma* (Lamarck, 1816) | 0.38 | UC |
| *Cyphastrea japonica* (Yabe & Sugiyama 1932) | 0.14 | UC |
| *Leptastrea purpurea* (Dana, 1846) | 1.14 | C |
| *Leptastrea transversa* (Klunzinger, 1879) | 0.86 | UC |
| *Merulina ampliata* (Ellis & Solander, 1786) | 0.38 | UC |
| *Platygyra daedalea* (Ellis & Solander, 1786) | 0.05 | R |
| *Platygyra lamellina* (Ehrenberg, 1834) | 0.48 | UC |
| *Platygyra sinensis* (Milne Edwards & Haime, 1849) | 0.29 | UC |
| *Leptoria phrygia* (Ellis & Solander, 1786) | 0.71 | UC |
| *Hydnophora microconos* (Lamarck, 1816) | 2.26 | C |
| *Hydnophora exesa* (Pallas, 1766) | 0.17 | UC |
| *Echinopora lamellosa* (Esper, 1795) | 5.14 | C |
| *Plesiastrea versipora* (Lamarck, 1816) | 0.07 | R |
| *Turbinaria peltata* (Esper, 1794) | 0.95 | UC |
| *Turbinaria mesenterina* (Lmarck, 1816) | 0.88 | UC |
| *Lobophyllia radians* (Milne Edwards and Haime, 1849) | 0.21 | UC |
| *Lobophyllia recta* (Dana, 1846) | 0.71 | UC |
| *Pavona varians* (Verrill, 1846) | 0.19 | UC |
| *Pavona decussata* (Dana, 1846) | 0.76 | UC |
| *Pavona explanulata* (Lamarck, 1816) | 0.07 | R |
| *Pavona duerdeni* (Vaghan, 1907) | 0.45 | UC |
| *Goniopora planulata* (Ehrenberg, 1834) | 0.83 | UC |
| *Goniopora minor* (Crossland, 1952) | 0.69 | UC |
| *Goniopora columna* (Dana, 1846) | 0.05 | R |
| *Porites solida* (Forskal, 1775) | 3.35 | C |
| *Porites lutea* (Milne & Edwards, 1860) | 7.30 | C |
| *Porites lichen* (Dana, 1846) | 0.93 | UC |
| *Porites nodifera* (Klunzinger, 1879) | 0.02 | R |
| *Porites compressa* (Dana, 1846) | 0.43 | UC |
| *Galaxea fascicularis* (Linneaus, 1767) | 1.09 | UC |
| *Galaxea astreata* (Lamarck, 1816) | 0.21 | UC |
| *Lobophytum crassum* (Von Marenzeller, 1886) | 0.14 | UC |
| *Sinularia* sp. (May, 1898) | 1.90 | C |
| *Sarcophyton* sp. (Lesson, 1834) | 0.81 | UC |
| *Lobophytum* sp. (Marenzeller, 1886) | 0.07 | R |

**Table 2.** Species wise data of bleached corals in GoM and PB (India)

| | Number of bleached corals | | | |
|---|---|---|---|---|
| **Species name** | **Mean** | **N** | **SD** | **Variance** |
| *Acropora cytherea* | 12.00 | 2 | .000 | .000 |
| *Acropora digitifera* | 13.00 | 1 | . | . |
| *Acropora muricata* | 36.50 | 6 | 14.829 | 219.900 |
| *Acropora humilis* | 8.00 | 1 | . | . |
| *Acropora hyacinthus* | 24.50 | 6 | 8.712 | 75.900 |
| *Cyphastrea japonica* | 10.00 | 2 | .000 | .000 |
| *Dipsastraea favus* | 22.57 | 8 | 8.284 | 68.619 |
| *Dipsastraea pallida* | 6.00 | 1 | . | . |
| *Dipsastraea speciosa* | 15.86 | 7 | 4.413 | 19.476 |
| *Favites abdita* | 6.00 | 2 | 1.414 | 2.000 |
| *Favites complanata* | 14.20 | 5 | 4.970 | 24.700 |
| *Favites flexuosa* | 6.00 | 2 | 5.657 | 32.000 |
| *Favites halicora* | 16.25 | 8 | 7.942 | 63.071 |
| *Goniastrea pectinata* | 6.67 | 3 | 4.163 | 17.333 |
| *Goniastrea retiformis* | 15.33 | 6 | 4.676 | 21.867 |
| *Hydnophora exesa* | 4.00 | 2 | 2.828 | 8.000 |
| *Leptastrea purpurea* | 5.00 | 2 | 2.828 | 8.000 |
| *Leptastrea transversa* | 3.00 | 1 | . | . |
| *Montipora aequituberculata* | 6.50 | 4 | 5.066 | 25.667 |
| *Montipora digitata* | 54.33 | 3 | 34.933 | 1220.333 |
| *Montiporafoliosa* | 14.25 | 4 | 5.909 | 34.917 |
| *Montipora verrucosa* | 5.00 | 1 | . | . |
| *Merulina ampliata* | 4.67 | 3 | 2.309 | 5.333 |
| *Montipora sp.* | 4.00 | 1 | . | . |
| *Porites lichen* | 18.00 | 1 | . | . |
| *Porites lutea* | 46.56 | 9 | 26.703 | 713.028 |
| *Porites solida* | 27.80 | 5 | 25.084 | 629.200 |
| *Platygyra daedalea* | 13.00 | 2 | 8.485 | 72.000 |
| *Platygyra lamellina* | 6.75 | 4 | 3.500 | 12.250 |
| *Plesiastrea versipora* | 3.00 | 1 | . | . |
| *Pocillopora damicornis* | 17.50 | 4 | 4.655 | 21.667 |
| *Turbinaria mesenterina* | 3.00 | 1 | . | . |
| *Turbinaria peltata* | 9.00 | 6 | 2.828 | 8.000 |
| Total | 18.34 | 116 | 17.158 | 294.402 |

**Table 3.** Descriptive statistics of different reef threats found in GoM (India)

| Study area | | Sedimentation | Coral disease | Algal proliferation | Animal invasion | Ghost nets | Anchor damage |
|---|---|---|---|---|---|---|---|
| Keezhakarai | Mean | 2.00 | 3.83 | 13.77 | 2.70 | 1.63 | 0.73 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| | SD | 1.819 | 2.306 | 4.166 | 2.120 | 1.426 | 0.785 |
| | SE of Mean | 0.332 | 0.421 | 0.761 | 0.387 | 0.260 | 0.143 |
| | Kurtosis | -0.875 | 0.567 | -0.073 | -0.238 | -0.710 | -1.153 |
| | Skewness | 0.405 | 0.163 | 0.345 | 0.377 | 0.323 | 0.524 |
| | Variance | 3.310 | 5.316 | 17.357 | 4.493 | 2.033 | 0.616 |
| Mandapam | Mean | 11.67 | 5.03 | 8.47 | 1.50 | 0.77 | 0.97 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| | SD | 3.962 | 2.684 | 4.091 | 1.280 | 1.006 | 1.159 |
| | SE of Mean | 0.723 | 0.490 | 0.747 | 0.234 | 0.184 | 0.212 |
| | Kurtosis | -0.120 | -0.142 | 0.614 | 0.171 | 1.988 | -1.215 |
| | Skewness | 0.586 | -0.107 | 0.270 | 0.529 | 1.375 | 0.638 |
| | Variance | 15.698 | 7.206 | 16.740 | 1.638 | 1.013 | 1.344 |
| Tuticorin | Mean | 14.33 | 5.17 | 13.07 | 3.03 | 1.10 | 1.10 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| | SD | 3.871 | 2.291 | 4.315 | 2.092 | 1.094 | 0.960 |
| | SE of Mean | 0.707 | 0.418 | 0.788 | 0.382 | 0.200 | 0.175 |
| | Kurtosis | -0.291 | -0.381 | 0.857 | -0.530 | 0.144 | -1.005 |
| | Skewness | 0.355 | -0.348 | 0.810 | 0.292 | 0.806 | 0.291 |
| | Variance | 14.989 | 5.247 | 18.616 | 4.378 | 1.197 | 0.921 |
| Vembar | Mean | 12.83 | 2.13 | 3.70 | 1.37 | 0.67 | 0.70 |
| | N | 30 | 30 | 30 | 30 | 30 | 30 |
| | SD | 4.735 | 1.676 | 2.322 | 1.326 | 0.802 | 0.794 |
| | SE of Mean | 0.864 | 0.306 | 0.424 | 0.242 | 0.146 | 0.145 |
| | Kurtosis | -0.684 | -1.287 | 0.817 | -1.030 | -1.062 | -1.120 |
| | Skewness | 0.078 | 0.058 | 0.409 | 0.404 | 0.700 | 0.610 |
| | Variance | 22.420 | 2.809 | 5.390 | 1.757 | 0.644 | 0.631 |
| Total | Mean | 10.21 | 4.04 | 9.75 | 2.15 | 1.04 | 0.88 |
| | N | 120 | 120 | 120 | 120 | 120 | 120 |
| | SD | 6.108 | 2.552 | 5.536 | 1.877 | 1.155 | 0.940 |
| | SE of Mean | 0.558 | 0.233 | 0.505 | 0.171 | 0.105 | 0.086 |
| | Kurtosis | -0.889 | -0.437 | -0.349 | 0.213 | 0.362 | -0.818 |
| | Skewness | -0.071 | 0.169 | 0.309 | 0.732 | 0.949 | 0.624 |
| | Variance | 37.302 | 6.511 | 30.643 | 3.524 | 1.334 | 0.883 |

The physicochemical parameters of water were also measured to monitor water quality changes through time in GoM. Dissolved oxygen, temperature, salinity, and pH have ranged between 5.70-7.20 mg/L, 28.80-33.00°C, 34.00-37.80 mg/L and 6.8-8.20, respectively. Among water quality parameters, Sea Surface Temperature (SST) was found to be higher (33.40-36.00°C) than the average temperature (30.0°C) from March 2019 to May 2019 (Table 3). The increased sea surface temperature during summer led to coral bleaching in GoM and PB. Regression analysis revealed that no other parameters influence the increase or decrease of coral cover except sea surface temperature. SST positively correlates with the bleached coral cover during environmental stress (Figure 7).

**Bleaching severity**

Bleaching assessment in GoM and PB revealed species and site-specific bleaching patterns in corals, where branching corals displayed adaptive resistance to bleaching, while massive corals were highly affected (Tables 2 and 3). A total of 2,128 individuals belonging to 33 species of hard corals have been documented as bleached in GoM and PB regions. A species-wise assessment revealed that massive corals were completely bleached, of which *P. lutea* was 46.56±26.70%, *P. solida* 27.80±25.08%, *D. favus* 22.57±±8.28% and *F. halicora* 16.25±7.94 (Table 3). Among the branching corals, *M. digitata* (54.33±34.93%) was bleached maximum, followed by *A. muricata* 36.50±14.82% and *A. hyacinthus* 24.50±8.71%. Bleaching of other coral species ranged between 3-18% in both GoM and PB. Cumulative occurrence on the number of bleached corals revealed that Tuticorin Island (30.44±26.06%) and PB (26.07±21.89%) have the highest affected region among all the study sites. In contrast, the coral colonies in Mandapam, Keezhakarai, and Vembar are moderately bleached. Based on the pattern of distribution on the number of bleached corals, Mandapam, Tuticorin and PB have the highest distribution value to measure the intensity of bleaching during the study (Figure 5). Present study also recorded the unconditional distribution of completely bleached corals (CB) and partially bleached corals (PB) to understand the effect of bleaching on corals (Figure 6). Mean value of completely bleached corals (23.79±18.96) are higher than that of partially bleached corals (8.39±4.92). Histogram plot of descriptive statistics value showed a higher occurrence of completely bleached corals than partially bleached corals (Figure 6). There is no sign of coral mortality due to bleaching observed during the survey. But regular monitoring is underway to check the prevalence of bleaching and changes in SST. Water quality parameters highly influence the responsive variable called bleaching vulnerability ($R^2$=0.918). ANOVA results revealed that the bleaching vulnerability is significantly different (F-36.224, P<0.001) from the predicted variables. Regression analysis curve concluded that pH (t= -2.396, P=0.032, $R^2$=0.306) and salinity (t=1.101, P=0.291, $R^2$=0.086) are weakly correlated to the occurrence of bleaching in coral colonies, whereas SST (t=7.570, P<0.001, $R^2$=0.815) is strongly correlated to the bleaching vulnerability (Figure 7). Average SST was varied from 29.40°C in January 2019 to 34.60°C in May 2019, which indicated that average SST rises 5°C more than the optimum temperature (23°-29°C) required for coral survival. In 2020, SST (35.40°C) remained 1°C higher in May than in 2019, which induced the bleaching severity up to 85% in PB and 46.20% in GoM. Among coral species, *M. digitata*, *A. muricata*, *P. solida*, *P. lutea*, *D. favus*, *D. speciosa*, *F. halicora*, *Favites complanata*, *Goniastrea retiformis*, and *Sinularia* sp. were completely bleached at all islands (Figure 8).

**Threats to the reefs**

The present study documented six categories of threats (sedimentation, coral disease, algal proliferation, animal invasion, ghost nets, and anchor damage) from GoM reefs. Sedimentation (10.21±6.10) and algal proliferation (9.75±5.53) were the most dominant threats to the reefs of GoM. The average frequency of algal proliferation in Keezhakarai (13.77±4.16) and Tuticorin (13.07±4.31) were found to be higher than that of the Mandapam and Vembar group of islands (Table 3). Reefs damaged by sedimentation were found to be higher in Tuticorin (14.33±3.87), followed by Vembar (12.83±4.75), Mandapam (11.67±3.96), and Keezhakarai (2.00±1.81) group of islands. Threats such as animal invasion, ghost nets, and anchor damage were found to have occurred in the least number than sedimentation, algal proliferation, and coral disease (Table 3). F-test results revealed that reefs damaged by boat anchors (F=1.250, P=0.295, >0.05) do not significantly distribute within the study area, while other threats are significantly distributed within the study area (Table 4).

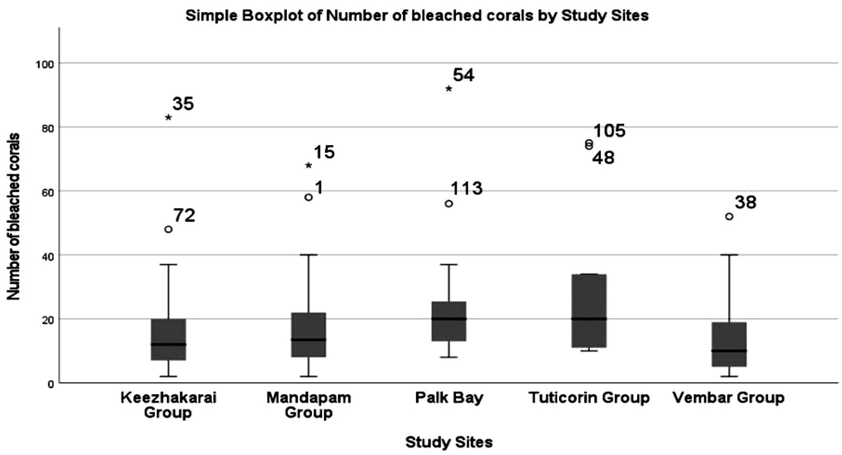


**Figure 5.** Box-plot diagram showed the number of bleached corals correspondence to study sites

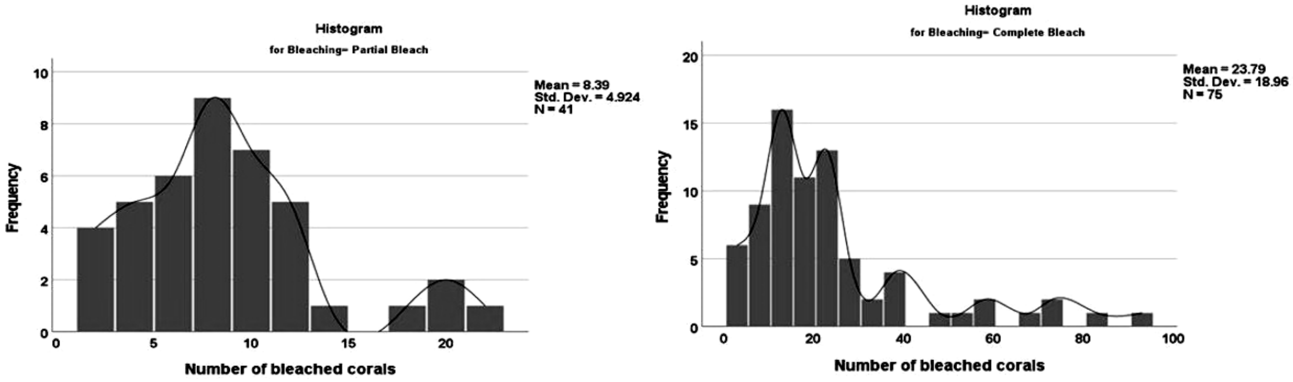


**Figure 6.** Histogram showing the details of partial and bleached coral status during the study

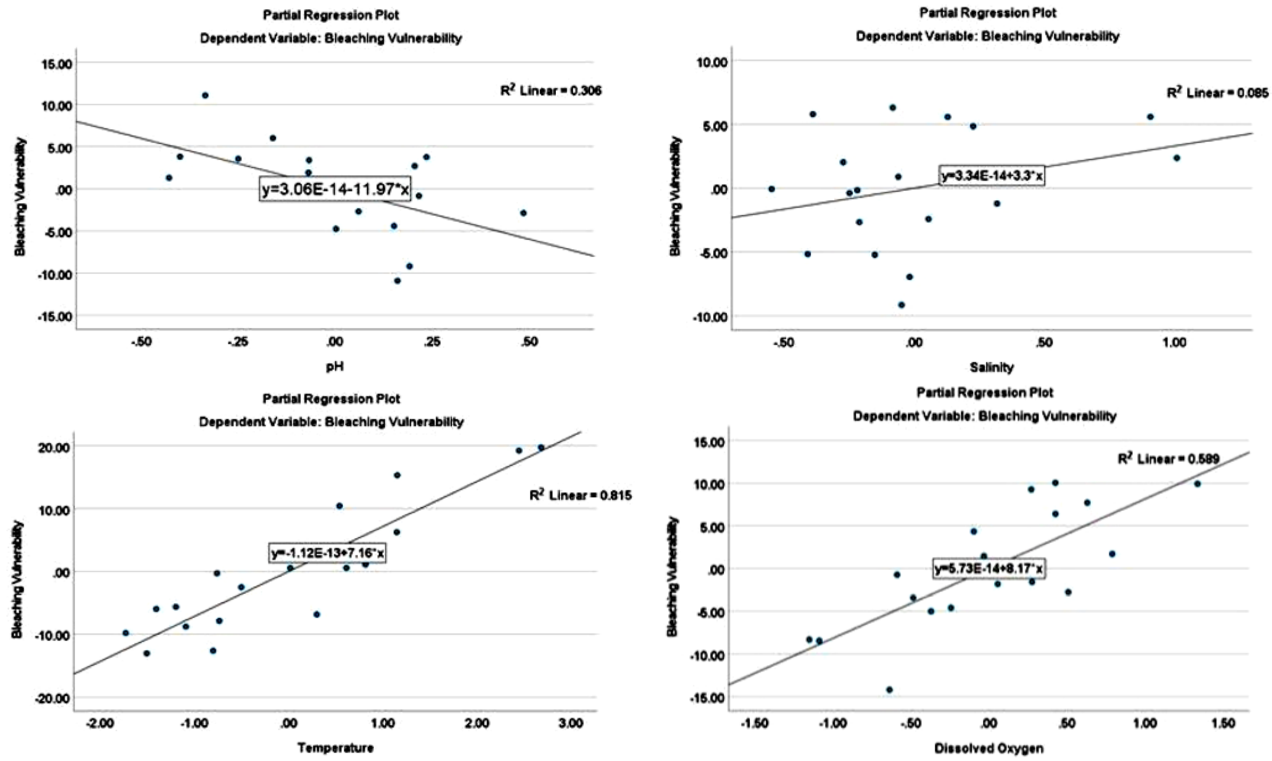


**Figure 7.** Linear regression analysis of bleaching severity (Dependent variables) with WQ parameters (Independent variables)

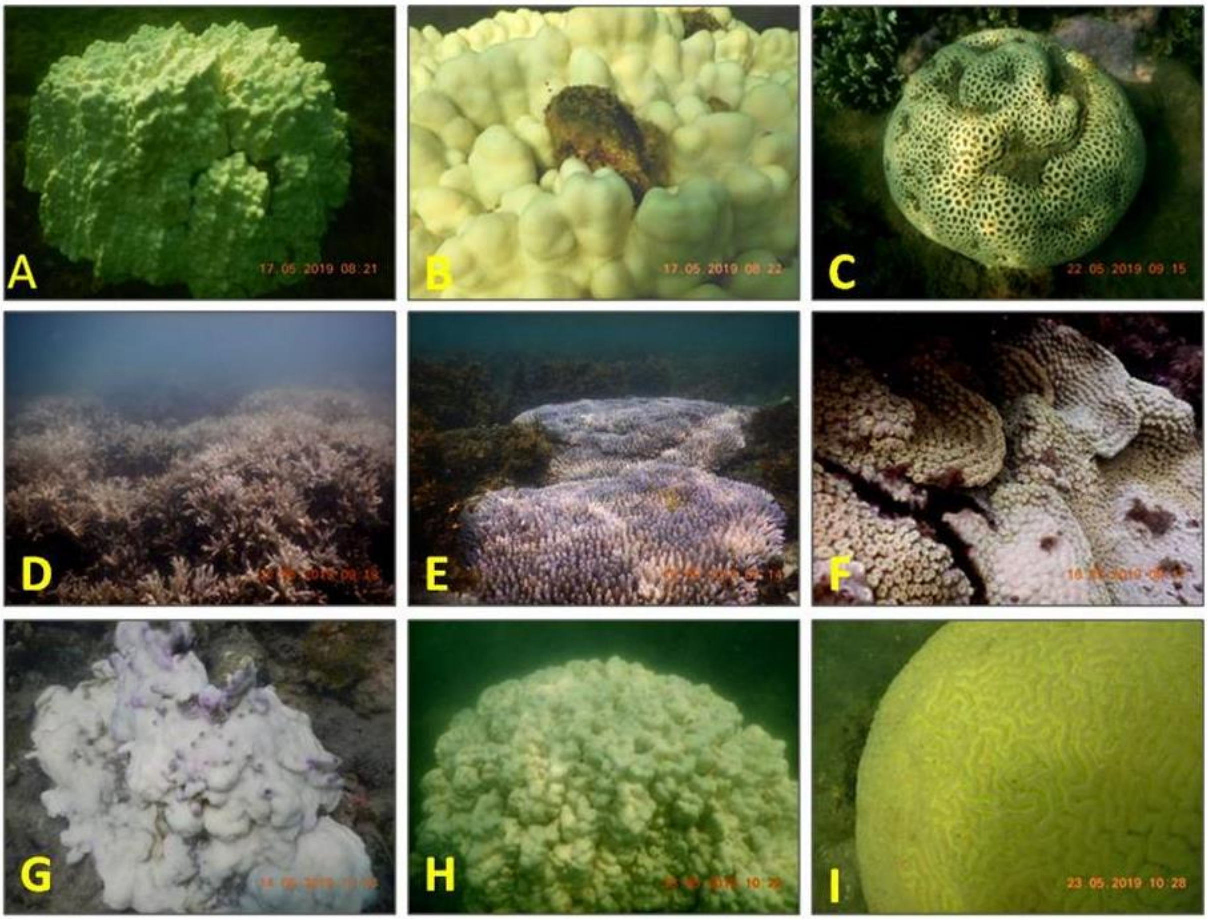


**Figure 8.** Bleaching in coral species – A-B Massive corals (*Porites* sp.) in PB; C-D. *Goniastrea* sp. in Tuticorin group; *Montipora digitata* reef in Tutitcorin group; *E. Acropora* reef in Keezhakarai group; F. *Turbinariapeltata* in Keezhakarai group; G-H. *Porites lichen* and *Porites lutea* in Mandapam group; I. *Leptoria Phrygia* in Vembar group

The normality distribution of different threats at islands of GoM has also been represented by the Boxplot diagrams, which showed a normal and symmetrical distribution of sedimentation and coral disease threats to the reefs. Algal proliferations were found to be extremely distributed, whereas animal invasion, ghost nets, and anchor damage were weakly distributed to the islands of GoM (Figure 9).

## Discussion

This study documented some important reef health details of the coral communities, the relative abundance of coral species, the bleaching status of corals, and threats to the reefs that exist in GoM and PB. Coral reefs are fragile and highly virulent to natural and anthropogenic disturbances, including climate change, sedimentation, destructive fishing, shoreline operations, and tangling ghost nets (Krishnan et al. 2018). Therefore, community structure is highly variant through time; hence, the percentage of live coral coverage also significantly varied compared to the earlier data of 2001 and 2015 (Shanmugaraj et al. 2013; ENVIS 2015). Based on the statistical data, it is inferred that non-Acropora corals (massive corals, foliose corals, sub-massive and branching non-Acropora) are more abundant than Acropora branching corals (Figure 4). Only in the Mandapam group of Island *Acropora hyacynthes, Acropora digitifera, Acropora gemmifera,* and *A. muricata* commonly distributed and abundant. Detail live form categories are recorded from each island of GoM and sites of PB during the reef monitoring. Earlier studies reported that live coral coverage in the reef of GoM increased from 25.30±8.43% in 2000 to 36.98±13.12% in 2005, 42.85±10.74% in 2009, and 37.31±10.38% in 2012 (Edward et al. 2012), whereas present study reported 39.55±15.45%. In PB, the percentage of live coral coverage increased from 9.89±8.73% in 2010 to 5.82±8.43% in 2013 (Venkataraman and Rajan 2013; Azzez et al. 2016) to 28.40±14.60% in the current study. These data are the key factor in defining this ecosystem's coral reef resilience, which is highly influenced by resistant coral species, coral diversity, herbivore biomass, coral disease, and macroalgae cover (McClanahan et al. 2012; Maynard et al. 2015). Within a limited time of massive natural stress, species abundance also responds to changes in habitat variation, distribution pattern, and species interaction (Karlson et al. 2004, 2007; Done et al. 2015). In the present study, we reported 79 species of corals from August 2018 to August 2020, while 117 coral species were documented from GoM (ENVIS, 2015). The occurrence of abundant species in the reefs of GoM is found for *M. digitata* (Table 1), which might be due to space competition.

Among the physicochemical parameters, low pH or increased $CO_2$ and Sea surface temperature (SST) are the important factors affecting corals' community structure. Accumulation of huge amount of $CO_2$ can lower the pH (<7.0) in marine water, which in turn reduce the growth, physical integrity, and calcification ability of marine invertebrates like corals and foraminifera (Kroeker et al. 2013; Guinotte and Fabry 2008). In the present study, pH varied between 6.80 and 8.20, which found well-maintained water quality in GoM and PB. However, due to rainfall, the pH levels become lower than 7 during July 2019. Therefore, SST is one of the intrinsic factors affecting the reef environment severely.

**Table 4.** ANOVA result of different threats observed in GoM, India

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Sedimentation * Study Area | Between Groups (Combined) | 2802.876 | 3 | 934.292 | 66.243 | 0.000 |
| | Within Groups | 1636.072 | 116 | 14.104 | | |
| | Total | 4438.948 | 119 | | | |
| Coral DIsease * Study Area | Between Groups (Combined) | 178.025 | 3 | 59.342 | 11.535 | 0.000 |
| | Within Groups | 596.767 | 116 | 5.145 | | |
| | Total | 774.792 | 119 | | | |
| Algal Proliferation * Study Area | Between Groups (Combined) | 1961.500 | 3 | 653.833 | 45.012 | 0.000 |
| | Within Groups | 1685.000 | 116 | 14.526 | | |
| | Total | 3646.500 | 119 | | | |
| Animal invasion * Study Area | Between Groups (Combined) | 63.567 | 3 | 21.189 | 6.909 | 0.000 |
| | Within Groups | 355.733 | 116 | 3.067 | | |
| | Total | 419.300 | 119 | | | |
| Ghost Nets * Study Area | Between Groups (Combined) | 17.092 | 3 | 5.697 | 4.664 | 0.004 |
| | Within Groups | 141.700 | 116 | 1.222 | | |
| | Total | 158.792 | 119 | | | |
| Anchor damage * Study Area | Between Groups (Combined) | 3.292 | 3 | 1.097 | 1.250 | 0.295 |
| | Within Groups | 101.833 | 116 | 0.878 | | |
| | Total | 105.125 | 119 | | | |

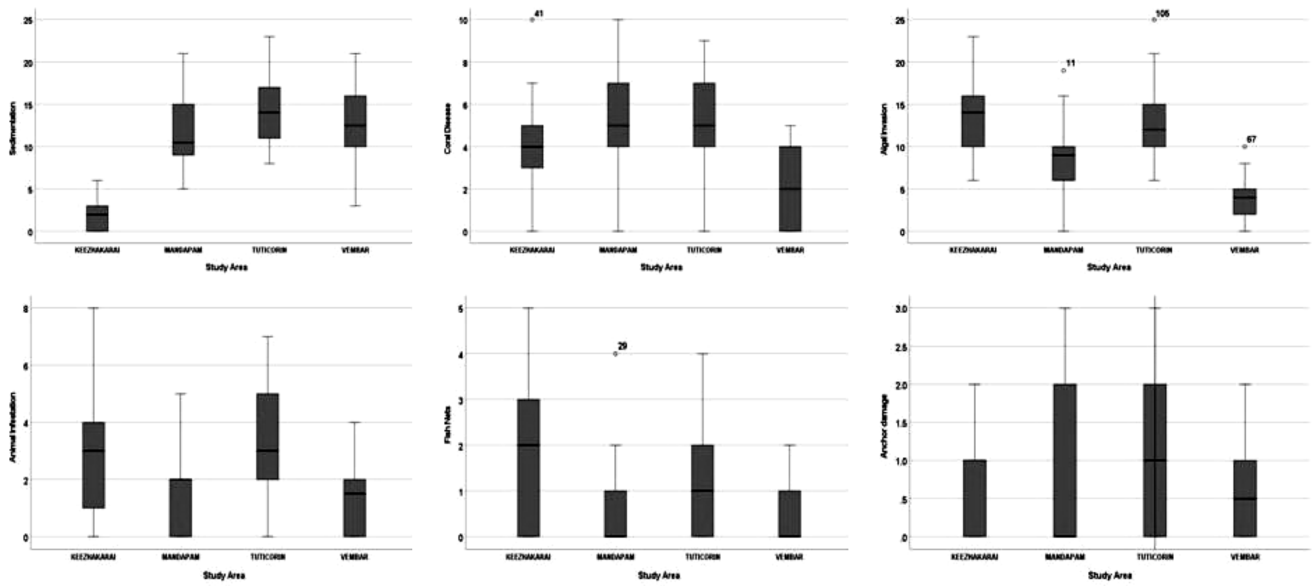


**Figure 9.** Box-Whisker analysis showing the status of each threat assessed in different sites of GoM and PB, India

The ocean temperature in the Indo-Pacific region is crossing the bleaching threshold quickly during the summer due to global warming (Hughes et al. 2017). As per the report of IPCC, the warming of coral reef waters in general increased globally (0.10-0.12 °C/decade, 1971-2010) and regionally (0.02-0.13 °C/decade, 1950-2009) (Hartmann et al. 2013; Rhein et al. 2013). For the last 24 years, GoM documented a thermal threshold of 30.23±0.39 and a bleaching threshold of 30.73 (Arora et al. 2010), indicating the vulnerability of corals to the bleaching threshold. The coral bleaching phenomenon has declined global coral reef status by 30%, and 60% 0f the remaining corals could be damaged by 2030 (Camp et al. 2018). This thermal-induced coral bleaching during 2014 and 2016 in the Indian and other tropical regions surpassed the previous bleaching event in intensity and duration (Oliver et al. 2018). In the present study, SST ranges between 29.00°C-35.80°C during January and May, causing severe coral bleaching during summer (Figure 7). During 2016 coral bleaching, the temperature ranged between 30°C-34°C which caused 71.48% of corals to bleach in PB and 46.04% of coral bleached in GoM (Krishnan et al. 2018). However, a similar result was found in the present study, where the Tuticorin group of Islands represents a high number of bleached corals than other areas of GoM, followed by PB (Figure 5). Earlier studies documented that branching corals were more tolerant to increased SST than massive corals, which is a sign of prolonging adaptive bleaching patterns found in GoM (Krishnan et al. 2018; Ramesh et al. 2020). In the current study, species-specific evaluation of bleaching revealed the same pattern of bleaching in which massive corals such as *P. lutea*, *P. solida*, *D. favus*, *D. speciosa*, *F. halicora* are bleached intensively, whereas, bleaching among branching corals limited mainly to *A. muricata*, *A. hyacinthus*, and *M. digitata*. During 2019-2020, there was no report of mass bleaching events from global coral reef data, which could be predicted that this bleaching was at a local level and can be mentioned as an annual phenomenon for GoM and PB. The species-specific bleaching pattern might be developed from the condition to past exposure to acute or chronic thermal stress on coral species. Different coral species have distinct abilities to respond to increased thermal stress through their symbionts *Symbiodinium* spp. (ENVIS 2015; Guest et al. 2016). Coral reef species have diverse Symbiodinium clade (Genetic variation) that brings coral resistance to the host corals (Guest et al. 2016). Therefore, in GoM and PB, it can be assumed that branching corals may have adapted with a more resistant clade of *Symbiodinium* than massive corals. Other encrusting coral species, *Hydnophora* sp., *Lobophyllia* sp., *Leptastrea* sp., and *Platygyra* sp. were partially bleached and may recover soon from this local bleaching event.

Threats to the coral reefs of GoM and PB are prevalent. Earlier studies documented reefs are highly disturbed by sedimentation, coral mining, macroalgal proliferation, coral disease, destructive fishing, and domestic sewage (Edward et al. 2012; George and Jasmine 2015). The present study investigated six categories of more acute threats in recent times: sedimentation, coral disease, macroalgal proliferation, animal invasion, ghost nets, and anchor damage (Table 3). Among the six categories of threats, macroalgal proliferation is abundant at all the sites of GoM, which could be considered the potential competitor to the reef-building corals, whereas sedimentation is found prevalent in the Mandapam and Tuticorin group of islands (Table 3). Though several earlier studies reported a high proliferation of macroalgae *Kappaphycus alvarezii* causes severe damage to the reefs of GoM and PB, the current study doesn't reveal any trace of these macroalgae in GoM (Mandal et al. 2010; Kamalakannan et al. 2014; Edward et al. 2015). Earlier studies also documented that the macroalgal genus *Caulerpa* sp. and *Turbinaria* sp. were the most dominant species at the reef of GoM (Manikandan and Ravindran 2017; Ramesh et al. 2019b). However, the present study recorded that *Caulerpa taxifolia, C. racemosa, Ulva reticulata, Padina gymnospora, Turbinaria* sp., *Sargassum* sp., and *Halimeda* sp. were found to be the most abundant in the GoM reefs (Figure 10).

The abundance of macroalgae reduces the chance of post-larval settlement of the coral species and also replace the live reef to macroalgae dominated reef. The coral disease was also found abundant in Mandapam and Tuticorin groups which were assumed to be spread faster after the macroalgal proliferation and frequent bleaching events (Figure 9). Pink line disease, Pink spot disease, Black band, and white band disease have been recorded from the reef of GoM (Ramesh et al. 2019a). The animal invasion has also recently been an increasing threat to the reefs of GoM (Thangaradjou et al. 2016; Raj et al. 2018). The present study recorded a higher occurrence of animal invasion in the Tuticorin and Keezhakarai group of Islands than in another region of GoM (Table 3). Another two stress factors that affect the reefs are ghost nets and anchor damage which is entirely raised by anthropogenic disturbances from the local fishermen communities. The fisher communities of GoM are characterized by low literacy rates, lack of awareness of environmental issues, and low income to take up livelihood options other than fishing. Therefore, fishers often forcefully involve themselves in more effective but illegal, destructive, and unsustainable fishing practices (Edward et al. 2007). The present study depicted that the consequences of these two factors are minimal, and possible mitigation could improve the health of the reefs. Coral colonies of the Keezhakarai group of islands are frequently disturbed (Figure 9) by the entangling of ghost nets and by the boat anchor, which breaks the big coral colonies while fishermen anchor the boat near the reef for fishing. Based on the investigations by the current study, it is inferred that corals in GoM are heading toward destruction by increased stress factors of algal assemblages, coral disease, and animal invasion.


**Figure 10.** Field observation on threats to coral reefs: A-B: Algal growth on live corals; C-D: Sedimentation slowly kills the corals; E: Coral disease (Pink line disease); F. Fishing gears retarded the growth of young coral colonies

Health monitoring studies of reef-building corals in GoM and PB revealed that only increased live coral cover could not improve the overall health of the reefs. It is a complex ecosystem; thus, controlling coral disease and macroalgal proliferation could improve the macrozoobenthic diversity in the islands. Thus, the substrate becomes resourceful by accumulating more reef fish in GoM and PB. Natural threats such as bleaching become a frequent phenomenon in GoM, which influence the additional threats to the reefs, such as Macroalgal proliferation and coral disease. The bleaching resistance capacity of *Acropora* sp. could be an advantage in targeting the coral recovery process as an alternative management program. Coral transplantation of *Acropora* sp. can also improve the natural recruitment process in degraded reef areas. NCCR has already initiated a coral reef restoration program in the Mandapam group of islands. Despite all such remedial actions taken up by management interventions, the future of coral reefs critically depends on their ability to respond to the rapid environmental changes with new adaptive strategies.

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# New record of the Armored Gurnard *Satyrichthys laticeps* (Schlegel, 1852) (Scorpaeniformes: Peristediidae) from Java South Sea (Eastern Indian Ocean)

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Manuscript received: 18 November 2022. Revision accepted: 1 December 2022.

**Abstract.** *Andeimida A, Wiadnya DGR, Hardiyan FZ. 2022. New record of* Satyrichthys laticeps *(Schlegel, 1852) (Scorpaeniformes: Peristediidae) from Java South Sea (Eastern Indian Ocean). Indo Pac J Ocean Life 6: 74-79.* Armored gurnard *Satyrichthys laticeps* (Schlegel, 1852) was originally described by H. Schlegel in 1852 based on a specimen collected by E. A. Forsten from Ambon. *S. laticeps* belongs to the family Peristediidae and is known to be the fourth oldest persitediid fish ever described after *Peristedion cataphractum* (Linnaeus, 1758), *P. orientale* Temminck & Schlegel, 1843, and *S. moluccensis* (Bleeker, 1850). *S. laticeps* is known to have a wide distribution in temperate and tropical Indo-Pacific, but its records in Indonesian waters are still very limited. So far, only three recorded specimens of *S. laticeps* have been collected from Indonesian waters. A single *Satyrichthys* specimen was collected from a market vendor at Pondokdadap Fishing port in November 2022 and preserved under the PDD 2211-01 (341 mm SL) label. Based on its morphometrical characteristics and measurements, the specimen of *Satyrichthys* found in Pondokdadap was characterized as *S. laticeps* by examining the possession of the antrorse spines on the caudal peduncle, four lip barbels, and two chin barbels on each side of the head, asymmetrical parietal bones, and no distinct markings on the dorsal fin. This study provides a new record of *S. laticeps* existence in the Java South Sea after a single specimen was collected from off the south coast of Java and Bali, Indonesia (BMNH 1987.1.23.73, 291 mm SL) in 1987.

**Keywords:** Eastern Indian Ocean, Java south sea, a new record, Peristediidae, *Satyrichthys*

## INTRODUCTION

The armored gurnard genus *Satyrichthys* can be separated from its relatives by the absence of teeth on the upper jaw, a long preopercular spine that visible from dorsal view, smooth lateral side of the head, and soft fin rays of dorsal and anal fin that fewer than twenty (Carpenter and Niem 1999; Kawai 2008). There are currently seven recognized species of *Satyrichthys*, which are; *Satyrichthys rieffeli* (Kaup, 1859), *S. moluccensis* (Bleeker, 1850), *S. laticeps* (Schlegel, 1852), *S. welchi* (Herre, 1925), *S. clavilapis* Fowler, 1938, *S. longiceps* (Fowler, 1943), and the recently described *S. milleri* Kawai, 2013 (Kawai, 2013; Higuchi and Kawai 2020). Six of seven extant species from the *Satyrichthys* genus are recorded to inhabit Indonesian Waters, except for *S. welchi* that has never been recorded from Indonesian Waters (Kawai 2013).

*Satyrichthys laticeps* was described as *Peristedion laticeps* by Schlegel (1852) based on a specimen collected by Forsten at Ambon Island (van Oijen et al. 2013). *S. laticeps* is among the earliest member of peristediid fishes that have been described, after the *Peristedion cataphractum* (Linnaeus, 1758), which was originally described as *Trigla cataphracta* Linn. *P. orientale* Temminck & Schlegel, 1843, and *S. moluccensis* (Bleeker, 1850), making it the fourth oldest peristediid fishes ever recorded by the date of the first description of the species (Schlegel 1852; van Oijen et al. 2013). *S. laticeps* is a deep sea species known to inhabit temperate and tropical waters with depths of 58–300 m (Kawai 2013). It also has the most widespread distribution in Indo-Pacific, which is present in both the Indian and Pacific Oceans (Kawai 2013; Pogoreutz et al. 2014; Kawai et al. 2017). However, the information on the distribution of most peristediid fishes is very limited and poorly understood (Pogoreutz et al. 2013). Currently, a total of 53 *S. laticeps* specimens have been recorded. Three originate from Indonesian Waters, two from Ambon, and one from off the south coast of Java and Bali (Kawai 2013). Additionally, a study conducted on the deep sea of West Java has successfully recorded another *Satyrichthys* species, namely *S. clavilapis* and *S. moluccensis*, in Indonesian Waters (Ho et al. 2021).

The information on the deep sea fishes that inhabit below 200 m in depth is still very limited, whereas the deep sea off southern Java is presumed to have a high diversity of marine deep-sea fishes (Ho et al. 2021). The most recent survey on the deep-sea fishes community in South Java (Eastern Indian Ocean) is the South Java Deep-Sea (SJADES) Biodiversity Expedition that was conducted in 2018 by a joint team of researchers from Indonesia and Singapore that successfully describes 222 species from 54 families (Ho et al. 2021). These records also include two recently described species, *Platygobiopsis hadiatyae* and

*Chelidoperca favolineata* (Matsunuma et al. 2019; Larson et al. 2020). Deep sea surveys increasingly provide valuable data on representing the deep-sea fish community, but their main challenges are the high cost and effort incurred in every survey and collection (Shao et al. 2014). However, the marine fish diversity information collected from the fish markets is mostly overlooked (Situ & Sadovy 2004). In Indonesia, several taxonomical breakthroughs have originated from fish market surveys, from the discovery of *Latimeria menadoensis* Pouyaud et al. 1999 in Sulawesi to the discovery of two new species of shovelnose sharks *Rhinobatos jimbaranensis* Last et al. 2006 and *R. penggali* Last et al. 2006 from Bali, all originated from specimens collected from the fish market (Wirjoatmodjo & Tjakrawidjaja 2002; Last et al. 2006). The Indonesian part of the Eastern Indian Ocean, which borders the islands of Java, Bali, and Nusa Tenggara, is known to have a very high concentration of fishing ports which falls under the Indonesian Fisheries Management Zone (id: Wilayah Pengelolaan Perikanan/WPP) number 573 and is known to have a high diversity of marine fishes species, including the deep-sea fishes (White et al. 2013).

This study reports a new record of *S. laticeps* based on one specimen collected from the Pondokdadap fishing port market in South Malang. However, this species is known to inhabit Indonesian Waters, and the detailed distribution of this species is very little known. Therefore, the specimen found in this study represents a new confirmed record of *Satyrichthys laticeps* from Java South Sea, Eastern Indian Ocean.

## MATERIALS AND METHODS

Pondokdadap fishing port is administratively located in Dusun Sendang Biru, Desa Tambakrejo, Kecamatan Sumbermanjing Wetan, Malang, East Java Province, Indonesia (Dwiyanto et al. 2019). The geographical position of Pondokdadap fishing port is 8°26'02.1 "S 112°40'56.6 "E. Pondokdadap fishing port is one of the most important tuna fishing bases in Java South Sea (Budianto et al. 2021). The majority of the fishing vessels of Pondokdadap fishing port operate at more than 12 nautical miles, with the dominant catch composed mainly of the Scombridae family with a small portion of fish from Coryphaenidae, Istiophoridae, Xiphiidae, and Carangidae, and occasional bycatch from Gempylidae, Lampridae, Molidae, and Mobulidae family (Wiadnya et al. 2019; Budianto et al. 2021).

The specimen of *Satyrichthys* sp. was collected opportunistically from a market vendor at Pondokdadap fishing port's fish market in November 2022. The exact origin of the specimen is uncertain, but the fishermen that caught the fish stated the fish caught on less than twelve miles offshore from Pondokdadap fishing port. A single specimen was temporarily preserved in the freezer and deposited at the Pondokdadap fishing port's office, labeled as PDD 2211-01. The morphometric measurements and counts of the specimen were made following Kawai (2013). All the measurements are measured using metal caliper and reported as a percentage of standard length (%SL), while the standard length is stated in millimeters. The morphological description of the specimen was in agreement with the morphological characteristics of *Satyrichthys* following Kawai (2008), who stated that the defining features consist of: No teeth on the upper jaw; lateral margin (side) of head smooth; rear scutes of lower lateral rows of bony plates are separated; only the rearmost lip and chin barbels are branched (chin barbels absent in some species), and the dorsal and anal fin has fewer than 20 soft rays.

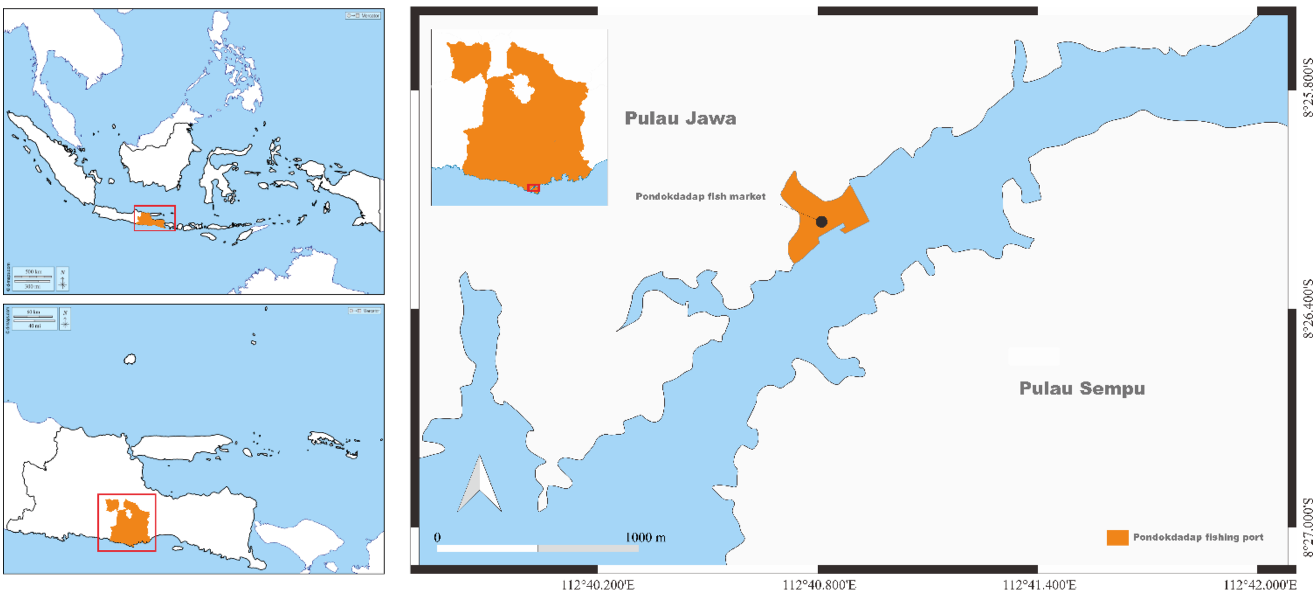


**Figure 1**. Location of Pondokdadap fishing port, pinpointing the location where the *Satyrichthys* sp. specimen was found

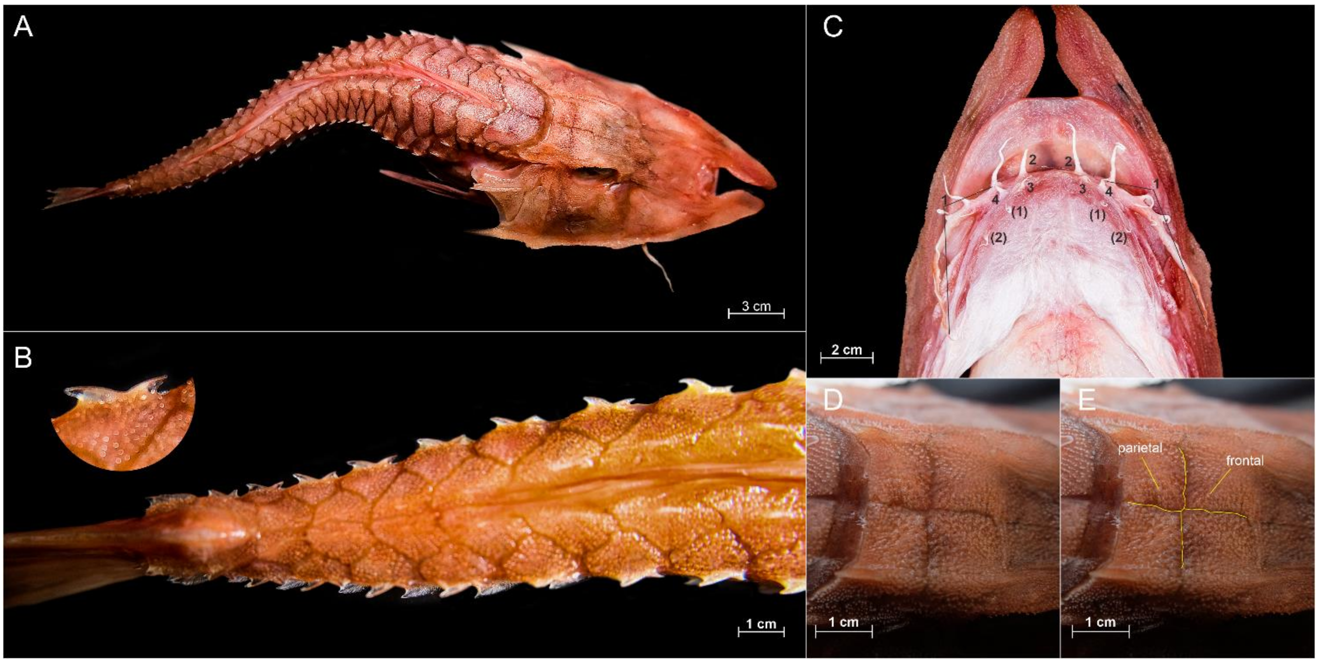


**Figure 2.** Dorsal view of the specimen *Satyrichthys laticeps* PDD 2211-01 (A), caudal peduncle showing forward-directed spine (B), counts of lip and chin barbels, numbers in parentheses are showing chin barbels, where numbers without parentheses are showing lip barbels (C), parietal bones showing asymmetrical size (D) highlighted by yellow lines (E)

## RESULTS AND DISCUSSION

**Family Peristediidae Jordan & Gilbert, 1883**
***Satyrichthys* Kaup, 1873**
***Satyrichthys laticeps* (Schlegel, 1852)**
*Peristedion laticeps* Schlegel, 1852: 43
(Figure 2; Table 1)

### Material examined

PDD 2211-01, 1 specimen, 341 mm SL; Pondokdadap Fishing port fish market, Malang, East Java Province, Indonesia, caught off the South Coast of Malang, Eastern Indian Ocean, November 2022 (Figure 2; Table 1).

### Diagnosis

A species of *Satyrichthys* with (1) four (some specimens might possess 3 or 5) lips and 2–5 chin barbels, (2) Upper lateral bony plates of the caudal peduncle possess forward-directed (antrorse) spines, (3) Unequal parietal bones size on midline, (4) Dorsal fin does not possess any dusky spots.

### Description

Measurements and counts of the specimen are shown in Table 1. Dorsal-fin rays VII,17; anal-fin rays 15; Dorsal and anal fin rays are not branched; pectoral fin rays 15, including two detached rays on the lower part of the pectoral fins; body scaleless, but covered with bony plates and spines; bony plates on dorsal row 24 on both side; bony plates on upper lateral row 31 on both side, where the bony plates on caudal peduncle possess forward-directed spines; bony plates on lower lateral row 19 on both side; bony plates on ventral row 20 on both side; bony plates before anus 2 on both side.

The body is elongated with a large and broad head, where the head length is 40.5% SL, and head width is 26.4% SL; the lateral margin of the head below the eyes is curved; a pair of flattened, turned rostral projection on the anterior side of the head inwards; rostral projection length about 8.8% SL; orbital diameter 7.3% SL and interorbital diameter 7.3% SL; body depth about 24.0% SL and body width about 19.4% SL.

Mouth sub-terminal and large, located on the ventral side of the body; lower jaw length 15.2% SL, and upper jaw length 16,1% SL; teeth are absent on both jaws; it has 4 lip barbels on the left and right side, where the outer lip barbels are the longest and possess 8 smaller barbels (flagella) on each barbel; It also has 2 chin barbels that are much smaller compared to the lip barbels.

Origin of the dorsal fin on the second dorsal bony plate, the distance from snout to dorsal fin is about 39.6% SL; few first rows of dorsal fin with bony rays while the remaining dorsal fin with soft rays; the distance from snout to anal fin about 52.8% SL; pectoral fin length 17.9% SL, with upper detached pectoral ray 15.2% SL and lower detached pectoral ray 12.9% SL; pelvic fin length 17.3% SL; length of first dorsal fin 12.0% SL; caudal peduncle length 11.4% SL and its depth 2.9% SL; caudal fin slightly forked.

### Colour when fresh (Figure 2)

Body reddish, with pinkish-white ventral parts. Spines on the bony plates with clear-translucent tips. Dorsal and pectoral fins are reddish and translucent, while pelvic fins and anal fins are translucent and paler. The caudal fin is reddish with a tint of orange on the edge.

## Distribution

Known distribution includes larger parts of temperate and tropical Indo-Pacific, from the Indian coast of South Africa, Arabian Sea, Sri Lanka, Andaman Sea, Indonesia, South China Sea, East China Sea, Taiwan, and Japan (Kawai 2013, 2014, 2017).

## Remarks

*Satyrichthys laticeps* could be reliably distinguished from its congeners by possessing 4 (rarely 5) lip barbels, the possession of forward-facing spines on the upper lateral row of the bony plates in the caudal peduncle, and asymmetrical parietal size on the midline (Kawai 2013; 2014). Furthermore, apart from species identification purposes, based on the assessment of *S. laticeps* barbels microstructure shows that the lip barbels of *S. laticeps* might be used to assist their foraging, movements, and maintaining balance in the deep sea (Ngamniyom 2020).

*laticeps* could be distinguished from *S. moluccensis* in the number of lip barbels (4 to 5 in *S. laticeps* vs. 3 in *S. moluccensis*) and chin barbels (2 to 5 in *S. laticeps* vs. 0 to 2 in *S. moluccensis*). *S. laticeps* also has asymmetrical parietal bones in the mid-line compared to *S. moluccensis* (Kawai 2013).

*S. welchi* is another closely related species to *S. laticeps* that possess antrorse spines on the upper lateral row of the caudal peduncle. It also has 4 lips and 3 chin barbels that fall under the count range of *S. laticeps*. The difference between the two is *S. welchi* possesses dark spots on the spinous dorsal fin, which is absent in *S. laticeps*. S. welchi also has symmetrical parietal bones in the midline (Kawai, 2013).

Although they possess a similar number of lip and chin barbels, *S. milleri* could be differentiated apart from *S. laticeps* by the coloration (reddish in *S. laticeps* vs. Dark brown in *S. milleri*) and the possession of the antrorse (forward-facing) spines on the upper lateral side of the bony plates in caudal peduncle in *S. laticeps*, which is absent in *S. milleri* (Kawai 2013; Kannan et al. 2017). In addition, *S. milleri* also possesses blackish fins and barbels, compared to the reddish fins and barbels in *S. laticeps* (Rajeeshkumar et al. 2016).

**Table 1**. Comparison of measurements and counts of *Satyrichthys laticeps* between the specimen PDD 2211-01 and a recent study by Pogoreutz et al. (2014). Holotype and range measurements and counts are taken from Kawai (2013)

| **Species** | ***S. laticeps*** | | | |
|---|---|---|---|---|
| **Source** | **PDD 2211-01** | **Pogoreutz et al. (2014)** | **Holotype** | **Range (n=52)** |
| Standard length | 341 mm | 278.25 mm | 230 mm | 89 - 550 mm |
| **Measurements** (%SL) | | | | |
| Body depth | 24.0 | 19.9 | 16.6 | 15.4-23.7 |
| Body width | 19.4 | 20.2 | 13.9 | 12.4-20.3 |
| Head length | 40.5 | 39.5 | 39.0 | 37.9-45.8 |
| Head depth | 17.0 | 17.7 | 16.3 | 15.9-24.1 |
| Head width | 26.4 | damaged | 28.1 | 24.4-40.2 |
| Distance from snout to dorsal fin | 39.6 | 38.0 | 38.5 | 37.2-43.7 |
| Distance from snout to anal fin | 52.8 | 54.5 | 54.2 | 51.8-59.6 |
| Distance from snout to anus | 48.4 | 51.0 | 48.4 | 46.2-53.6 |
| Snout length | 19.9 | 20.2 | 20.6 | 19.9-23.1 |
| Rostral projection length | 8.8 | damaged | 9.5 | 6.3-12.4 |
| Longest barbel length | 16.1 | 15.0 | 19.0 | 11.4-26.7 |
| Upper jaw length | 16.1 | 15.6 | 16.0 | 14.8-17.9 |
| Lower jaw length | 15.2 | 17.0 | 15.0 | 14.4-18.1 |
| Orbital diameter | 7.3 | 8.0 | 8.2 | 7.0-11.9 |
| Interorbital width | 7.3 | 6.9 | 7.2 | 6.8-10.4 |
| Pectoral fin length | 17.9 | 22.0 | 18.1 | 14.7-26.2 |
| Length of upper detached pectoral ray | 15.2 | 17.6 | 14.9 | 13.2-21.6 |
| Length of lower detached pectoral ray | 12.9 | 13.0 | 11.4 | 10.4-17.6 |
| Pelvic fin length | 17.3 | 18.3 | 20.6 | 16.8-22.5 |
| Length of first dorsal spine | 12.0 | 10.6 | 11.1 | 0.8-14.4 |
| Caudal peduncle length | 11.4 | 13.2 | 11.1 | 9.6-13.3 |
| Caudal peduncle depth | 2.9 | 2.9 | 2.8 | 2.2-3.4 |
| **Counts** | | | | |
| Dorsal fin rays | VII, 17 | VII, 15 | VII, 17 | VI-VII, 13-17 |
| Anal fin rays | 15 | 15 | 17 | 14-17 |
| Pectoral fin rays | 15 | 15 | 15 | 14-17 |
| Bony plates in dorsal row | 24 | 23 | 26 | 23-27 |
| Bony plates in upper lateral row | 31 | 29 | 32 | 29-32 |
| Bony plates in lower lateral row | 19 | 18 | 21 | 16-22 |
| Bony plates in ventral row | 20 | 19 | 22 | 19-22 |
| Bony plates before the anus | 2 | 2 | 2 | 2 |
| Lip barbels (left, right) | 4,4 | 4,4 | 4,4 | 4 (rarely 5), 4 (rarely 3) |
| Chin barbels (left, right) | 2,2 | 3,3 | 3,3 | 2-5, 2-4 |

A new species, *Satyrichthys kikingeri,* described by Pogoreutz et al. (2013), bears a close resemblance to *S. laticeps* based on an assessment by Kawai (2014). The holotype of *S. kikingeri* possesses 4 lip barbels on each side and two chin barbels on each side. It also possesses 15 anal fin rays, pectoral fin rays (including detached rays), and soft dorsal fin rays, with VII spine on the dorsal fin. The morphometric measurements and counts of S. kikingeri mostly fall under the measurements and counts range of *S. laticeps*; therefore, it is revealed that *S. kikingeri* is considered a synonym of S. laticeps (Kawai 2014).

Other previously described species under the *Satyrichthys* genus that were brought into synonymity with *S. laticeps* include *S. adeni* (Lloyd, 1907), described from the Gulf of Aden, which failed to provide any description of any lip or chin barbels, but has a slightly different description on its coloration, which stated that *S. adeni* has a reddish yellow body with gray pectoral fins and dorsal fin tipped with black (Lloyd 1907). Further examination of *S. adeni* by Kawai and Tashiro (2008) from a specimen collected in Suruga Bay, Japan, stated the pectoral fins lose their coloration in alcohol, and it has no black spots on its dorsal fin tip (Kawai and Tashiro 2008). Meristic and morphometric identification of the holotype of *S. adeni* shows that its measurements and counts fall on the measurements and counts of *S. laticeps*. Thus it is now accepted as a synonym of *S. laticeps* (Kawai 2013).

There are seven extant species under the genus *Satyrichthys*, namely *Satyrichthys moluccensis* (Bleeker, 1850), *Satyrichthys laticeps* (Schlegel, 1852), *Satyrichthys clavilapis* Fowler, 1938, *Satyrichthys longiceps* (Fowler, 1943), *Satyrichthys rieffeli* (Kaup, 1859) *Satyrichthys welchi* (Herre, 1925), and *Satyrichthys milleri* Kawai, 2013, where all of them are known to be found in Indonesian Waters (Kawai 2013; White *et al.* 2013). All species of *Satyrichthys* are found in deep water and sometimes incidentally caught as bycatch, even though it has little to no commercial value (Fischer and Bianchi 1984; Carpenter and Niem 1999). Unfortunately, some reports on the finding of *Satyrichthys* from Puger fishing port, East Java, and Kedonganan fish market, Bali, failed to provide sufficient photographs. Therefore, the exact species remains unknown as no specimen was taken or preserved (Yassin 2022; Anggono 2022, pers. comm.). This study provides a new record of *S. laticeps* from a single specimen collected at Pondokdadap fishing port fish market caught off the southern coast of Malang, Java South Sea, Eastern Indian Ocean.


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# Estimation of aboveground biomass and carbon stock in Damas Beach, Trenggalek District, East Java, Indonesia

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**Abstract.** *Nur AAI, Arifiani KN, Ramadhandi AR, Sabrina AD, Nugroho GD, Kusumaningrum L, Ramdhun D, Bao TQ, Yap CK, Budiharta S, Setyawan AD. 2022. Estimation of aboveground biomass and carbon stock in Damas Beach, Trenggalek District, East Java, Indonesia. Indo Pac J Ocean Life 6: 80-86.* Vegetation plays a vital role in providing environmental services in the form of storing carbon which can mitigate climate change. This study aimed to calculate Aboveground Biomass (AGB) and carbon stock in Damas Beach, Trenggalek District, East Java Province, Indonesia using an allometric equation. Biomass and carbon data at a tree (dbh >20 cm) and pole (dbh 10-20 cm) levels were collected using sampling plots distributed randomly at three stations, namely mangrove vegetation (Station I), coconut plantation (Station II), and agroforestry (Station III). The results showed that across the three research stations, there were a total of 23 plant species classified as tree and pole levels. At tree level, *Rhizophora stylosa* Griffith had the highest carbon stock with a value of 85.48 MgC/ha, while the lowest value was *Nypa fruticans* Wurmb with 0.02 MgC/ha. Similarly, at the pole level, the species with the highest carbon stock was *R. stylosa*, with a value of 65.88 MgC/ha, and the lowest was *Theobroma cacao* L. with 0.11 MgC/ha. The mangrove vegetation (Station I) had the highest carbon stock value of 200.53 MgC/ha. In contrast, the coconut plantation vegetation (Station II) has the lowest total carbon stock, with a value of 84.68 MgC/ha. Conservation and management need to be improved in the Damas Beach area because if the area is disturbed, the ability of vegetation to absorb carbon will decrease.

**Keywords:** Allometric equation, environmental service, pole and tree, vegetation

## INTRODUCTION

The increasing temperature of the earth leads to changing climate which causes changes in rainfall patterns, extreme weather, rising sea surfaces, and big waves. Among various causes of climate change, the accumulation of greenhouse gases in the atmosphere due to anthropogenic activities is considered the most important contributor, particularly since the industrial era began. Among greenhouse gases, carbon dioxide ($CO_2$) has the biggest influence on global warming (Pratama 2019). The increase of $CO_2$ concentration in the atmosphere is predicted to occur in the future in line with the increase of the human population and global industry (Shafiya et al. 2021). Large-scale burning of fossil fuels (e.g., oil, coal and natural gas) and carbon losses from Land Use, Land-Use Change and Forestry (LULUCF) are anthropogenic activities with the largest contribution to $CO_2$ emissions (Suwardi and Syamsuardi 2013).

Climate change has various negative impacts on human life since human activities highly depend on natural conditions (Nurhayati et al. 2020). Therefore, adaptation and mitigation strategies are required to tackle the problems caused by the changing climate. In doing so, humans can be assisted by the natural environment itself, which is commonly referred to as environmental services. Environmental services are the benefits that society derived from the dynamic interrelationships among biotic (e.g.,, plants, animals and micro-organisms) and abiotic elements (e.g. soil, water and gases) of the environment. Environmental services can be in the form of direct/tangible benefits (e.g., timber, food, water) and indirect/intangible benefits (e.g., soil fertility, flood and erosion control, hydrological system, biodiversity, natural beauty, and carbon sequestration and storage) (Roslinda and Kartikawati 2019).

Environmental services in the form of carbon storage can mitigate the greenhouse effect (Rahardjanto et al. 2022). One of the carbon pools is in vegetation stored as biomass. Vegetation can play an important role in reducing greenhouse gases concentration by absorbing and accumulating $CO_2$ in the leaves, branches, stems, and roots as biomass, in the litter and soil organic matter (McPherson and Simpson 1999; Hikmatyar et al. 2015). Vegetation with high species diversity might have high carbon storage capacity (Idris et al. 2013). Besides being increasingly studied in climate change research, plant biomass has been historically studied in plant physiology since it is an important indicator of growth and vegetation dynamics (Yan et al. 2013).

Vegetation can occur in various ecosystems, one of which is found in the coastal area. Coastal areas provide various human benefits, including serving as a carbon sink (Canu et al. 2015). Coastal areas have several ecosystem types with the mangrove ecosystem considered the most important ecological function. Regarding climate change mitigation, the existence of mangrove forests in coastal areas is very essential in reducing $CO_2$ gas in the atmosphere (Taillardat et al. 2018). Mangroves are one of the blue carbon elements because they play a role in utilizing $CO_2$ for photosynthesis and storing it in biomass and soil sediments (Suryono et al. 2018).

Damas Beach, located in Karanggandu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia, is a coastal ecosystem with the potential for high carbon sequestration despite its importance for the local community as a source of livelihood from fisheries. Yet, no information is available regarding the amount of carbon stored in the vegetation that occurred on the beach. Therefore, this study aimed to estimate Aboveground Biomass (AGB) and carbon stock in Damas Beach. In doing so, a non-destructive method was used by employing allometric equations to avoid damage to the vegetation (Huff et al. 2017; Ibrahim and Muhsoni 2020). We expected the results of this study might enrich the existing literature on climate-related ecological studies to improve the understanding of carbon sequestration from vegetation (Jara et al. 2015; Bhaskara et al. 2018), especially in the context of the coastal ecosystem.

## MATERIALS AND METHODS

### Study area

The study was conducted at Damas Beach, Kranggandu Village, Trenggalek District, East Java, Indonesia (Figure 1). Damas Beach is geographically located at 8°19'47"S and 111°41'39"E on June 2022. This beach is located 53 km from the center of the Trenggalek District. Damas Beach has a land area of 5.5 hectares with a coastal line of 2 km, and is 5 km southwest of Prigi Beach, a well-known tourist spot in Trenggalek and is located on the coast of Prigi Bay.

### Data collection

The data collection was conducted in June 2022. Carbon storage in Damas Beach was estimated by calculating the weight of Aboveground Biomass (AGB). The AGB was calculated using an indirect non-destructive method, namely by allometric equations, to avoid damage to the Damas Beach ecosystem (Louhaichi et al. 2018). The sampling technique used was simple random sampling at three research stations. Station I consisted of mangrove vegetation, Station II was a coconut plantation and Station III was agroforest (i.e., land use management that combined timber trees with short-term agricultural crops).

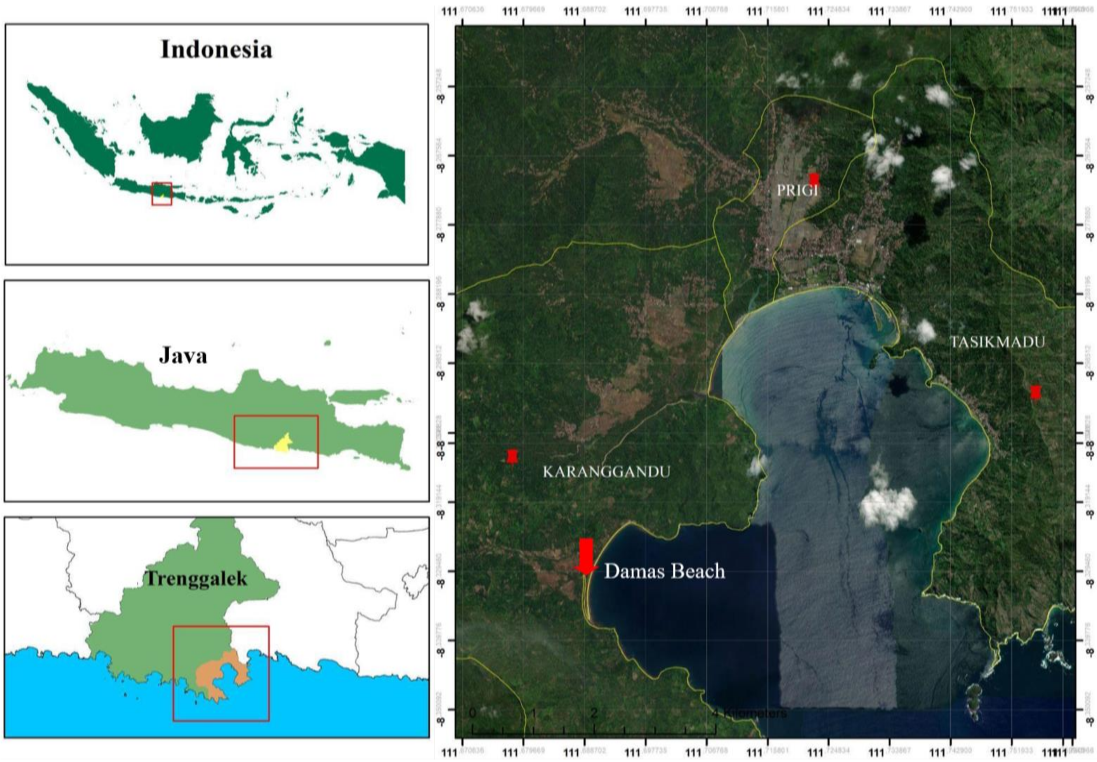


**Figure 1.** The map of the research location in Damas Beach, Karanggandu Village, Watulimo Sub-district, Trenggalek District, East Java, Indonesia

The estimation of aboveground biomass was focused on two vegetation levels, i.e., trees for vegetation with a diameter at breast height (dbh) >20 cm, and pole for dbh 10-20 cm. Biomass and carbon data were collected using sampling plots, established using simple random sampling to represent the species composition of each station. Sampling plots were divided into plots measuring 20x20 $m^2$ each to collect data for tree stands and 10x10 $m^2$ for pole stands. In total, 131 sampling plots were created. Local names of plants, dbh, and plant heights were recorded on a tally sheet, while secondary data included Latin names, allometric equations, and the specific gravity of wood.

**Data analysis**

Estimates of vegetation carbon storage at Damas Beach were inferred from the calculation of AGB biomass using specific allometric formulas for each plant species (Table 1). Then the total biomass per species was summed to obtain the total biomass of each species. Next, biomass was multiplied by 0.5 as a proportion of the carbon content of the plant species (Arsalan et al. 2020). Following the standardization of the National Standardization Agency (2011), the carbon content in the plots (poles and trees) was converted to carbon per hectare using the following equation:

$$C_n = \frac{C_x}{1.000}\ x\ \frac{10.000}{l_{sub-plot}}$$

Where: $C_n$ is carbon per hectare in each sub-plot in units of MgC/ha; $C_x$ is carbon per sub-plot in units of kg; the $l_{sub-plot}$ is the total area of the sub-plot in $m^2$. Allometric calculations were calculated based on the wood density of each species, dbh and height (Purwiyanto and Agustriani 2017).

## RESULTS AND DISCUSSION

In total, there were 23 species of 17 families across the three research stations (Tables 2 and 3). The most dominant species in Station I or mangrove vegetation was *Rhizophora stylosa* Griffith. The dominance of *R. stylosa* in mangrove vegetation was also found in several areas in Indonesia, including Weh Island, Aceh (Dewiyanti 2010), Kemujan Island, Karimunjawa (Wirasatriya et al. 2022), and Pacitan, East Java (Irwansyah et al. 2021; Sholiqin et al. 2021; Wiraatmaja et al. 2022). This is understandable since *R. stylosa* can grow at habitats with low to high salinity. This species can optimize nutrients and sunlight in the growth process, making it highly adaptable to various environmental conditions (Heriyanto and Subiandono 2012). At Station II, or coconut plantation, the most dominating species was *Cocos nucifera* L. While at Station III with agroforestry vegetation, the most dominating species was *Durio zibethinus* Murray. The *C. nucifera* and *D. zibethinus* were the dominant species in Stations II and III because they were the main plantation commodities for communities in Damas Beach. The existence of species dominance in an area shows that the physical and environmental conditions favor the species.

The biomass gain of vegetation is affected by the density of vegetation, the diversity of its diameter and the distribution of its specific gravity; where land use consisting of trees with species that have a high wood density value and large diameter, the biomass will be higher when compared to land that has species with low wood density values such as poles (Hairiah and Rahayu 2007). Poles are young trees with a diameter of 10 to less than 20 cm which have a high rate of photosynthesis so they have the potential to absorb carbon. Poles can contribute to carbon stock storage, although smaller than tree vegetation (Hopkins and Huner 2009). The effect of main contribution of biomass lies in the stem so that the carbon stored in the pole is smaller than the carbon stored in trees with a larger diameter than the pole.

**Table 1.** Species-specific allometric equations to calculate aboveground biomass in Damas Beach, Trenggalek, Indonesia

| Species | Equation | References |
|---|---|---|
| *Acacia auriculiformis* A.Cunn. ex Benth. | $0,0775\ x\ (D^{2,14})^{0,9018}$ | (Mugiono 2009) |
| *Aegiceras corniculatum* (L.) Blanco | $0,251\ x\ 0,6784\ x\ D^{2,46}$ | (Komiyama et al. 2005) |
| *Albizia chinensis* (Osbeck) Merr. | $0,0272\ x\ D^{2,831}$ | (Sugiharto 2002) |
| Branched tree | $0,11\ x\ \rho\ x\ D^{2,62}$ | (Ketterings et al. 2001) |
| *Casuarina equisetifolia* L. | $-1,17 + 2,119\ x\ (ln\ ln\ D)$ | (Brown 1997) |
| *Cocos nucifera* L. | $\frac{(3,14\ x\ \rho\ x\ h\ x\ D^2)}{40}$ | (Hairiah et al. 2001) |
| *Nypa fruticans* Wurmb | $Log\ B = 0,85\ Log\ D^2 x\ L + 1,54$ | (Matsui et al. 2014) |
| *Rhizophora stylosa* Griffith | $0,9789\ \ x\ D^{2,6848}$ | (Clough and Scott 1989) |
| *Sonneratia alba* Sm. | $0,251\ x\ 0,475\ x\ D^{2,46}$ | (Komiyama et al. 2005) |
| *Swietenia mahagoni* (L.) Jacq. | $0,048\ x\ D^{2,3}$ | (Adinugroho and Sidiyasa 2001) |
| *Tectona grandis* L.f. | $0,290091\ x\ D^{2,3}$ | (Hendri 2001) |
| *Terminalia catappa* L. | $\rho\ x(-1\ 499) + 2.148\ x\ ln\ D + 0.207\ x\ Ln\ D^2 - 0.0281\ x\ Ln\ D^3$ | (Chave et al. 2005) |
| *Theobroma cacao* L. | $0,012088\ x\ D^{1,98}$ | (Yuliasmara et al. 2009) |

Note: D is the diameter at breast height (dbh); L is the length of the frond; ρ is the wood density (World Agroforestry 2022)

At the pole stands, 19 species were found from 15 different families (Table 2). Most species were found at Station III with a total of 12 species. The largest AGB and carbon stock per hectare in pole level with dbh of 10-20 cm at the study site was dominated by *R. stylosa* with an AGB of 131 MgB/ha, equating to carbon stock of 65.88 MgC/ha (Table 2). Besides the high dominance of *R. stylosa*, the relatively high carbon stock contributed by this species was because mangrove plants can store more biomass than other plants (Dinilhuda et al. 2018). The high biomass was also contributed by *Aegiceras corniculatum* (L.) Blanco with an AGB of 54.65 MgB/ha or 27.33 MgC/ha.

Meanwhile, at Station II which is a coconut plantation, 4 species were found at the pole level with the largest AGB value coming from the species *Pandanus utilis* Bory with a value of 4.02 MgB/ha or equivalent to carbon stock of 2.01 MgC/ha. Followed by *C. nucifera* with an AGB value of 2.86 MgB/ha (equal to 1.43 MgC/ha). At Station III, which is an agroforestry, the species *Artocarpus heterophyllus* Lam. is the species with the largest AGB, namely 20.03 MgB/ha or equivalent to 10.01 MgC/ha (Table 2).

For the tree level (vegetation with dbh of more than 20 cm), 20 species were found (Table 3). Most species were found in Station III or agroforestry, comprising 13 species. The highest AGB and carbon stock per hectare in tree level was also contributed by *R. stylosa* from Station I with AGB of 170.96 MgB/ha, or equivalent to carbon stock of 85.48 MgC/ha (Table 3), Similarly in South Sulawesi, based on research by Analuddin et al. (2020), the carbon stock of the *R. stylosa* forest in South Sulawesi, Indonesia, is much higher than other mangrove vegetations in several regions of the world, with a value of 264.50 MgC/ha.

Station III had the largest total AGB at tree level with a value of 233.73 MgB/ha or equivalent to 116 MgC/ha. The largest value at Station III came from the species *Tectona grandis* L.f. with an AGB of 64.31 MgB/ha (equal to 32.15 MgC/ha). This value is much smaller than *R. stylosa* at Station I. However, the amount of AGB and carbon stock produced at the tree level at Station I was lower than in Station III (Table 4). This happened because there were few mangroves at the tree level found in the research site and a large number of trees at Station III.

The average of AGB from 3 stations at Damas Beach, Trenggalek was 302.27 MgB/ha or equivalent to 151.13 MgC/ha (Table 4). The average from 3 stations at tree stands was 199.90 MgB/ha (equal to 99.95 MgC/ha), meanwhile, the average at pole stands was 102.36 MgB/ha (equal to 51.18 MgC/ha). As for each station, Station I had the highest carbon sequestration with a value of 200.53 MgC/ha, followed by Station III with a value of 168.18 MgC/ha and Station II was the lowest with a carbon storage value of 84.68. MgC/ha (Table 4).

## Discussion

The average AGB in Damas Beach was 302.27 MgB/ha, or equivalent to a carbon sequestration of 151.13 MgC/ha (Table 4). In general, the value of biomass and carbon stock of each species is different and is influenced by the sequestration ability, which can be inferred from dbh tree, density value tree, and height tree using allometric equation (Ariani et al. 2016). Plants absorb $CO_2$ from the air through photosynthesis and then convert it into organic matter (Handoyo et al. 2020).

The value of carbon stocks in other parts of Indonesia also varies. According to Kusumaningtyas et al. (2019) and Pricillia et al. (2021), the average carbon stock was 68.1 MgC/ha in Nusa Lembongan, Bali and 15.8 MgC/ha in Segara Anakan Lagoon, Central Java. Meanwhile, in other Asian regions, such as China, the average value is around 355.25 ± 82.19 MgC/ha (Liu et al. 2014). Then, Rozainah et al. (2018) reported that the mean aboveground carbon in Peninsular Malaysia was 156.35 MgC/ha in Delta Kelantan and 70.17 MgC/ha in Johor Park, Malaysia.

**Table 2.** Aboveground biomass and carbon stock of vegetation at pole layer with diameter at breast height of 10-20 cm

| Station | Family | Local name | Scientific name | AGB (MgB/ha) | Carbon stock (MgC/ha) |
|---|---|---|---|---|---|
| **Station I** | Primulaceae | Gedangan | *Aegiceras corniculatum* (L.) Blanco | 54.65 | 27.33 |
| (Mangrove) | Lythraceae | Perepat | *Sonneratia alba* Sm. | 10.20 | 5.10 |
| | Rhizophoraceae | Bakau | *Rhizophora stylosa* Griffith | 131.76 | 65.88 |
| **Station II** | Arecaceae | Kelapa | *Cocos nucifera* L. | 2.86 | 1.43 |
| (Coconut tree) | Casuarinaceae | Cemara Laut | *Casuarina equisetifolia* L. | 0.64 | 0.32 |
| | Combretaceae | Ketapang | *Terminalia catappa* L. | 0.33 | 0.16 |
| | Pandanaceae | Pandan laut | *Pandanus utilis* Bory | 4.02 | 2.01 |
| **Station III** | Anacardiaceae | Mangga | *Mangifera indica* L. | 9.08 | 4.54 |
| (Agroforestry) | Euphorbiaceae | Macaranga | *Macaranga* sp. | 8.14 | 4.07 |
| | Fabaceae | Petai Cina | *Leucaena leucocephala* (Lam.) de Wit | 7.89 | 3.95 |
| | Fabaceae | Sengon | *Albizia chinensis* (Osbeck) Merr. | 6.01 | 3.01 |
| | Fabaceae | Akasia | *Acacia auriculiformis* A.Cunn. ex Benth. | 11.45 | 5.73 |
| | Fabaceae | Jengkol | *Pithecellobium jiringa* (Jack) Prain | 11.73 | 5.86 |
| | Lamiaceae | Jati | *Tectona grandis* L.f. | 6.95 | 3.48 |
| | Malvaceae | Kakao | *Theobroma cacao* L. | 0.22 | 0.11 |
| | Malvaceae | Durian | *Durio zibethinus* Murray | 9.93 | 4.96 |
| | Moraceae | Nangka | *Artocarpus heterophyllus* Lam. | 20.03 | 10.01 |
| | Myrtaceae | Cengkeh | *Syzygium aromaticum* (L.) Merr. & Perry | 5.20 | 2.60 |
| | Sapindaceae | Rambutan | *Nephelium lappaceum* L. | 7.08 | 3.54 |

Note: AGB: Aboveground biomass

**Table 3.** Aboveground biomass and carbon stock of vegetation at tree layer with diameter at breast height of 20 cm

| Station | Family | Local name | Scientific name | AGB (MgB/ha) | Carbon stock (MgC/ha) |
|---|---|---|---|---|---|
| **Station I** | Arecaceae | Nipah | *Nypa fruticans* Wurmb | 0.05 | 0.02 |
| (Mangrove) | Lythraceae | Perepat | *Sonneratia alba* Sm. | 8.14 | 4.07 |
| | Primulaceae | Gedangan | *Aegiceras corniculatum* (L.) Blanco | 25.30 | 12.65 |
| | Rhizophoraceae | Bakau | *Rhizophora stylosa* Griffith | 170.96 | 85.48 |
| **Station II** | Arecaceae | Kelapa | *Cocos nucifera* L. | 160.81 | 80.41 |
| (Coconut tree) | Casuarinaceae. | Cemara Laut | *Casuarina equisetifolia* L. | 0.46 | 0.23 |
| | Combretaceae | Ketapang | *Terminalia catappa* L. | 0.26 | 0.13 |
| **Station III** | Achariaceae | Keluak | *Pangium edule* Reinw. | 24.92 | 12.46 |
| (Agroforestry) | Anacardiaceae | Mangga | *Mangifera indica* L. | 9.31 | 4.65 |
| | Fabaceae | Petai Cina | *Leucaena leucocephala* (Lam.) de Wit | 5.34 | 2.67 |
| | Fabaceae | Sengon | *Albizia chinensis* (Osbeck) Merr. | 11.56 | 5.78 |
| | Fabaceae | Akasia | *Acacia auriculiformis* A.Cunn. ex Benth. | 9.26 | 4.63 |
| | Fabaceae | Jengkol | *Pithecellobium jiringa* (Jack) Prain | 9.67 | 4.83 |
| | Fabaceae | Petai | *Parkia speciosa* Hassk. | 5.40 | 2.70 |
| | Lamiaceae | Jati | *Tectona grandis* L.f. | 64.31 | 32.15 |
| | Malvaceae | Kakao | *Theobroma cacao* L. | 0.15 | 0.07 |
| | Malvaceae | Durian | *Durio zibethinus* Murray | 39.50 | 19.75 |
| | Meliaceae | Mahoni | *Swietenia mahagoni* (L.) Jacq. | 18.20 | 9.10 |
| | Moraceae | Nangka | *Artocarpus heterophyllus* Lam. | 29.97 | 14.98 |
| | Sapindaceae | Rambutan | *Nephelium lappaceum* L. | 6.17 | 3.09 |

Note: AGB: Aboveground biomass

**Table 4.** Total aboveground biomass and plant carbon stock at each station

| Station | Biomass and carbon stock | | | | Total | |
|---|---|---|---|---|---|---|
| | Tree | | Pole | | | |
| | AGB (MgB/ha) | Carbon stock (MgC/ha) | AGB (MgB/ha) | Carbon stock (MgC/ha) | AGB (MgB/ha) | Carbon stock (MgC/ha) |
| Station I (Mangrove) | 204.45 | 102.22 | 196.62 | 98.31 | 401.06 | 200.53 |
| Station II (Coconut tree) | 161.53 | 80.76 | 7.84 | 3.92 | 169.37 | 84.68 |
| Station III (Agroforestry) | 233.73 | 116.87 | 102.63 | 51.32 | 336.37 | 168.18 |
| Average | 199.90 | 99.95 | 102.36 | 51.18 | 302.27 | 151.13 |

Note: AGB: Aboveground biomass

In this study, tree stands with a dbh of more than 20 cm had an average AGB of 199.90 MgB/ha or could absorb carbon of 99.95 MgC/ha, while pole stands with a value of 102.36 MgB/ha or were able to absorb carbon of 51.18. MgC/ha (Table 4). The dimension (i.e., diameter, height) of plants will affect the total biomass and carbon stored. The carbon stored at the tree level was greater than that at the poles, which is in agreement with the studies by Purwiyanto and Agustriani (2017) and Purwanto et al. (2021).

Mangrove vegetation at Station I had the highest AGB value and carbon stock per hectare compared to other stations, which stored 401.06 MgB/ha or equal to 200.53 MgC/ha (Table 4). Among the carbon sequestered in the world, about 55% is captured by organisms living in the ocean (blue carbon) (Lovelock and Duarte 2019). Blue carbon is a term for carbon pools in coastal and marine ecosystems. Coastal ecosystems can absorb more carbon than terrestrial ecosystems. The ecosystems considered blue carbon pools include mangroves, tidal swamps, seagrasses, etc. The sediments in the coastal ecosystem where mangroves grow store a large amount of nutrients. This is because, the litter from mangroves including dead trees, leaves, propagules, and twigs as well as roots, becomes a source of organic carbon in the sediments of mangroves (Alongi 1998). This causes mangroves as very productive ecosystems and has high potential as a global carbon sink (Dittmar and Lara 2001; Alongi 2007).

At Station II, coconut plantations consisted of 4 species, namely *C. nucifera* and the rest were *Casuarina equisetifolia* L., *Terminalia catappa* L. and *P. utilis*. The total AGB at Station II was 169.37 MgB/ha or stored carbon as much as 84.68 MgC/ha (Table 4). Coconut (*C. nucifera*) was the dominant species at this station, with a total AGB of trees and poles of 163.67 MgB/ha and a carbon stock of 81.84 MgC/ha. The AGB value and carbon stock in the coconut plantation were smaller than those in the other stations (Table 4). This result is in line with the research by Ikhwan (2021) in Lubuk Kertang, North Sumatra, Indonesia, in which coconut stands had only 19 MgC/ha while other vegetation reached 158 MgC/ha. The low carbon stock in coconut plantations was also found in

Honda Bay, the Philippines, by Castillo et al. (2018) with 11.9-12 MgC/ha.

At Station III, a forest area with an agroforestry system, the plant species found were *D. zibethinus*, *Syzygium aromaticum* (L.) Merr. & Perry, *T. grandis*, *Theobroma cacao* L., *Albizia chinensis* (Osbeck) Merr. and others (Tables 2 and 3). Station III had a total AGB of 336.36 MgB/ha, equivalent to carbon sequestration of 168.18 MgC/ha (Table 4). The result of this study is within the range of carbon stock in agroforestry systems in Southeast Asia have the potential to store carbon from 12 MgC/ha to 228 MgC/ha (Murthy et al. 2013). The result of this study is greater when compared to carbon stock in the agroforestry system in Kurushetra, North India with 131.65 Mg/ha (Kumar 2017) and in Central Sulawesi, Indonesia, with a value of 42.42 MgC/ha (Wardah et al. 2011).

In conclusion, the coastal ecosystem in Damas Beach has the ability to provide environmental services in the form of storing carbon. The species at tree layer with the highest carbon stock was *R. stylosa* with a value of 85.48 MgC/ha, while the lowest was *Nypa fruticans* Wurmb with 0.02 MgC/ha. Similarly, the species at the pole level with the highest carbon stock was *R. stylosa* with a value of 65.88 MgC/ha and the lowest value was *T. cacao* with 0.11 MgC/ha. The area with the highest biomass was Station I or mangrove vegetation with a carbon stock value of 200.53 MgC/ha, while the station with the lowest total carbon stock was Station II, or coconut plantation, with a value of 84.68 MgC/ha. Conservation and management need to be improved in the Damas Beach area because if there is a disturbance in the area, either due to anthropogenic factors or natural factors such as natural disasters, the number of stored carbon stocks will decrease or even disappear, causing carbon emissions not to be absorbed.

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# Spatial models of suitable sandy substrates for brittle star community conservation in Sancang Coast, West Java, Indonesia

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[1]Program of Biology Education, Faculty of Teaching and Education Science, Universitas Siliwangi. Jl. Siliwangi No.24, Tasikmalaya 46115, West Java, Indonesia

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Manuscript received: 5 November 2022. Revision accepted: 4 December 2022.

**Abstract.** *Suprapto PK, Husna IR, Meylani V, Basukriadi A, Wibowo AA, Nurdin E. 2022. Spatial models of suitable sandy substrates for brittle star community conservation in Sancang Coast, West Java, Indonesia. Indo Pac J Ocean Life 6: 87-93.* The brittle star is known as one of the echinoids with the largest members. Currently, brittle star species are threatened due to harvests for fulfilling decorative species demands in aquariums. This study aims to determine suitable sandy substrates for the brittle star community in Sancang Coast, West Java, Indonesia, in three representative stations. Brittle star presences and environmental variables were surveyed using belt transect methods, and sandy substrate suitability was determined using scoring and an interpolation method aided by GIS. Results show three species belong to the Ophiocomidae, with *Ophiocoma scolopendrina* (Lamarck, 1816) (brittle lagoon star) being the most abundant. About 394,631 $m^2$ of sandy substrates were available, and an estimated 47.52% is considered very suitable for brittle stars. Most suitable sandy substrates were located on the West side, characterized by low water temperature, high salinity, and alkaline water. In contrast, less suitable sandy substrates were located on the coast's east side, characterized by high water temperature, low salinity, and acidic water. To conclude, this research has identified which parts of the Sancang Coast should be prioritized to conserve brittle stars.

**Keywords:** Environment**,** *Ophiocoma scolopendrina,* Ophiocomidae, Sancang, suitable

## INTRODUCTION

The Ophiuroidea, or brittle stars, snake stars (euryalids with non-branching arms), and basket stars (euryalids with branching arms), are the biggest group of extant echinoderms, with 2,064 documented species found in all seas from the intertidal to the deepest depths (Stöhr et al. 2012). The 2,064 ophiuroid species described range from the intertidal to the hadal depths and from the equator to the polar regions. Regarding brittle star biogeography, the Indo-Pacific area has the highest overall species richness (825 species at all depths). Because of the existence of many Indo-Pacific species that partially spread into these regions, adjacent regions were also quite species-rich, including the Indian (316), South Pacific (355), and North Pacific (398). The West Atlantic was a secondary region with increased species diversity (335). The regions with relatively low species richness include the Arctic (73 species), East Atlantic (118), South America (124), and Antarctica (126) (Martín-Ledo and González 2013; Lau et al. 2021). Some of the Indo-Pacific species richness could be attributed to its vast area (99.3 million $km^2$). Around 64% of species (1,316) were restricted to a single region, and the highest proportion of endemic species included the East Pacific (63%) and West Atlantic, with 61% of endemic species found here (O'Hara et al. 2011).

Indonesian waters were also reported to have significant brittle star biodiversity within the Indo-Pacific region. In Pandaratan Beach of Sumatra Island, brittle stars accounted for 9.15%–14.71% of the echinodermata community registered for *Ophiocoma erinaceus* (Müller & Troschel, 1842) species (Susetya 2019). Even on Java Island (Pakpahan et al. 2020), brittle stars are known to dominate the intertidal zones. According to Muzaki et al. (2019), the most dominant species in Pidakan Beach of East Java are brittle stars, represented by *Ophiocoma dentata* (Müller & Troschel, 1842) (Family Ophiocomidae), which accounted for 52.50%, and *Ophiomastix annulosa* (Lamarck, 1816), which accounted for 17.46%. Due to their occurrence in all marine habitats, brittle stars have emerged as a key taxonomic group for biogeographic or macro-ecological studies. They have a variety of life history strategies and trophic and are diverse and abundant enough to be statistically analyzed without becoming a major taxonomic exercise with every survey. Since their skeletal parts occur in large numbers as microfossils in most marine sediments and are taxonomically identifiable, including deep-sea cores, brittle stars have a high potential to serve as model organisms to assess the impact of palaeoceanographic events and macro-evolutionary patterns on the composition and diversity of past communities.

Although humans rarely harvest brittle stars, some *Ophioderma* and *Ophiarachna* species are harvested and sold as marine aquarium species. On the other hand, as brittle stars are a dominant component of seafloor fauna, they can be impacted by other human activities such as mining or trawling. Anthropogenic activities occurring in coastal areas, including trampling, tourism, or harvesting marine biota in sandy substrates, have been reported to have a negative impact on the local fauna. Even though there are no or limited studies on the direct impact of trampling on echinoderms, the lower species richness of echinoderms could be related to decreasing food sources in an area with higher anthropogenic activities. In addition, anthropogenic activity has been reported to cause a decrease in bivalves, gastropods, and crustaceans, which are the food source for many brittle stars considering that brittle stars were omnivorous predators that preyed on at least 24 taxa representing foraminiferans, crustacean fragments, and sediment particles (Lafite et al. 2021).

Recently, a sandy ecosystem that is an important habitat for brittle stars was threatened due to sand mining (Nishi et al. 2015). Then this condition demands a study to select the remaining sandy substrates suitable for conserving brittle stars in the future. Therefore, this study aims to determine suitable habitats for brittle stars in sandy substrates in the Sancang Coast intertidal zones, West Java, Indonesia.

## MATERIALS AND METHODS

### Study area

This research was conducted on the sandy substrate of the intertidal zones of Sancang Coast, Garut District, West Java, Indonesia, on July 19-21, 2020. The study area was part of the Leuweung Sancang Natural Reserve. The research location consists of 3 stations, namely station 1, located in Ciporeang on the East side with geocoordinates of 7°44′19″ S and 107°52′9″ E, station 2, located in Cikujangjambe on the middle side with geocoordinates of 7°44′19″ S and 107°52′38″ E, and station 3, located in Cibako on the West side with geocoordinates of 7°44′24″ S and 107°52′26″ E. The intertidal zones comprised seagrass in the middle and surrounded by sandy substrates. The sandy substrates were bordered by a natural reserve and Sandy Beach recreational area on the North side, the Indian Ocean on the south side, and Karang Gajah Rivermouth on the East side near Ciporeang. The research location is shown in Figure 1. These sample sites were selected due to the presence of sandy substrates.

### Procedures

*Brittle star surveys*

Brittle star samplings were carried out using the belt transect method, in which a transect was drawn perpendicularly from the coast to the sea for 100 m. Sampling was carried out at 3 stations (Figure 1), and each station contained 100 plots per station with a size of 1 x 1 m per plot. Identification of brittle stars was carried out by comparing the morphology of the brittle star species obtained with the morphological characteristics in the book Identification, "A Guide to Common Echinoderms of Andaman and Nicobar Islands," by Raghunathan et al. (2013), and scientific articles based on shape, color, spines, and patterns of brittle stars. The survey was carried out during the low tide to get a better view while surveying the brittle star community.

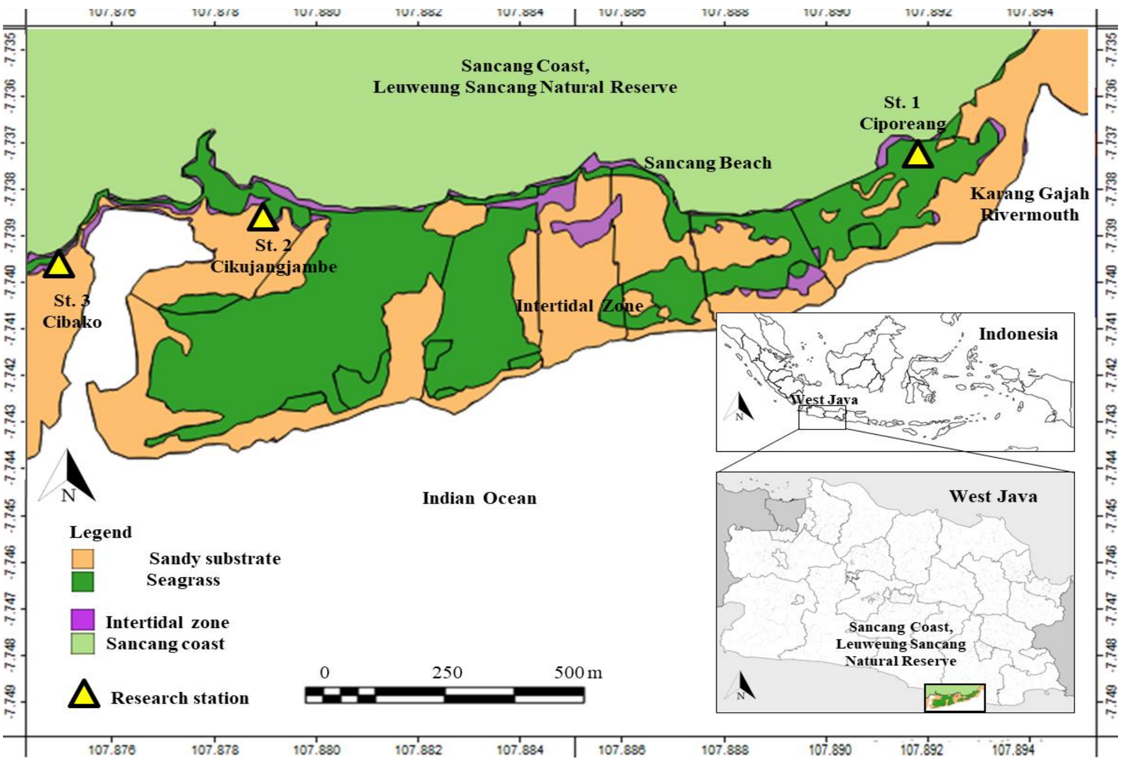


**Figure 1.** Location of the study area, research station, and sandy substrates at intertidal zones of Sancang Coast, Garut District, West Java, Indonesia

*Environmental variable assessments*

Assessments of the environmental variable at each station were conducted around 07.00-09.00 AM following low tide on all sampling days. Measured environmental variables included pH, salinity (‰), dissolved oxygen (DO, mg/L), and water temperature ($^0$C). All variables were assessed in situ using digital multiparameter devices. Those devices include a refractometer, a DO meter, and a digital thermometer. Following the presence of brittle stars, the environment variables were measured at the surface of sandy substrate depth.

*Suitable sandy substrates analysis*

Estimations of suitable habitats for brittle stars followed the workflow (Figure 2) and method described by Meixler and Bain (2012) and Boitt et al. (2021). The suitability method used was the scoring and overlay of environmental variables and brittle star individual numbers mapped into a sandy substrate map. First, all the environmental variable values, including pH, salinity, dissolved oxygen, and water temperature, were tested for their correlations using Principal Component Analysis (PCA) and then scored from lowest to highest. The variable with the lowest score was considered the least suitable, and the one with the highest score was considered the most suitable. Then all the score values were tabulated into the Geographical Information System (GIS) table along with their geocoordinates.

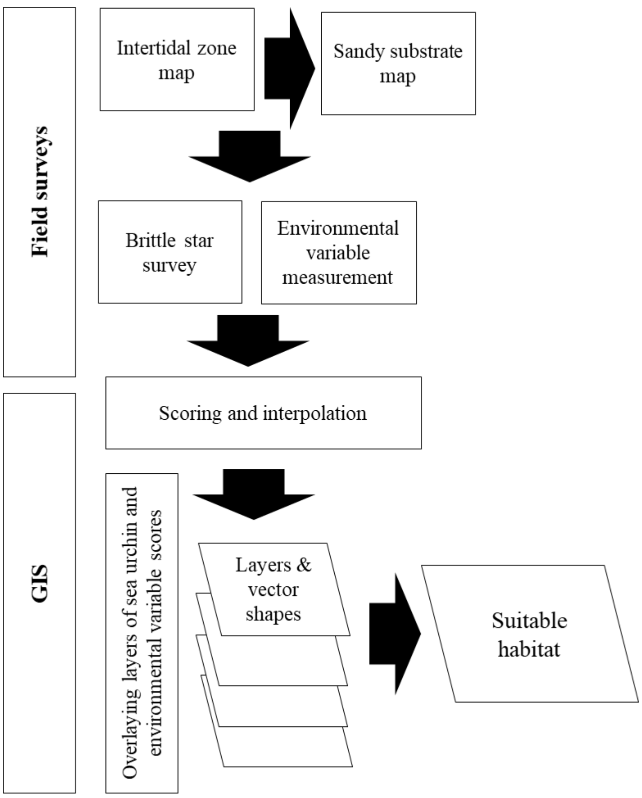


**Figure 2.** Workflow for determining suitable sandy substrates at Sancang Coast, Garut District, West Java, Indonesia intertidal zones

The tabulated GIS tables contained environmental variables and brittle star individual numbers that were used and interpolated to create GIS layers and vector shapes. Next, all the layers were overlaid, and the score values in each environmental variable layer and vector shape were summed to create composite layers. The final step was to classify score values in composite layers. The vector shapes with the highest score values were classified as the most suitable habitat and high-very-high classes. While the vector shapes with the lowest score values were classified as least suitable for sandy substrate and low-very low classes. This process was conducted using GIS software (ArcView 3.3).

**Data analysis**

The correlations of environmental variables with the brittle star community were analyzed using Principal Component Analysis (PCA). This analysis was also used to observe and compare the values and quantities of environmental variables and Brittle Star individuals in stations 1, 2, and 3. Besides, Chi-square ($x^2$) was used to test the differences between environmental variables and the brittle star community among locations, with the significance level at $P < 0.05$. All sample sites were tested equally.

## RESULTS AND DISCUSSION

**Brittle star community**

Based on the study results, 3 brittle star species were observed on the sandy substrates of the Sancang Coast that belonged to the family Ophiocomidae, *Ophiocoma* genus, which included *O. aethiops* (Lütken, 1859), *O. echinata* (Lamarck, 1816), and *O. scolopendrina* (Lamarck, 1816). Based on the statistical test (Table 1, $x^2$ = 249.4992, P =0.00001), the numbers of individuals of each species were significantly different among stations, indicating the effects of locations on the brittle star community. The *O. aethiops* was abundant in Cikujangjambe, followed by Cibako and Ciporeang. Abundances of *O. echinata* and *O. scolopendrina* followed similar patterns as Cibako > Cikujangjambe > Ciporeang. That indicates that, in general, the brittle star community is high in Cibako compared to other locations. The *O. scolopendrina* were brittle star species found frequently in every location and dominated the brittle star community.

PCA results have confirmed this brittle star community pattern (Figure 3). Cibako was characterized by the dominance of *O. echinata* and *O. scolopendrina*. While Cikujangjambe was characterized by the dominance of only the *O. aethiops* species, Besides that, Ciporeang was characterized by a low number of members of the brittle star community.

**Environmental variable patterns**

The results of environmental variable assessments (Table 1) show the spatial pattern and distribution of measured environmental variables. Based on the result, the water temperature increased toward the Ciporeang site, or station 1, on the East side. The highest water temperature measured at station 1 was 28.3°C, and the lowest at station 3 was 27.9°C. A similar pattern can be observed for DO. The DO was also rising along the Sancang Coast's sandy substrates. The highest water DO observe in station 1 was equal to 5.64 mg/L, and the lowest water DO in station 3 was equal to 5.54 mg/L. In contrast, pH and salinity showed the opposite pattern. According to the result, pH declined towards the Ciporeang site, or station 1, on the East side, with the lowest pH value at 8.33. While pH increased toward station 3 and made the water in here alkaline. Similarly, salinity was also observed declining towards the Ciporeang site, or station 1, on the east side, with the lowest salinity values at 32.2‰. At the same time, salinity increased towards station 3 and made the water in here more saline with a salinity of 34‰. This condition makes the sandy substrates at Cibako in the West have colder water, alkaline water, high salinity, and less DO. While the sandy substrates at Ciporeang on the East side have warmer water, acidic water, low salinity, and oxygen-rich water.

The current environmental variable patterns were confirmed by PCA results (Figure 3). Based on the results, Ciporeang was significantly characterized by temperature increases. While increases in salinity and pH characterize the Cibako and Cikujangjambe, increases in DO do as well.

**Table 1.** Statistical results (Chi-square) of environmental variables with the brittle star community across all 100 plot samples at sandy substrates of intertidal zones of Sancang Coast, Garut District, West Java, Indonesia

| Variables | Units | Stations | | | Chi-square | |
|---|---|---|---|---|---|---|
| | | 1 Ciporeang (East) | 2 Cikujangjambe (Middle) | 3 Cibako (West) | $x^2$ | P |
| *O. aethiops* | Individuals | 35 | 712 | 207 | 249.4992 | 0.00001* |
| *O. echinata* | Individuals | 29 | 277 | 279 | | |
| *O. scolopendrina* | Individuals | 152 | 715 | 755 | | |
| Water temperature | $^0$C | 28.3 | 27.8 | 27.9 | 0.5154 | 0.999991 |
| Dissolved oxygen | mg/L | 5.64 | 5.72 | 5.54 | | |
| Salinity | ‰ | 32.2 | 33.7 | 34 | | |
| pH | | 8.33 | 8.4 | 8.38 | | |

Note: *Statistical significance level at <0.05

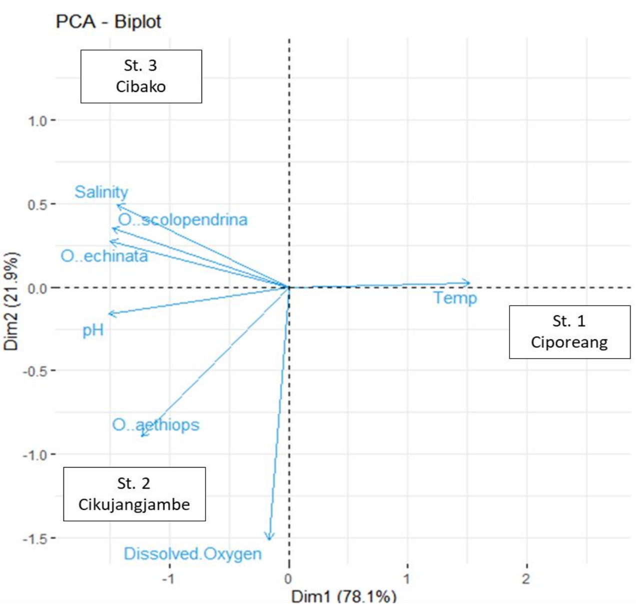


**Figure 3.** PCA of environmental variables with the brittle star community at sandy substrates of intertidal zones of Sancang Coast, Garut District, West Java, Indonesia

**Brittle star community correlations with environmental variables**

The PCA results explained brittle star community correlations with environmental variables (Figure 3). In this study, there were both converse and inverse correlations. Positive correlations were mostly observed in Cibako. In this study, abundances and increasing individuals of *O. echinata* and *O. scolopendrina* were positively correlated with increases in salinity and pH. It indicates that in Cibako, brittle stars increased when the water became more saline. Besides, it will increase the brittle star population when water becomes alkaline. The positive correlations of environmental variables were also observed in Cikujangjambe. Here, the number of brittle stars will increase when water is enriched with oxygen. Compared to Cibako and Cikujangjambe, negative community-level correlations with environmental variables were observed in Ciporeang. Here, the absence of brittle stars was caused by water temperature increases. The rise in temperature in Ciporeang has also contributed to the reductions in salinity, pH, and DO and led to the declining brittle star community.

**Suitable sandy substrates**

Based on the analysis, an estimated 394,631 m2 of sandy substrates were available on Sancang Coast, spanning from Ciporeang in the East to Cibako in the West (Figure 4). From those areas, between 22,529 $m^2$ (5.7%) to 187,559 $m^2$ (47.52%) were considered to have a high or very high suitability level. In greater detail (Figure 5), Cibako, located on the West, has the largest sandy substrates classified as very suitable. Sandy substrate suitability in the middle at Cikujangjambe was more heterogeneous. In this case, the sandy substrate suitability was considered low to moderate. The Ciporeang site, located in the East, was considered unsuitable, considering that almost 75% of its sandy substrates were classified as very unsuitable.

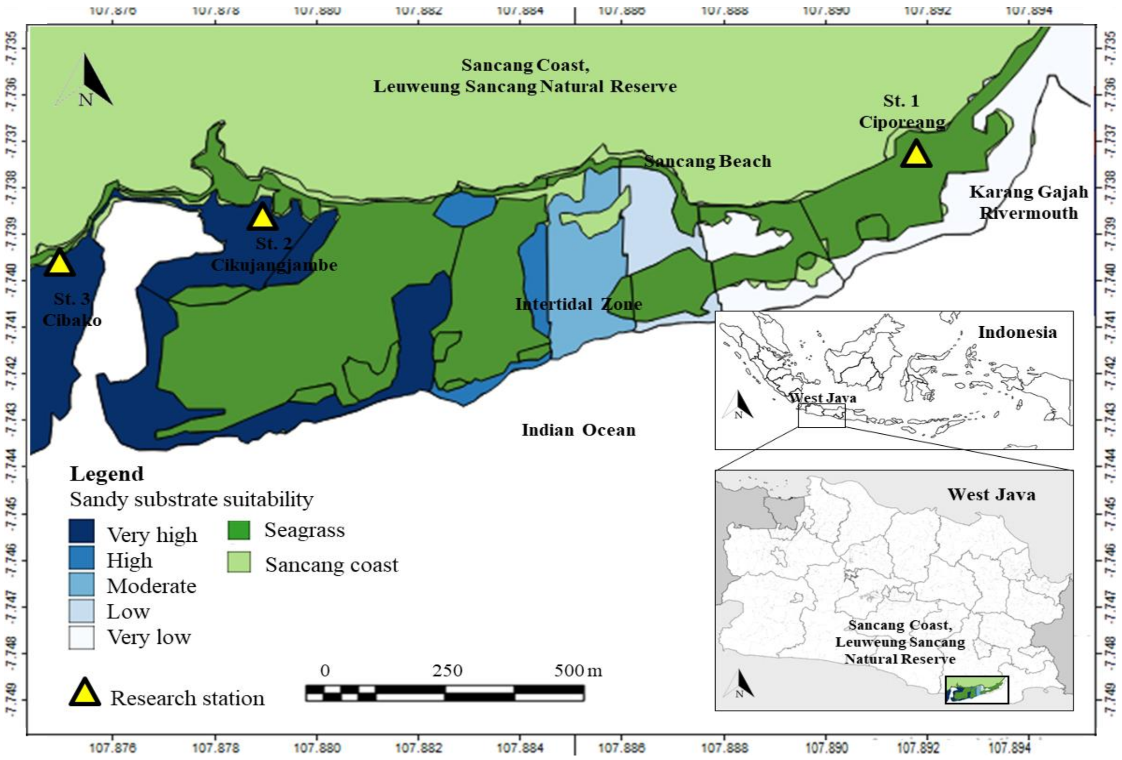


**Figure 4**. Sandy substrate suitability for brittle star community at intertidal zones of Sancang Coast, Leuweung Sancang Natural Reserve, West Java, Indonesia

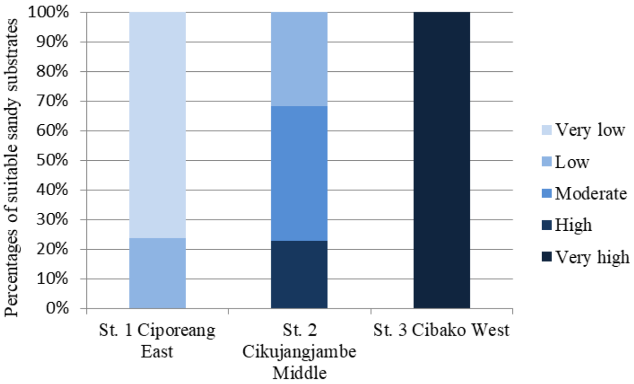


**Figure 5.** Area compositions of suitable sandy substrate classes (very low, low, moderate, high, very high) for brittle star community in stations 1, 2, and 3 at intertidal zones of Sancang Coast, Leuweung Sancang Natural Reserve, West Java, Indonesia

## Discussion

This study elaborated on the importance of brittle star conservation by elaborating on the suitable habitats for conserving the brittle star community in the sandy substrates at intertidal zones of the Sancang Coasts. That agrees with previous studies highlighting current threats to brittle stars and the importance of designating conservation areas by determining suitable habitats. The determination of suitable habitat will lead to the establishment of Marine Protected Areas (MPA) that have proven to be a successful tool for the conservation of marine forests and the control of brittle star populations. That is because information about suitable habitats will guide and inform which parts of the habitats should be protected and can yield significant results in conservation efforts. Here, *O. scolopendrina* was a brittle star species that is very common and abundant in comparison to other brittle star species. This condition is in agreement with the results from nearby coastal in Rancabuya Coast, West Java (Paujiah et al. 2018). In Rancabuaya, *O. scolopendrina* was present in every location, including sandy substrates with high numbers. That confirms that the sandy substrates of the West Java Coast are suitable and potentially support brittle star conservation practices. Despite its current geographical distribution, the records of *O. echinata* in this study were in agreement with the results from Paujiah et al. (2018) and a recent study by Bahtiar et al. (2020) that confirm the presence of *O. echinata* within Indonesia's tropical waters. Similar to *O. echinata*, *O. aethiops* is present within Indonesia's tropical waters with a density of 0.045 indv/m$^2$, as confirmed by Katili (2011)

In this study, the sandy substrates of the Sancang Coasts were the point of interest to be recommended for brittle star-suitable habitats. That agrees with the previous study (Geraldi et al. 2016). According to Muzaki et al. (2019), most brittle star species were found only in the bottom substrates, composed of coarse to fine sand. Brittle stars prefer soft bottom substrates that enable them to burrow themselves and hide during low tide or high light intensity. That is due to the negative phototaxis properties of brittle stars, as observed by Muyassaroh et al. (2021). The selected sandy substrates in this study indicate that brittle stars prefer lower temperatures and avoid substrates with warm water. According to Angreni et al. (2017) and Susetya (2019), Brittle star abundance was negatively correlated with temperature because high temperatures would cause high evaporation, increasing salinity. An increase of 3 in salinity would lead to flaking skin or even death in extreme conditions (Fang et al. 2014).

Less suitable sandy substrates were identified on the East side of the studied coast in Ciporeang. This site is characterized by very distinct environmental variables and low abundances of brittle stars in comparison to other locations. This condition is related to the locations of Ciporeang that are close to the river mouth. The presence of a river mouth and anthropogenic activities nearby (Scherner et al. 2013; Souza et al. 2013; Cabral et al. 2019) has the potential to discharge pollutants and nutrients that can contaminate the pristine coastal ecosystems nearby and affect the populations of marine organisms (Brauko et al. 2016), including brittle stars. Eutrophication originating from the land is a common problem among coastal ecosystems near river mouths that greatly affects the diversity of organisms, from fish to small benthic invertebrates (Brauko et al. 2020). Eutrophications contribute to altering the pristine sandy beaches by creating drifting algae mats that induce episodic hypoxia (Barros et al. 2017) that may affect brittle star species. Eutrophication processes in the form of increased phytoplankton production may increase the accumulation of organic pollutants in benthic sediment-ingesting fauna, including brittle stars. This condition explains the lower abundance of brittle stars in Ciporeang, which makes the sandy substrates in this site classified as unsuitable.

Another distinct environmental variable of unsuitable sandy substrates is the declining pH values, which indicate ocean acidification. This condition is considered unsuitable since acidification (Wood et al. 2011) has adverse effects on brittle stars, as documented in previous studies (Kroeker et al. 2013; Hu et al. 2014). Furthermore, acidic water and lowering pH values have been reported to decrease the dry weight of both intact and regenerating brittle stars (Christensen et al. 2017). Besides that, lowering pH values has also been reported to cause increased mortality and a reduced growth rate of brittle larval stars as observed under low pH conditions. For example, according to Yu et al. (2015), brittle larval stars appeared more sensitive and experienced over 80% mortality after 7-day exposure to pH 7.7.

To conclude, this study has determined the sandy substrates of the Sancang Coast that are suitable for conserving brittle stars. In the future, it is recommended to elaborate more on the environmental variables of brittle stars to obtain a more comprehensive understanding of the brittle star habitat requirements. Considering that brittle stars are substrate dwellers, further research should encompass all aspects of substrates and sediments. In addition, those environmental variables should cover physico-chemical aspects of sediments ranging from sediment sizes and types to sediment organic matters (Geraldi et al. 2016).

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# Effects of urbanization on coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana

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**Abstract.** *Dadzie-Paintsil E, Mensah JV. 2022. Effects of urbanization on coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana. Indo Pac J Ocean Life 6: 94-105.* Wetlands play an important role in the livelihood of humankind; on the other hand, the reciprocal gesture on ecosystem protection is on the decline. The result is the loss of wetlands, especially in urban areas. This study examined the effects of urbanization on coastal wetlands in the Sekondi-Takoradi Metropolis of Western Region Ghana. Therefore, using a mixed-method research design, 358 respondents were sampled from the metropolis to respond to the data collection instruments: questionnaire, interview, and Focus Group Discussion (FGD). The Statistical Product and Service Solutions (SPSS) program version 14 was used to facilitate quantitative data analysis, while content analysis was used for qualitative data analysis. The major finding was that wetlands in the Sekondi-Takoradi Metropolis was affected by urbanization, resulting in the loss of some portions of the wetlands. Furthermore, wetlands were perceived as 'wastelands' which should be used for other use. One major recommendation is that residents should be sensitized by the Metropolis Assembly and the Environmental Protection Agency to appreciate the value of the coastal wetlands in the metropolis. Again, there should be the co-management of the wetland resources and the provision of alternative sources of livelihood by the local authority, central government, and concerned non-governmental organizations.

**Keywords:** Ecosystem, Sekondi-Takoradi Metropolis, urbanization, wetlands

## INTRODUCTION

Wetlands, both inland and coastal worldwide, are essential and deliver numerous benefits or ecosystem services to humans, including to provide services such as food and fiber, essential for human welfare, regulating services, recharging groundwater, and protecting from natural hazards, which are critical to vital ecosystem functions sustainably. Wetlands also have spiritual values and provide sustainable opportunities for recreation and tourism, considerable aesthetic, cultural, and educational (Mensah 2003; Yusuph and Munishi 2018).

Moreover, coastal wetlands also play a vital role in spatial development. They maintain ecosystem balance, serve as open spaces, and provide habitats for birds, fish, mammals, and invertebrates. They also provide a habitat for a high concentration of birds, flood prevention, and storm protection (Bishop et al. 2017). Regardless of its benefits, wetlands worldwide have been abused, encroached on, and degraded due to the human population's direct or indirect socio-economic activities. As a result, the world is continuously losing its wetlands. The Millennium Ecosystem Assessment Report (2005) suggested infrastructure development (such as dams, dikes, and levees), pollution, overharvesting, land conversion, water withdrawals, and the introduction of invasive alien species drive the increase in the loss of wetlands and their vital species globally. Furthermore, the recent Asian tsunami analysis by Dahdoub-Guebas et al. (2005) suggests that there may be an inverse relationship between tsunami damage and mangrove presence, which means that an increase in the loss of wetlands could increase the damage and the effect of natural disasters like hurricane, floods, and tsunami.

Usually, wetlands are shallow water-logged areas characterized by emergent vegetation. They could remain flooded all year round or undergo drastic changes in water level depending on the season. What constitutes a coastal wetland varies from considerations based on the level of ocean-derived salinity of the open water body or proximity to the sea. Marine wetlands include the open coast not subject to the influence of the lagoon system and river water. While forced resettlements and encroachments are also identified as associated with the development of extractive industries, which could drive the community's people to lose wetlands, die from contamination, venerate ancestral homes, and see their livelihoods jeopardized (Gary 2009).

Worldwide urban sprawl has been caused by population and income growth, little environmental awareness, and relaxed legal regulations. Traditional communities have revered wetlands. However, modern-day communities abutting wetlands see them as wastelands. Modernization and urban sprawls have encumbered suitable lands for development, and marginalized poor people who need land development are pushed to the peripheral lands, considered cheap or wastelands. That is why wetlands are encroached on, filled for physical development and waste disposal sites, and abused. Many of these wetlands are also used for solid waste and water disposal and are considered breeding grounds for mosquitoes by the population (Angulo 2000). Additionally, because of technical difficulties and greater costs of urban expansion into other areas, such as the coastal range, the sprawl has been concentrated in the floodplains and wetlands (Riffo and Villarroel 2000).

The spread and emergence of urbanization have also significantly contributed to the loss of its wetlands which were once a habitat for most aquatic animals. Historically and globally, urbanization is a natural phenomenon wherever a surplus to feed non-agricultural workers with agriculture produces. Moreover, urbanization is generally considered as either the degree or increase in urban character. It may refer to a geographical area combining the urban and the immediate periphery, often rural (Satterthwaite et al. 2010).

The recent dramatic pace of urbanization in the Sekondi-Takoradi Metropolis, Ghana, and its destructive effect on coastal wetlands is currently obvious. Therefore, this study aimed to describe the current state of coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana; identify the institutions responsible for the protection and management of coastal wetlands in the Sekondi-Takoradi Metropolis; examine the urban activities that affect the coastal wetlands, and analyze the perception of stakeholders on the use and management of coastal wetlands.

## MATERIALS AND METHODS

### Study area

The Sekondi-Takoradi Metropolis, with Sekondi as the administrative capital, on the southeastern part of the Western Region, Ghana (Figure 1). The city's population grew from 103,834 in 1970 to 369,166 in 2000, with a growth rate of 3.2%, projected to 444,752 by 2013. The annual temperature is 22ºC, with annual rainfall is 1,380 mm, and an average of 122 rainy days. Precipitation occurs mainly from March to July, with nearly 70% rainfall. The second rainy season is between September to November, which is very severe. The dry seasons occur from August to September and extend from December to February, heralding the harmattan and drying up the area. The metropolis does not experience severe weather conditions and is favorable as a tourist spot destination. Their natural vegetation has been degraded largely due to farming practices and human activities, with existing vegetation being woodland in the north and central areas.

### Research design

This study used the descriptive research method. As a result of the respondents' nature, mostly fishermen, assembly members, opinion leaders, youth representatives, and chiefs, the majority of which cannot write and read, to ascertain the data on the status of the wetlands in the Sekondi-Takoradi Metropolis, the research relied heavily on Focus Group Discussions. Retrieving data of such nature requires a descriptive approach to allow the respondent to describe the nature and state of the wetlands.

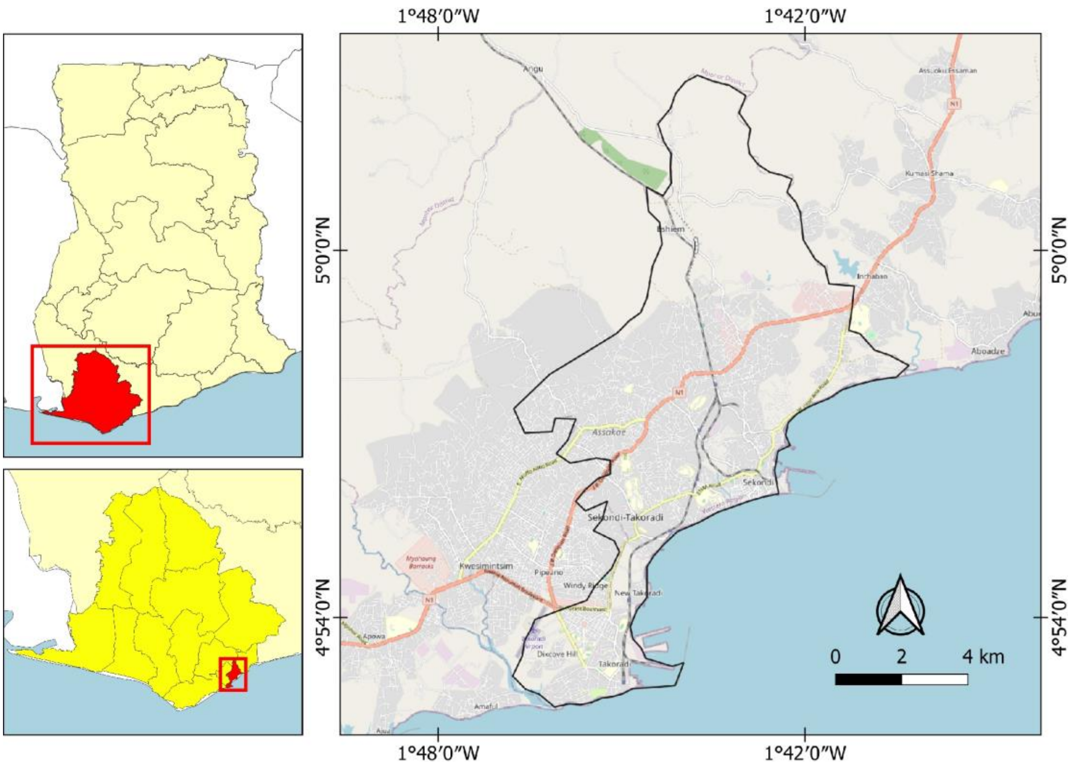


**Figure 1.** Sekondi-Takoradi Metropolis area in the regional and national context. Source: https://data.humdata.org/dataset/cod-ab-gha (2022)

**Study population**

The study population comprises the adult population (18 years and above) in all ten wetlands communities in the Sekondi-Takoradi Metropolis. The communities used are Whindo, Apremdo, Effia, Effiakuma, Sekondi, Bakado, Buabakrom, Kojokrom, New Takoradi, and Takoradi. These are areas where the wetlands are located in the metropolis. In addition, the study identified key stakeholders such as Assembly members, Chiefs, Opinion leaders, and representatives of Youth Groups who have stayed in the metropolis for not less than three years. That facilitated the identification of significant changes like the coastal wetlands. According to Ghana Statistical Service (2002) as shown in Table 1, the total population of these ten communities is approximately 225,491 people.

**Sample size and sampling procedure**

The non-probability sampling technique was employed to achieve the research objectives. Therefore, the quota sampling technique was used to select the respondents. This technique was adopted because respondents needed to meet several requirements and characteristics. For instance, a respondent must be a chief, assembly member, opinion leader, or youth group representative. In addition, the population is adequately represented using quota sampling if the sample strongly correlates with the study variable. Due to time and resource constraints, 1% of the study population's total population constituted the study's sample size. Hence, as indicated in Table 1, the sample size is 225 people.

**Sources of data**

The residents in ten communities in the Sekondi-Takoradi Metropolis were used to gather primary data. The primary data were derived from the respondents' answers during the survey process. On the other hand, the secondary data were obtained from journals, reports, books, and other relevant materials.

**Data collection instruments**

The questionnaire, interview, and Focus Group Discussion (FGD) tools were used as the main data-gathering instruments for this study. A questionnaire is not simply a 'tool' for collecting and recording information about a particular issue of interest but also consists mainly of a list of questions and should also include clear instructions and administrative details or space for answers. Should questionnaires always have a definite purpose related to the research objectives, and it needs to be clear from the outset how the findings will be used. The youth group's representatives and assembly members administered the interview guides. The questionnaires were divided into three main sections: The first section contains socio-demographic of the respondents' characteristics, such as educational background, sex, the number of years they have stayed in the Sekondi-Takoradi Metropolis, knowledge and status of wetlands, activities that affect wetlands, perceptions, institutions for wetland protection and management, urbanization impact, and recommendations.

The FGD is a rapid assessment, the semi-structured data-gathering method in which a selected set of participants (chiefs and opinion leaders in this case) gather purposively to discuss concerns and issues based on a list of key themes drawn up by the researcher/facilitator (Kumar 1987). This study explored the respondents' perceptions of the wetlands' encroachment and its impact on these communities.

**Pretesting of instruments**

A one-day pretest was conducted to test the instruments before the actual survey. After the questions had been answered, the researcher asked the respondents for any suggestions or necessary contributions to establish further improvement and validity of the instruments. Therefore, the researcher revised the data collection instruments. Then, the researcher excluded irrelevant questions and changed difficult or vague terminologies into simpler ones.

**Fieldwork**

The researchers recruited four assistants who helped collect and process data. After pretesting the instruments, the researchers sent an introductory letter to the institutional heads, chiefs, opinion leaders, and various representatives. An agreed date was scheduled at the interviewee's and discussants' convenience. Next, the research team solicited responses from the target population with the help of questionnaires, interview guides, and FGD guides.

**Fieldwork challenges**

As every reputable study encountered challenges, this study was no exception. For example, because discussants in some communities postponed our scheduled dates on more than three occasions, organizing discussants was arduous. Sometimes, the researchers and the research assistants had to wait the entire day for the discussants. Moreover, controlling the discussants' emotions was another challenge regarding the subject in question. Nevertheless, the researchers were able to calm nerves after thoroughly explaining the study's objectives and the intended use of the eventual result.

**Table 1.** The projected size of the study population and sample distribution

| Community | Population size | Ratio (%) | Sample size |
|---|---|---|---|
| Apremdo | 11,996 | 0.05 | 312 |
| Bakado | 1,858 | 0.00 | 82 |
| Buabakrom | 605 | 0.003 | 1 |
| Effia | 5,771 | 0.026 | 6 |
| Effiakuma | 45,245 | 0.200 | 45 |
| Kojokrom | 13,141 | 0.058 | 13 |
| New Takoradi | 18,668 | 0.083 | 19 |
| Sekondi | 50,672 | 0.225 | 50 |
| Takoradi | 75,428 | 0.335 | 75 |
| Whindo | 2,107 | 0.009 | 2 |
| Total | 225,491 | 1.000 | 225 |

Source: Ghana Statistical Service (2002)

**Data processing and analysis**

All recorded responses were transcribed after data collection. The transcribed data and questionnaire responses were edited and coded for analysis. The coded data were entered into a computer program named Statistical Product and Service Services (SPSS) version 14. Tables and basic descriptive statistics such as averages, percentages, and frequencies were generated for the analysis. In addition, content analysis exposed the qualitative data gathered using the FGD guide and interview guide.

## RESULTS AND DISCUSSION

**Background characteristics of respondents and discussants**

*Types of respondents*

The ten selected communities involved in this study were 286 community members. About 61 were involved in organized focus group discussions, while the remaining provided information through questionnaires. Ten assembly members were also involved in organizing the focused group discussion participants. The youth were represented in all 10 communities, and about 8 institutional heads were contacted. Table 2 depicts the types of respondents used for the entire study.

The researcher also engaged chiefs, assembly members, youth representatives, opinion leaders, and women's organization representatives in the Sekondi-Takoradi Metropolis communities to constitute the study's discussants. The people, as mentioned earlier, were engaged due to their knowledge of the subject matter at hand and the history and environs of their community, deeply.

The third groups the researchers interviewed were institutional heads or representatives in the metropolis whose activities and operations directly or indirectly impact the conservation wetlands. These interviews to ascertain from their perspective the role they play in protecting and conserving the wetlands.

*Sex of respondents*

Although all the assembly members and chiefs used for this study were males, more than half (50.6%) of the respondents were females (Table 2). On the other hand, more than 50 % of the community members are females. Also, 3 out of 8 institutional heads similar to representing 37.5%, were females.

*Age distribution of respondents*

Table 3 shows the age distribution of the respondent used in all ten communities in the Sekondi-Takoradi Metropolis, about 40.8% of the respondents were between the ages of 30 and 39. Only 8 out of 225 youth, representing 3.5%, were less than 19 years old. Even though the destruction of the wetlands in the Sekondi-Takoradi Metropolis environment is worrying, there is still hope due to the interest expressed by the youth in preserving and maintaining these coastal wetlands. This assertion is bolstered by the fact gathered in the field that most of the respondents are relatively young and have indicated interest and zeal to preserve what is left of the coastal wetlands.

*Marital status of respondents*

Table 3 presents the marital status of respondents. The majority (60%) of the respondents used for the study were married. However, 29, 22, and 38 out of 225 respondents were also single, separated, and divorced, respectively.

**Table 2.** Type and sex distribution of respondents

| Type of respondent | Male | | Female | | Total | |
|---|---|---|---|---|---|---|
| | F | % | F | % | F | % |
| Community members | 125 | 43.7 | 161 | 56.3 | 286 | 100.0 |
| Assembly members | 15 | 100.0 | 0 | 0 | 15 | 100.0 |
| Youth group rep. | 12 | 63.2 | 7 | 36.8 | 19 | 100.0 |
| Opinion leaders | 7 | 58.3 | 5 | 41.7 | 12 | 100.0 |
| Chiefs | 8 | 100.0 | 0 | 0 | 8 | 100.0 |
| Institutional rep. | 5 | 62.5 | 3 | 37.5 | 8 | 100.0 |
| Total | 172 | 49.4 | 176 | 50.6 | 348 | 100.0 |

Note: Rep.: representatives

**Table 3.** Characteristic of respondents

| Characters | Frequency | Percent |
|---|---|---|
| **Age (years)** | | |
| Less than 19 | 8 | 3.5 |
| 20-29 | 76 | 33.7 |
| 30-39 | 92 | 40.8 |
| 40-49 | 25 | 11.1 |
| 50-59 | 14 | 6.5 |
| 60+ | 10 | 4.4 |
| Total | 225 | 100.0 |
| **Marital status** | | |
| Single | 29 | 12.9 |
| Married | 136 | 60.4 |
| Divorced | 38 | 16.9 |
| Separated | 22 | 9.8 |
| Total | 225 | 100.0 |
| **Level of education** | | |
| Never been to school | 12 | 5.3 |
| Basic school | 87 | 38.7 |
| Secondary | 100 | 44.4 |
| Tertiary | 26 | 11.6 |
| Total | 225 | 100.0 |
| **Occupational status** | **Frequency** | **Percent** |
| Fisherman/fishmonger | 88 | 39.1 |
| Trader | 82 | 36.4 |
| Civil servant | 25 | 11.1 |
| Artisan | 23 | 10.2 |
| Other | 6 | 2.7 |
| Student | 1 | 0.4 |
| Total | 225 | 100.0 |

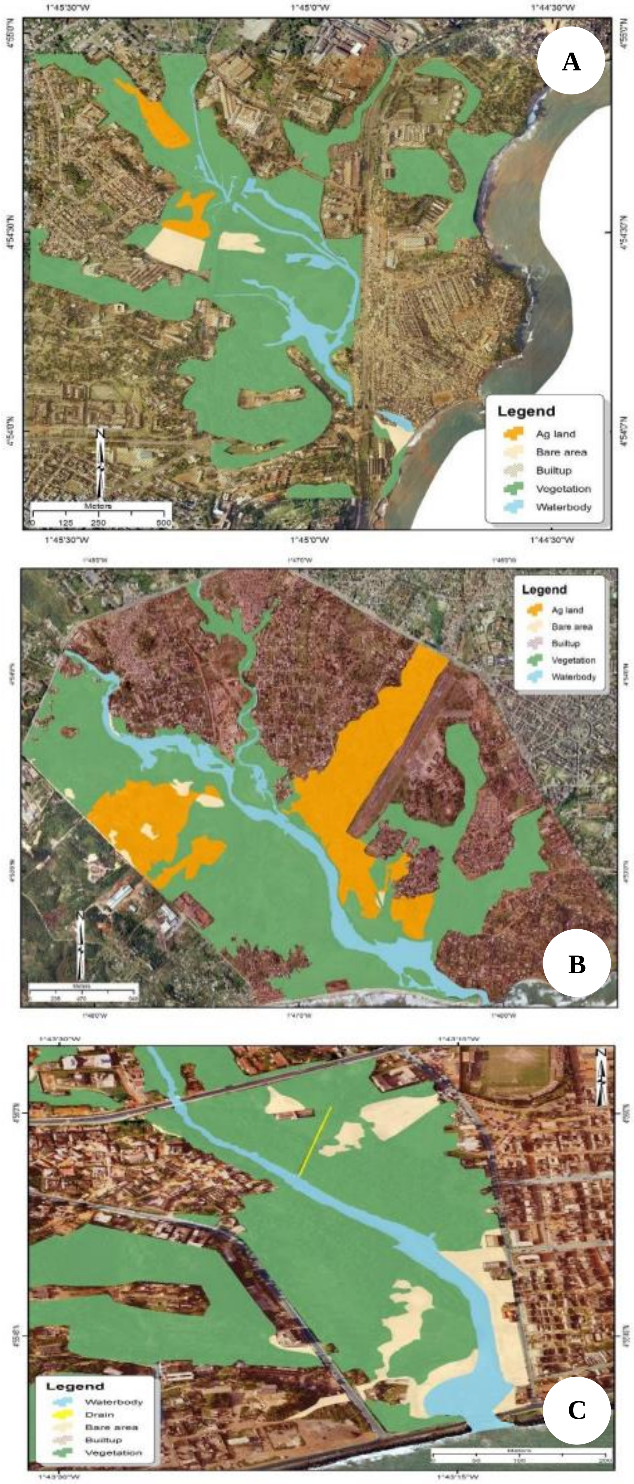


**Figure 2.** An aerial view of A. Butuah lagoon at New Takoradi, B. Whin River at Beach Road, C. Essei Lagoon at Sekondi

*The educational level of respondents*

The literacy rate in Sekondi-Takoradi Metropolis is relatively high. However, only 5.3% of the respondents have never been to school, 44.4% had secondary education, and 11.6% had tertiary education (Table 3).

*Occupation of respondents*

The majority of the ten selected community respondents were fishermen and fishmongers. As shown in Table 3, 39.1% of the respondents were either fishermen or fishmongers.

**Knowledge and current state of wetlands in the Sekondi-Takoradi Metropolis**

Three coastal wetlands were identified per the definition of a wetland used in this study. Figure 2 shows the respondents, the institutional representative, and some discussants identified as the Butuah Lagoon, Whin Estuary, and Essei Lagoon. Based on their knowledge of a wetland, the respondents were asked via questionnaires to identify wetlands in the Sekondi-Takoradi Metropolis. Table 4 shows that 39.6% of the respondents were able to identify the Whin Estuary as a wetland. Similarly, 29.3% and 31.1% of the respondents also identified the Essei and Butuah lagoons as wetlands.

The researchers' aim at this study stage was to allow the discussants to identify any wetlands in the Sekondi-Takoradi Metropolis in the case of the FGD. The discussants were allowed again to furnish the researcher with what they knew and perceived about the wetlands. The call for intensive education and sensitization on protecting and preserving the wetlands in the metropolis was very relevant. This request was made because people still perceived wetlands as 'wasteland,' Brown (1985) confirmed in the earlier study on the likely impact of municipal wastes on wetlands. Thus, the call on the Assembly and the government to support them in reclaiming these sites. Mensah (2003) made similar finding and call in a study on coastal wetlands in the Central Region of Ghana.

Wetlands in the Sekondi-Takoradi Metropolis have changed in appearance, size, and composition due to several factors. Therefore, attention must be paid to the current state of the wetlands to preserve and maintain them. The wetlands are now polluted with waste, particularly polythene wrappers, indicated in that study, which take longer to decay. Most of the wetlands are also encroached on by the prospective developers, leading to the narrowing of their channels. As a result, the water in these wetlands is not hygienic for domestic use and is now dirty, in sharp contrast with clean water as a benefit of the wetland, as espoused by Richard and Connell (2001).

**Table 4.** Knowledge of wetlands in the Sekondi-Takoradi Metropolis, Ghana

| Name of wetland | Frequency | Percent |
|---|---|---|
| Whin estuary | 89 | 39.6 |
| Butuah lagoon | 70 | 31.1 |
| Essei lagoon | 66 | 29.3 |
| Total | 225 | 100.0 |

From Table 5, 47.1% of the respondents indicated that the wetlands in their communities had been polluted with waste. About 31.1% of the respondents also stated that residents have encroached on these wetlands for industrial, commercial, and residential uses contrary to the approved scheme, which designates it as an open space area (green buffer). A case in point is Kojokrom, where 38.5% of respondents indicated that the wetlands' water is dirty and unhealthy for domestic use. In addition, residents have also encroached upon portions of the Sekondi-Takoradi Metropolis's wetlands, which has narrowed their channels.

In Bakado, an opinion leader on an FGD recounted the benefit of reclaiming a marshy area in their community. Similarly, a youth representative in Sekondi called on their chief and the Assembly to reclaim a portion of the Essei lagoon to point out the benefits some encroachers have derived from wetlands.

The public education need is justified by these contrasting views expressed while one group looked at encroachment on the wetlands as negative, the other saw it as positive. Sustainable resource use becomes paramount, thus the essence of public education. Most discussants could identify the three main wetlands in the Sekondi-Takoradi Metropolis (Essei, Butua, and Whin). Almost 95% of the discussants acknowledged that the Lagoons, as mentioned earlier, and the Whin Estuary and its environs located in Sekondi, New Takoradi, and Takoradi, respectively, were wetlands. However, some of the tributaries of these lagoons were not seen as wetlands. Moreover, about 87% of the discussants indicated that there are no more wetlands, as mentioned earlier, their current state was now deplorable compared to their state ten years back.

The chief of Buabakrom indicated that their community flooded the last three years due to waste disposal into the stream. In a similar faction, some developers were reported by the assembly member of Whindo for encroachment on the Whin River to the Sekondi-Takoradi Metropolis Assembly (STMA). An opinion leader at New Takoradi also expressed their displeasure with how the Butuah lagoon is deteriorating. A similar sentiment about the state of the Essei lagoon in recent times was also expressed by one of the youth representatives of Sekondi. Finally, a market woman at Kojokrom indicated that the Essie and the Whin rivers are now choked compared to their state in the early 1990s.

The chief Imam of Bakado, on the other hand, indicated that the Oberayeba stream is now in a better state than it used to be. He indicated that their community flooded during rainy seasons in the past years but has stopped over the past three years due to the dredging and diversion of the stream. It indicated they no longer enjoyed the benefits, such as fish harvested from the river. In general, from the study's responses, it was evident that the wetlands in the Sekondi-Takoradi Metropolis were under threat and disappearing faster due to increased population and human activities.

## Benefits of coastal wetlands

Table 6 shows the respondents for the study admitted that the wetlands in the Sekondi-Takoradi Metropolis have significant benefits, which are enormous and cannot be overemphasized. These benefits range from food to shelter and supply humanity's basic needs, as supported by Costanza et al. (1997). In terms of food, more than 54% of the respondents identified crabs and fish as some of the benefits derived from the wetlands by the communities, which also serve as a source of income for some of the study communities' residents. In addition, especially in New Takoradi and Adakope, mangroves are also harvested from the wetlands for building. Therefore, preserving the wetlands in the metropolis should be put in place for the residents to continue deriving the above benefits.

**Table 6.** Benefits of coastal wetlands to the residents

| Benefit | Frequency | Percent |
|---|---|---|
| Mangrove for building | 78 | 34.7 |
| Fish | 76 | 33.8 |
| Crab | 48 | 21.3 |
| Grass for roofing | 14 | 6.2 |
| Water for Irrigation | 9 | 4.0 |
| Total | 225 | 100.0 |

**Table 5.** Community and current state of wetland

| Community | Dirty | Encroached upon by buildings | Narrow channel | Polluted with waste | Total |
|---|---|---|---|---|---|
| Apremdo | 3 (25) | 3 (25) | 0 | 6 (50) | 12 (100) |
| Bakado | 0 | 0 | 0 | 1 (100) | 1(100) |
| Buabakrom | 0 | 0 | 0 | 1(100) | 1(100) |
| Effia | 0 | 1 (16.7) | 1 (16.7) | 4 (66.7) | 6(100.0) |
| Effiakuma | 10(22.2) | 10 (22.2) | 0 (.0) | 25(55.6) | 45(100) |
| Kojokrom | 5(38.5) | 1(7.7) | 1(7.7) | 6(46.2) | 13(100) |
| New Takoradi | 5(26.3) | 2(10.5) | 0 | 12(63.2) | 19(100.0) |
| Sekondi | 12(24.0) | 11(22) | 0 | 27(54) | 50(100) |
| Takoradi | 6(7.9) | 42(55.3) | 5(6.6) | 23(30.2) | 76(100) |
| Whindo | 0 | 0 | 0 | 2(100) | 2(100) |
| Total | 41(18.2) | 70(31.1) | 7(3.1) | 107(47.5) | 225(100) |

Note: Percentage figures are in parentheses

**Figure 3.** Mangrove trees are used for building at Adakope, Ghana

Moreover, wetlands furnish people living closer to them or even beyond with numerous benefits: flood control, water supply source for domestic use, irrigation, coastal protection, and serving as a habitat for wildlife species. From the data gathered, the discussants also acknowledged that they derived many benefits from the wetlands. For example, a fisherman from Sekondi stated how they used to harvest a lot of tilapia during the rainy seasons from the Essei lagoon in the past years. He also added that they could not use canoes anymore because of the siltation of the lagoon, even though they were used for fishing on the lagoon. The mangroves were also cut for construction buildings in some communities, such as Adakope (Figure 3). A fishmonger indicated that some ten years back in New Takoradi, the Butuah lagoon was a food source for the residents during the rainy season; they also recounted how fishermen abandoned the sea to fish in the lagoon during that period.

A Sekondi's chief also indicated that the Essie estuary served as a site for foreign and local tourists and for educational purposes for students and researchers. At Effiakuma, the assembly member stated that the Whin lagoon was a tourist site. It was also revealed that in the past, fishermen, especially during the lean seasons, depended on these wetlands for fishing. Notwithstanding the benefits, a teacher from Kojokrom illustrated that human activities in the Sekondi-Takoradi Metropolis have contributed to reducing these benefits beyond imagination. He cited that the area between the Effia-Nkwanta Hospital and Sekondi has been reclaimed for residential and industrial use before an area that used to be a vast wetland with serene vegetation and birds.

Especially in the dry season, it was also evident that communities such as Bakado and Essaman mostly relied on the Essei lagoon for irrigation purposes. A farmer at Whindo indicated that even though the volume of water in the river has recently reduced, the Whin estuary is used to irrigate their vegetable farms. As a result of the lagoon's ability to purify and retain large volumes of water was lost, which provided a clean and reliable source of water for domestic use in the past. These wetlands maintain perennial rivers and streams because the Essei and Whin rivers flow throughout the year. They occasionally release their stored water slowly; community stakeholders revealed that during the interaction.

Mangroves and other plants are harvested for medicine and fuel, traditionally. Particularly, fishmongers in New Takoradi and Adekope often use the mangroves along the Butuah lagoon and the Whin estuary to process fish in commercial quantities for Takoradi and Sekondi markets, respectively. In addition, mats, baskets, and thatching materials derived from grasses and reeds are sometimes harvested in these wetlands. Livestock in the metropolis also relies heavily on the grasslands along these wetlands, especially in the dry season.

**Problems associated with coastal wetlands**

They pointed out some challenges they face living closer to the wetlands, contrary to the benefits the respondent identified above. The problems identified are flooding and the breeding of mosquitoes. About 49.8% of the respondents indicated that the wetlands breed mosquitoes in the Sekondi-Takoradi Metropolis, resulting in many residents, especially children, being infested with malaria. About 41.3% of the respondents also attested that most residents in their communities, especially those closer to the wetlands, relocate to other communities during the rainy seasons.

When they are not properly managed, as beneficial as coastal wetlands can be, they can especially create problems for residents living closer to them. For example, wetlands in the Sekondi-Takoradi Metropolis have ironically turned into breeding grounds for mosquitoes instead of spawning grounds for fish, as asserted by Costanza et al. (1997).

Table 7 shows that about 49.8% of the respondents indicated that the wetlands had become a breeding ground for mosquitoes. The respondents also indicated that most of the wetlands have been enroachment upon by prospective developers for residential and commercial buildings and have been choked with filth causing their communities to get flooded during rainy seasons.

At Whindo, the respondents particularly expressed their displeasure with the menace of mosquito breeding they have to cope with; respondents pointed out breeding mosquitoes as the main problem they faced due to the community's proximity to the wetland. However, refer to Rey et al. (2012), the mosquito population decreased after conservation measures in the wetlands. Table 8 presents community-specific problems related to coastal wetlands.

**Effects of urbanization on coastal wetlands**

There have been enormous physical developments in the Sekondi-Takoradi Metropolis over the past two decades. Most of these developments could seriously threaten the preservation of the wetlands. Table 9 shows that 97.3% of the respondents affirmed this position, which calls for adopting and implementing a stringent bye-law to stem this.

There are a lot of activities that affect wetlands worldwide. This study shows in the metropolis, four main physical development activities affect the three identified wetlands. These are the encroachment and subsequent development into residential, commercial, and industrial building activities and refuse to dump on site. Among the four main activities, residential development is the one that affects the loss of wetlands most in the Sekondi-Takoradi Metropolis, as shown in Table 10.

About 38.2% of the respondents identified residential building construction as one of the main activities affecting wetlands. About 29.3% of the respondents identified an activity affecting wetlands, which is the commercial building. Dumping of refuse in the Sekondi-Takoradi Metropolis was identified by 24.9% of the respondents as another activity that affect the three main wetlands.

From Table 10, about 34.2% of the respondents identified the residential building as the main activity in the Sekondi-Takoradi Metropolis, affecting the loss of coastal wetlands. Commercial activities have also increased in the past few years. These have also affected wetlands in one way or the other. Thus 30.2% identified commercial activities in the Sekondi-Takoradi Metropolis as another activity that affects the loss of wetlands. Industrial activities and refuse disposal have also affected wetlands, with the last choking the wetlands. The improper disposal of waste into the wetlands pollutes and affects the aquatic life within its immediate environments.

However, the activities affecting wetlands in the Sekondi-Takoradi Metropolis vary from one community to another. For instance, in Effiakuma, as many as 33 out of 45 respondents representing 73.3%, believed the loss of wetlands affected by the commercial activities in the community. Similarly, 35 out of 76 respondents representing 46.1% in Takoradi, indicated that residential buildings affect coastal wetlands (Table 11). In addition, some of the respondents in Takoradi confirmed the increasing inflow over the past 5 years of people from other parts of the country into the Sekondi-Takoradi Metropolis. However, all the respondents In Bakado and Buabakrom believe improper waste disposal affects the wetlands significantly. Referring to Asselen et al. (2013), agricultural development, population growth, and market/economic factors were identified as important causes of various types of land change (e.g., desertification and deforestation).

Natural resources worldwide are depleted or affected by natural occurrences like flooding, tsunami, earthquakes, and to a larger extent, human activities. The wetlands in the Sekondi-Takoradi Metropolis are no exception. Human activities in the metropolis have impacted the wetlands significantly. Building construction and waste disposal were some of the case points in this study. The impact of these activities is astounding due to the gradual effect on wetlands as their fauna and flora species are being lost.

**Table 7.** Problems associated with the coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana

| Problems identified | Frequency | Percent |
|---|---|---|
| Breeding mosquitoes | 112 | 49.8 |
| Flooding | 93 | 41.3 |
| Flooding & breeding mosquitoes | 17 | 7.6 |
| Breeding reptiles | 3 | 1.3 |
| Total | 225 | 100.0 |

**Table 9.** The threat of physical developments to the wetland

| Response | Frequency | Percent |
|---|---|---|
| Threats | 219 | 97.3 |
| No threats | 6 | 2.7 |
| Total | 225 | 100.0 |

**Table 10.** Activities affecting coastal wetlands loss in Sekondi-Takoradi Metropolis, Ghana

| Activity | Frequency | Percent |
|---|---|---|
| Residential building | 86 | 38.2 |
| Commercial building | 66 | 29.3 |
| Refuse dumping | 56 | 24.9 |
| Industrial | 17 | 7.9 |
| Total | 225 | 100.0 |

**Table 8.** Community and problems associated with coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana

| Community | Flooding | Breeding mosquitoes | Breeding reptiles | Flooding & breeding mosquitoes | Total |
|---|---|---|---|---|---|
| Apremdo | 4 (33.3) | 4 (33.3) | 0 | 4 (33.3) | 12 (100) |
| Bakado | 0 | 0 | 0 | 1 (100) | 1(100) |
| Buabakro | 0 | 1 (100) | 0 | 0 | 1(100) |
| Effia | 3(50) | 0 | 0 | 3(50) | 6(100) |
| Effiakuma | 10(22.2) | 7(15.6) | 11(24.4) | 17(37.8) | 45(100) |
| Kojokrom | 3(23.1) | 10(76.9) | 0 | 0 | 13(100) |
| New Takoradi | 6(31.6) | 6(31.6) | 3(15.8) | 4(21.1) | 19(100) |
| Sekondi | 0 | 20(40) | 0 | 30(60) | 50(100) |
| Takoradi | 0 | 35(46.1) | 12(15.8) | 29(38.2) | 76(100.0) |
| Whindo | 0 | 2(100) | 0 | 0 | 2(100) |
| Total | 26(11.6) | 85(37.8) | 26(11.6) | 88(39.1) | 225(100) |

**Table 11.** Community and activities affecting coastal wetlands loss

| Community | Residential building | Commercial building | Industrial | Refuse dumping | Total |
|---|---|---|---|---|---|
| Apremdo | 2(16.7) | 4(33.3) | 2(16.7) | 4(33.3) | 12(100) |
| Bakado | 0 | 0 | 0 | 1(100) | 1(100) |
| Buabakrom | 0 | 0 | 0 | 1(100) | 1(100) |
| Effia | 2(33.3) | 2(33.3) | 0 | 2(33.3) | 6(100) |
| Effiakuma | 5(11.1) | 33(73.3) | 2(4.4) | 5(11.1) | 45(100) |
| Kojokrom | 5(38.5) | 2(15.4) | 6(46.2) | 0 | 13(100) |
| New Takoradi | 4(21.1) | 5(26.3) | 5(26.3) | 5(26.3) | 19(100) |
| Sekondi | 23(46) | 10(20) | 0 | 17(34) | 50(100) |
| Takoradi | 35(46.1) | 11(14.5) | 4(5.3) | 26(34.2) | 76(100) |
| Whindo | 1(50) | 1(50) | 0 | 0 | 2(100) |
| Total | 77(34.2) | 68(30.2) | 19(8.4) | 61(27.1) | 225(100) |

Note: Percentage figures are in parentheses

About 96% of discussants indicated that the main cause of pollution and destruction of these wetlands is the human activities mentioned earlier. The assembly member noted, for instance, in Bakado that the wetland was choked with silt and debris from upstream. Furthermore, they associated this with construction and development activities at Kansaworado and its environs. Similarly, a sub-chief in Sekondi also associated the choked lagoon with the wreckless waste disposal and building activities upstream; the Assembly recently also said this resulted in the total blockade of the lagoon. Finally, the end is that the lagoon has lost its unique flora and fauna species.

Moreover, an opinion leader in Takoradi recounted how improper waste disposal and building construction along the Whin River has significantly affected the river. People living along the river throw both liquid and solid waste into it. They said most of this liquid waste is not good for some fish in the river; hence, they occasionally observe dead fish floating on the Whin river. Solid waste also prevents the river's free flow, especially during the dry and causes the river to overflow its banks during the rainy season. The assemblymember also noted that people have encroached upon the river banks, which have been personally reported to the Assembly.

In Effiakuma, New Takoradi, and Kojokrom, the situation was not far different. In New Takoradi, a fishmonger indicated that some residents were using the wetland as an easing site, which they visit every morning, and refuse dumping. That quickly added to how these activities had affected their low fish harvesting catch and the area's aquatic life in general.

### Institutions responsible for wetland protection and management

There are institutions in Sekondi-Takoradi Metropolis whose activities are in one way or the other related to the preservation, protection, and management of wetlands. In responding to this question, most discussants only identified the Assembly and two Non-Governmental Organizations (NGOs), namely Friends of the Nation (FON) and Coastal Resources Centre (CRC). However, an opinion leader at Bakado commended FON for the sensitization programs they organized in July 2012 for the residents in the community.

The assembly member for Apremdo also acknowledged that he was invited to a forum organized by Friends of the Nation (FON) to sensitize them on the need to preserve and protect wetlands and the coast. Table 12 shows details of the responses that most discussants identified three main institutions for protecting and preserving the wetlands in the Sekondi-Takoradi Metropolis. First, FON was highly recognized by the discussants as an institution that organizes workshops and sensitization programs for the people in the community. About 72% of the discussants could recognize FON and its role in preserving wetlands in the metropolis's.

The discussants also recognized another NGO called CRC (Hen Mpoano). Thus, 62% of the institutions acknowledged their role in protecting the wetlands in the Sekondi-Takoradi Metropolis. Furthermore, the NGO CRC was recognized for educating the residents on the need to preserve the wetlands and planting trees along the wetlands. Interestingly, the discussants could not separate the roles of the various departments in the Assembly. Hence, for this study's purpose, the role of Town and Country Planning, Works Department, Lands Commission, Environmental Health Sanitation and Management, and Parks and Gardens have been merged. As a result, the Assembly was perceived by the discussant as a law enforcement agency with the sole responsibility of preventing people from encroaching on wetlands and preserving them. On the other hand, the tourist Board and the Fisheries Commission were not recognized by the discussants as institutions interested in wetlands preservation.

**Table 12.** Institutions responsible for the preservation of wetlands

| Institution | Number of discussants | Percent |
|---|---|---|
| Environmental Protection Agency | 10 | 8 |
| Game and Wildlife | 6 | 5 |
| Assembly | 67 | 54 |
| Fisheries Commission | 12 | 8 |
| Parks and Gardens Department | 2 | 2 |
| Friends of the Nation (NGO) | 89 | 72 |
| Coastal Resource Centre (NGO) | 76 | 62 |

**Role of the institutions**

Every institution is set up to play a particular role in the country. However, due to the institution's malfunctioning or inadequate resources, most of these responsibilities have been left unattended. For example, the Parks and Gardens Department is responsible for beautifying the town and cities of the country. The department also plants trees along river banks and preserves some extinct plant species in the country. However, their role has been restricted to nursing plants, grasses, and flowers. A respondent indicated that the department was handicapped regarding resources and could not effectively execute its mandate.

The Wildlife Division is also responsible, in general, for conserving wildlife and managing wildlife-protected areas, in particular within the country's representative ecological zone. All five RAMSAR sites in the country have also been mandated to be managed by this division, sensitizing residents on the importance of natural resource protection. Again, the division is responsible for preserving and protecting the country's animals, flora, and fauna. Workshops and seminars were sometimes organized to create awareness of the need for the protection of the natural environment.

The orderly development of human settlements has been mandated to the Town and Country Planning department to plan and manage, and also provides planning schemes to guide this orderly development. Moreover, possible conflicts can be detected and resolved between the actual situation on the ground, approved schemes, and ownership claims. While wetlands are protected by buffers provision on the schemes, the department also ensures that no physical development occurs within any wetlands area through the permitting system. In addition, through development control, the Works Department ensures that no physical development occurs in a wetland and its buffer as proposed in the approved scheme for the area.

In collaboration with other institutions, Ghana's Environmental Protection Agency (EPA) manages, protects, and enhances the country's environment. The agency also creates awareness of the mainstream environment in national, regional, district, and community development. The EPA again ensures that the country's desire for effective, long-term maintenance of environmental quality consistent with the implementation of environmental policy and planning is integrated. Furthermore, it is the responsibility of the EPA to ensure the environmentally sound and efficient use of renewable and non-renewable resources in the process of national development. It also guides development to reduce, prevent, and eliminate pollution and actions that lower the quality of life as far as possible.

In addition, FON is a non-profit organization that provides services to communities and institutions through research, capacity building, networking, and advocacy that could catalyze increased action for sustainable natural resource management and healthy environments. FON also educates and creates awareness about natural resources' health and good governance. Moreover, FON provides advocacy for the rights of the voiceless communities on natural resources. The benefits of wetlands in the Sekondi-Takoradi Metropolis cannot be overemphasized. A representative from GWD indicated three major wetlands in the metropolis, which have not been declared as the country's RAMSAR sites. However, numerous benefits recounted from these wetlands offer communities abutting it and the metropolis. Wetlands provide water supply, flood control, and irrigation, protecting the coast and wildlife species habitat. A Ghana Tourist Authority (GTA) representative also stated that little had been done about the wetlands to serve the purpose of these wetlands as recreational centers. A respondent from the EPA stated that wetlands serve as spawning grounds for fish and some marine species. However, the encroachment and disturbance of the wetlands are attributed to the current low catch by fishermen. For example is the Essei Lagoon, which has been choked with refuse, especially closer to the estuary.

**Belief systems associated with coastal wetlands**

In African tradition, there are a lot of belief systems that are associated with natural resource usage. These sometimes help in the preservation of the natural resource in question. Though 70.7% of the respondents were unaware of any belief system associated with any of the wetlands within the Sekondi-Takoradi Metropolis, names such as "Matei" and "Nana Obrayeba" resonate well with the people of Sekondi and Bakado, respectively (Table 13). Additionally, to protect and preserve the wetlands from encroachment and pollution in the past, respondents recognized that the fear and respect of such belief systems helped. Verschuuren (2016) states that spirituality contributes significantly to wetland services and values but often remains overlooked and undervalued. The declining observance of cultural beliefs and taboos has contributed to the degradation of coastal wetlands in the Central Region of Ghana (Mensah 2003).

**Challenges faced by government institutions**

In the course of administering their role, the institutions such as Game and Wildlife are confronted with many challenges that hinder the effective delivery of their services, which have been around for a while. They must be addressed to facilitate the preservation and protection of wetlands in the Sekondi-Takoradi Metropolis and, by extension, the country. Almost all the institutions are grappling with the most challenging is the high rate of indiscipline among the community members. Most communities perceive wetlands as 'wasteland'; hence any attempt by a particular institution to discourage the use of these areas is considered as those retarding the growth and development in the metropolis. The Metropolis Town and Country Planning Office observed a confrontation with prospective developers in their duties that people become furious when denied permits to develop in such areas.

**Table 13.** Belief systems associated with coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana

| Response | Frequency | Percent |
|---|---|---|
| Don't know | 159 | 70.7 |
| Essei | 50 | 22.2 |
| Matei | 13 | 5.8 |
| Nana Obrayeba | 3 | 1.3 |
| Total | 225 | 100.0 |

During the interview, The EPA further revealed that residents around wetlands perceive dumping refuse in these wetlands as assisting the government in reclaiming those sites. The drastic decline in fish catch resulting from the loss of the entire mangrove through clearing in a lagoon at Anlo Beach near Shama, cited by the Game and Wildlife Division of the Ministry of Lands, Minerals & Natural Resources, a lack of education as responsible for the loss of the entire mangrove. Therefore, the division organized a sensitization program to educate them on the decline of the catch and the need to maintain the mangrove and other plants in the lagoon. However, many people in the study area do not appreciate why wetlands in the middle of the city are undeveloped.

Another significant challenge was inadequate budgetary support and logistics. For example, a Parks and Gardens Department representative stated that her department was constrained in carrying out its duties due to inadequate funds. Hence, their inability to perform their role of beautifying and developing the wetland buffers in the city. Furthermore, institutions in the Sekondi-Takoradi Metropolis also lacked the basic logistics to monitor and manage these areas. The result was the difficulty in policing the wetlands.

The weak collaboration among the institutions has also been a serious challenge in managing and preserving the wetlands in the Sekondi-Takoradi Metropolis. The GWD, for instance, indicated that their work after detecting any improper conduct by the resident or any individual ends in prompting the authorities in charge to prohibit or prosecute those who infringe on such areas. However, it sometimes falls on deaf ears hence rendering them ineffective. The representative from FON also recounted instances where some residents reported encroachment and improper disposal of waste into the lagoons and wetlands to the authorities responsible for protecting and preserving these areas. These people sometimes end up being taunted as laughing stock in their communities because the authorities fail to take appropriate actions to deter others in the community. Thus, the inaction of a particular institution sometimes compromises the work of other institutions that try to protect and preserve the wetlands.

Another significant challenge is the absence of a bye-law to protect, conserve and determine the use of wetlands. GWD, in this instance, indicated that it has been simply impossible and difficult for people to misuse the designated RAMSAR sites. Again, some institutions are faced with the absence of implementation and enforcement of laws that preserve and protect the wetlands in the Sekondi-Takoradi Metropolis. CRC (HENPOANO) indicated that the Assembly is overwhelmed and lacks the commitment to deal with recalcitrants who defy the laws in developing wetlands due to the absence of a bye-law. Other legal instruments, such as the LI 1630 (Section 2), which deals with developers who build without a permit, in the meantime, would have to be enforced to stem this cancer.

**Suggested solutions to protect and preserve coastal wetlands**

Several institutions like EPA, CRC, and Game and Wildlife Commission were implementing measures to preserve the coastal wetlands in the Sekondi-Takoradi Metropolis. These measures could therefore be complemented by the measures mentioned earlier. In all the study communities, about 75.1% of the respondents stated that the wetlands in the metropolis must be dredged to ensure easy flow to avoid flooding and breeding of mosquitoes which have been some of the problems facing residents living closer to the wetlands. About 15.6% of the respondents indicated that the wetlands should be preserved by planting trees along their banks. As a result of encroachment of the wetlands in the metropolis, 6% of the respondents also mentioned that the channel of some of the wetlands should be diverted (Table 14).

A rise in population in the metropolis and the country at large has increased land demand for development. However, the pressure to obtain land for development should not compromise the protection and preservation of these wetlands. The FON representative indicated the need to educate and sensitize people to understand the significant role wetlands play in the ecological balance of the environment. From the study, it was evident people had low or no idea about the significance of wetlands in their communities. They rather saw it as a wasteland and a nuisance to their communities. Hence, educating and sensitizing them would help to appreciate these wetlands and preserve them for future generations.

A respondent during the interview revealed that the communities should be involved in preserving the wetlands. For instance, the people of Essaman and Bakado had a strong belief that some of these lagoons were gods (usually called "Matei" and "Nana Obrayeba"); hence they revered and protected these lagoons through various traditional practices aimed at maintaining and preserving them. Again, a respondent from the Game & Wildlife Division also suggested during discussions that all the wetlands in the Sekondi-Takoradi Metropolis must be put under one formal management regime like RAMSAR to make its management easier and more difficult to infringe. Further, wetlands could be protected by putting them under Community Resource Management Areas (CREMAS) to involve the community. In this case, the people in the community itself would serve as watchdogs and prompt the authorities.

**Table 14.** Suggested solutions to conserving coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana

| Remedies | Frequency | Percent |
|---|---|---|
| Dredged | 169 | 75.1 |
| Preserved | 35 | 15.6 |
| Diverted | 14 | 6.2 |
| Diverted | 7 | 3.1 |
| Total | 225 | 100.0 |

In collaboration with the NGOs who work directly on wetlands, the Assembly should draft bye-laws solely to preserve the wetlands. The absence of the bye-laws makes it difficult for the authorities to prosecute people who misuse wetlands which would serve as a deterrent to others. A respondent from EPA also revealed that the Assembly should ensure compliance with the Environmental Impact Assessment to assess the impact of every activity that residents embark on in the Sekondi-Takoradi Metropolis before permits are issued.

In conclusion, the structure of the Sekondi-Takoradi Metropolis throughout history encouraged urbanization with its accompanying devastating effects, yet current measures and research to avert the challenges have failed to look at the possible impact urban activities on coastal wetlands; Urbanization generally would accelerate the waste generation and the rate of construction of new houses, offices, roads, and related real estate development. Most often, as this study has revealed, the residents perceived wetlands as wastelands, built their homes, and dumped refuse. Wetlands, especially coastal wetlands, are widely regarded as an important natural resource that requires a complex combination of policies, programs, and activities at the national and local levels to harness and protect their potential effectively.

Even though wetlands have also been seen negatively as breeding mosquitoes and reptiles; appropriate measures should be used to protect and manage the wetlands for the use of current and future generations; To preserve coastal wetlands, strategies like the formation of Wetland Conservation Clubs and establishment of buffer zone laws should be part of the wetland management agenda of the Sekondi-Takoradi Metropolis.

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