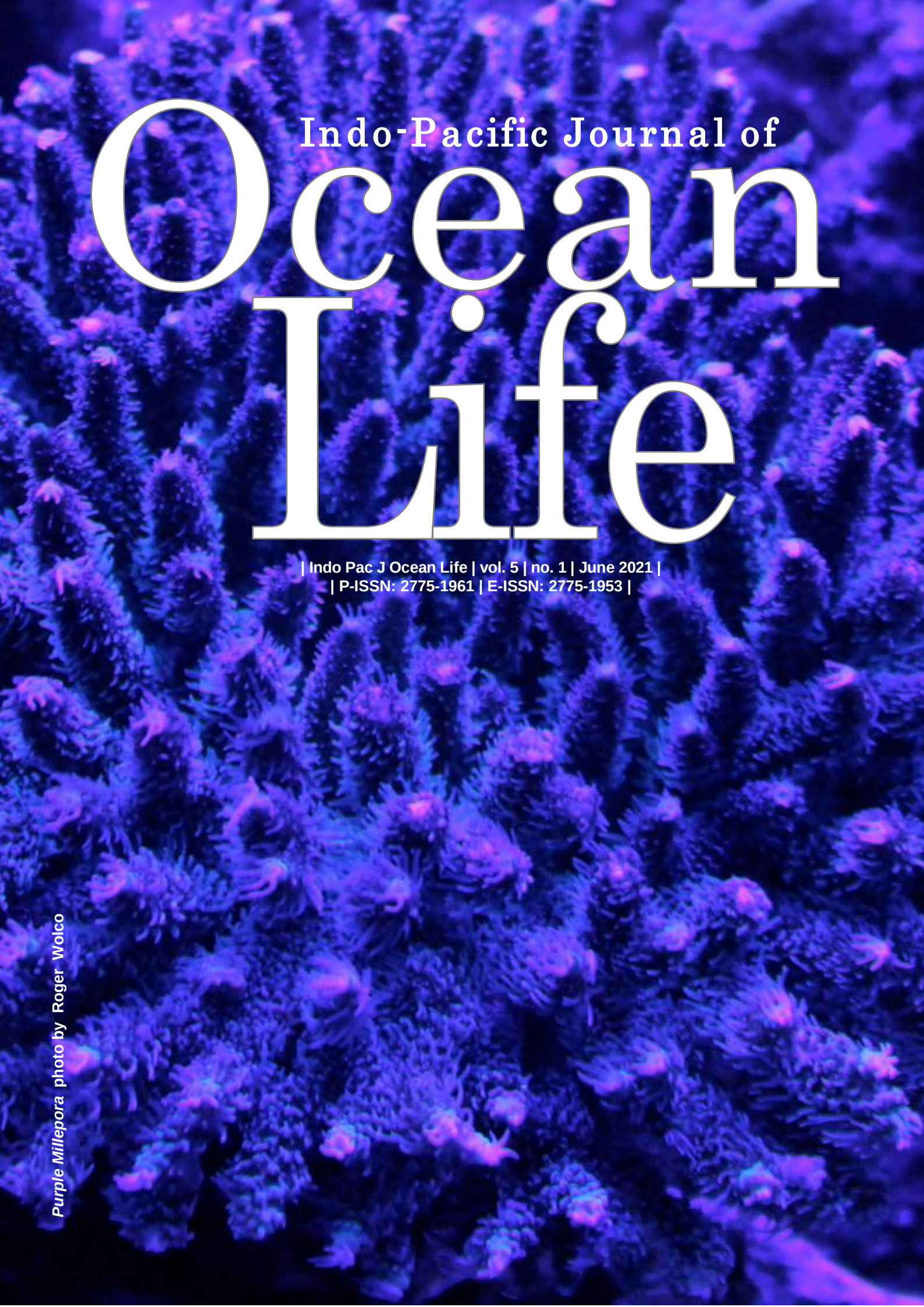

Indo-Pacific Journal of Ocean Life

| Indo Pac J Ocean Life | vol. 5 | no. 1 | June 2021 |
| P-ISSN: 2775-1961 | E-ISSN: 2775-1953 |

Purple Millepora photo by Roger Wolco

Indo-Pacific Journal of
Ocean Life

| Indo Pac J Ocean Life | vol. 5 | no. 1 | June 2021| P-ISSN: 2775-1961 | E-ISSN: 2775-1953 |

Published semiannually **PRINTED IN INDONESIA**

P-ISSN: 2775-1961 E-ISSN: 2775-1953

Indo-Pacific Journal of
Ocean Life

| Indo Pac J Ocean Life | vol. 5 | no. 1 | June 2021 |

ONLINE
http://smujo.id/ol

p-ISSN: 2775-1961; **e-ISSN:** 2775-1953

PUBLISHER
Society for Indonesian Biodiversity

CO-PUBLISHER
Universitas Papua, Manokwari, Indonesia

OFFICE ADDRESS
Research Center for Pacific Marine Resources, Institute for Research and Community, Universitas Papua.
Old Rectorat Complex Block III No. 7-8, Jl. Gunung Salju, Amban, Manokwari 98314, Papua Barat, Indonesia
Tel./fax.: +62-986-212156/211455, email: editors@smujo.id

PERIOD OF ISSUANCE
June, December

Society for Indonesian Biodiversity

Universitas Papua, Manokwari, Indonesia

Published by Smujo International for The Society for Indonesian Biodiversity and Universitas Papua Manokwari, Indonesia

GUIDANCE FOR AUTHORS

Aims and Scope: ***Indo Pacific Journal of Ocean Life*** (**Indo Pac J Ocean Life**) (*formerly Ocean Life*) encourages submission of manuscripts dealing with all aspects of maritime and marine resources in estuaries, coastal zones, continental shelves, the seas and oceans, including marine biodiversity and fisheries resources, biochemistry, physiology, behavior, and genetics of marine life, socio-economic and cultural aspects, conservation and management, as well as biogeochemistry, marine pollution, and climate change.

Article types The journal seeks for: (i) **Research papers**, (ii) **Reviews**, and (iii) **Short communications**. Original full-length research manuscripts are limited to 8,000 words (including tables and figures) or proportional to articles in this publication number (beyond that, it should be with notice). Review articles are also limited to 8,000 words, while Short communications should be less than 2,500 words, except for pre-study (can be more).

Submission The journal only accepts online submissions through the open journal system **(https://smujo.id/ol/about/submissions)** or, for login problems, email the editors at unsjournals@gmail.com (or editors@smujo.id). Submitted manuscripts should be the original works of the author(s). Please ensure that the manuscript is submitted using the template, which can be found at (https://biodiversitas.mipa.uns.ac.id/D/template.doc). The manuscript must be accompanied by a cover letter containing the article title, the first name and last name of all the authors, and a paragraph describing the claimed novelty of the findings versus current knowledge. Please also provide a list of five potential reviewers in your cover letter. They should come from outside your institution and better from three different countries. Submission of a manuscript implies the submitted work has not been published (except as part of a thesis or report, or abstract) and is not being considered for publication elsewhere. When a group writes a manuscript, all authors should read and approve the final version of the submitted manuscript and its revision; and agree on the submission of manuscripts for this journal. All authors should have made substantial contributions to the concept and design of the research, acquisition of the data and its analysis, drafting the manuscript, and correcting the revision. All authors must be responsible for the work's quality, accuracy, and ethics.

Ethics Author(s) must be obedient to the law and/or ethics in treating the object of research and pay attention to the legality of material sources and intellectual property rights.

Copyright If the manuscript is accepted for publication, the author(s) still hold the copyright and retain publishing rights without restrictions. For the new invention, authors must manage its patent before publication.

Open Access The journal is committed to free-open access that does not charge readers or their institutions for access. Readers are entitled to read, download, copy, distribute, print, search, or link to the full texts of articles, as long as not for commercial purposes. The license type is CC-BY-NC-SA.

Acceptance Only articles written in US English are accepted for publication. Manuscripts will be reviewed by editors and invited reviewers (double-blind review) according to their disciplines. Authors will generally be notified of acceptance, rejection, or need for revision within 1 to 2 months of receipt. Manuscripts will be rejected if the content does not align with the journal scope, does not meet the standard quality, is in an inappropriate format, or contains complicated grammar, dishonesty (i.e., plagiarism, duplicate publications, fabrication of data, citations manipulation, etc.), or ignoring correspondence in three months. The primary criteria for publication are scientific quality and significance. **Uncorrected proofs** will be sent to the corresponding author by system or email as .doc or .docx files for checking and correcting typographical errors. The corrected proofs should be returned in 7 days to avoid publication delays. The accepted papers will be published online in chronological order at any time but printed at the end of each month.

Free of charge This publication is dedicated entirely to the advancement of science and technology, therefore author(s), or author institution(s) are not subject to publication fees. **Reprints** The sample journal reprint is only available by special request. Additional copies may be purchased when ordering by email and sending back the uncorrected proofs.

Manuscript preparation Manuscript is typed on A4 (210x297 mm^2) paper size, in a single column, single space, 10-point (10 pt) Times New Roman font. The margin text is 3 cm from the top, 2 cm from the bottom, and 1.8 cm from the left and right. Smaller lettering sizes can be applied in presenting tables and figures (9 pt). Word processing program or additional software can be used; however, it must be PC compatible, use the template, and be Microsoft Word based (.doc or .rtf; not .docx). **Scientific names** of species (incl. subspecies, variety, etc.) should be written in italics, except in italicized sentences. Scientific names (genus, species, author) and cultivar or strain should be mentioned completely for the first time mentioning it in the body text, especially for taxonomic manuscripts. The genus name can be shortened after the first mention, except in early sentences, or where this may generate confusion; name of the author can be eliminated after the first mention. For example, *Rhizopus oryzae* L. UICC 524 can be written hereinafter as *R. oryzae* UICC 524. Using trivial names should be avoided. **Biochemical and chemical nomenclature** should follow the order of the IUPAC-IUB. For DNA sequences, it is better to use Courier New font. Standard chemical abbreviations can be applied for common and clear used, for example, completely written butilic hydroxyl toluene (BHT) to be BHT hereinafter. **Metric measurements** should use IS denominations, and other systems should use equivalent values with the denomination of IS mentioned first. A dot should not follow abbreviations like g, mg, mL, etc. Minus index (m^{-2}, L^{-1}, h^{-1}) suggested being used, except in things like "per-plant" or "per-plot." **Mathematical equations** can be written down in one column with text; in that case, they can be written separately. **Numbers** one to ten are written in words, except if it relates to measurement, while values above them are written in number, except in early sentences. The fraction should be expressed in decimal. In the text, it should be used "%" rather than "percent." Avoid expressing ideas with complicated sentences and verbiage/phrasing, and use efficient and effective sentences.

The title of the article should be written in compact, clear, and informative sentence, preferably not more than 20 words. Name of author(s) should be completely written, especially for the first and the last name. **Name and institution** address should also be completely written with street name and number (location), postal code, telephone number, facsimile number, and email address. We choose local names in Bahasa Indonesia for universities in Indonesia. The mention of "strata" program, should be avoided. Manuscript written by a group, author for correspondence along with address is required (marked with "♥"). **The title page** (first page) should include title of the article, full name(s), institution(s) and address(es) of the author(s); the corresponding authors detailed postage and e-mail addresses (P), and phone (O) and fax numbers (O).

Abstract A concise abstract is required (about 200 words). The abstract should be informative and state briefly the aim of the research, the principal results and major conclusions. An abstract is often presented separately from the article, thus it must be able to stand alone (completely self-explanatory). References should not be cited, but if essential, then cite the author(s) and year(s). Abbreviations should be avoided, but if essential, they must be defined at their first mention. **Keywords** are about five words, covering scientific and local name (if any), research themes, and special methods used; and sorted from A to Z. **Abbreviations** (if any): All important abbreviations must be defined at their first mention there. **Running title** is about five words.

Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

References Preferably 80% of it comes from scientific journals published in the last 10 years. In the text, give the author names followed by the year of publication and arrange from oldest to newest and from A to Z; in citing an article written by two authors, both of them should be mentioned; however, for three and more authors only the first author is mentioned followed by et al. For example, Saharjo and Nurhayati (2006) or (Boonkerd 2003a, b, c; Sugiyarto 2004; El-Bana and Nijs 2005; Balagadde et al. 2008; Webb et al. 2008). Extent citation should be avoided, as shown with the word "cit." Reference to unpublished data and personal communication should not appear in the list but should be cited in the text only (e.g., Rifai MA 2007, pers. com. (personal communication); Setyawan AD 2007, unpublished data). In the reference list, the references should be listed in alphabetical order. Names of journals should be abbreviated. Always use the standard abbreviation of a journal's name according to the **ISSN List of Title Word Abbreviations** (www.issn.org/2-22661-LTWA-online.php). Please include DOI links for journal papers. The following examples are for guidance.

Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

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:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

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.

THIS PAGE INTENTIONALLY LEFT BLANK

INDO PAC J OCEAN LIFE
Volume 5, Number 1, June 2021
Pages: 1-7

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o050101

Isolation and 16S rRNA characterization of culturable bacteria derived from fire coral *Millepora intricata* in Morela Coastal Waters, Maluku, Indonesia

MOCHAMAD UNTUNG KURNIA AGUNG[1,2,♥], NUNING KHAIRUNNISA[3], SRI ASTUTY[1], MUHAMMAD WAHYUDIN LEWARU[1,2], YUNIAR MULYANI[2,4]

[1]Department of Marine Science, Faculty of Fisheries and Marine Science, Universitas Padjadjaran. Jl. Raya Bandung Sumedang Km. 21, Jatinangor, Sumedang 45363, West Java, Indonesia. Tel.: +62-22-87701519, Fax.: +62-22-87701518, ♥email: mochamad.untung@unpad.ac.id

[2]Laboratory of Microbiology and Molecular Biotechnology, Faculty of Fisheries and Marine Science, Universitas Padjadjaran. Jl. Raya Bandung Sumedang Km. 21, Jatinangor, Sumedang 45363, West Java, Indonesia

[3]Program of Marine Science, Faculty of Fisheries and Marine Science, Universitas Padjadjaran. Jl. Raya Bandung Sumedang Km. 21, Jatinangor, Sumedang 45363, West Java, Indonesia

[4]Department of Fisheries, Faculty of Fisheries and Marine Science, Universitas Padjadjaran. Jl. Raya Bandung Sumedang Km. 21, Jatinangor, Sumedang 45363, West Java, Indonesia

Manuscript received: 20 October 2020. Revision accepted: 10 January 2021.

Abstract. *Agung MUK, Khairunnisa N, Astuty S, Lewaru MW, Mulyani Y. 2021. Isolation and 16S rRNA characterization of culturable bacteria derived from fire coral* Millepora intricata *in Morela Coastal Waters, Maluku, Indonesia. Indo Pac J Ocean Life 4: 1-7.* Millepora, well recognized as fire coral, has nematocytes that contain toxins as self-defense, allowing the associated bacteria to have a high level of adaptation to survive in this extreme environment. This research aims to isolate and characterize fire corals *Millepora intricata*-associated bacteria obtained from Morela coastal waters, Maluku, Indonesia using classical culture method. Sampling of *M. intricata* was carried out in August 2017 from the depth of 2-3 meters. The bacteria were grown in sea water-Nutrient Agar (NA) medium, streak plate method then used until pure isolates were obtained. Molecular identification of isolates was performed using 16S rRNA gene marker. The results indicated that nine culturable pure isolates were successfully obtained from *M. intricata*. Three isolates (MI.P1.B; MI.P2.C; and MI.P2.D2.K) then further proceed into molecular identification and sequencing. Alignment result based on the 16S rRNA databases repositored in the genebank (NCBI) showed that isolate MI P1.B has similarity to registered sequence of *Pseudoalteromonas arabiensis* strain k53 (NCBI acc no. NR_113220.1) with a sequence identity of 98%. Isolate MI.P2.C has a close relationship (98%) to registered sequence of *Halomonas aquamarina* strain DSM 30161 (NCBI acc no. NR_042063.1). Meanwhile, isolate MI.P2.D2.K has similarity to registered sequence of *Halomonas zhanjiangensis* strain JSM 078169 (NCBI acc no. NR_104283.1) with a sequence identity of 99%.

Keywords: Culturabel bacteria, fire coral, *Millepora intricata*, 16S rRNA gene marker

INTRODUCTION

Coral-associated bacteria play critical roles in the biogeochemical cycle, material transformation and maintaining health of coral reef ecosystem (Mahmoud and Kalendar 2016). The diversities of bacterial communities associated with corals are significantly affected by factors including species, geography and season (Hong et al. 2009; Li et al. 2014). The coral host physiology also significantly contributed to the composition of their associated bacterial communities, especially for the bacterial community that inhabits the mucus layer. During stress or when repelling predators the chemical composition of the coral mucus changes, concomitant with a shift in the composition of the mucus bacterial communities (Lee et al. 2016). Some corals secreted toxins as self-defense from predators, Millepora, is one of them (Veron 2000; Razak and Hoeksema 2003).

Millepora, a non-scleractinian coral, member of the family of Milleporidae (Suharsono 2008) have delicate hairs that protrude from the limestone skeleton called stinging cells or *nematocytes* that contain a cocktail of toxins which is released after appropriate stimulation (Espiritu et al. 2016) and sometimes it can change the composition of their bacterial community. Bacteria surviving inhabit this extreme environment developing the ability to respond to and resist toxin threats from the host and may indicate some unique properties in their adaptation mechanisms. Indonesia has at least six species of Millepora namely *Millepora intricata*, *M. platyphylla*, *M. exaesa*, *M. dichotoma*, *M. tenella*, and *M. boschmai* (Suharsono 2008). Various species are spread in several regions in Indonesia, including Maluku. According to Fatkhurrochman (2017), two species of Millepora have been found in Morela coastal waters, Maluku, namely *M. intricata* and *M. platyphylla*.

Molecular identification based on 16S rRNA gene is powerful and widely used for decades for prokaryotic cells, due to the slow rates of evolution of this region of the gene (Woese and Fox 1977). This gene is highly conserved between different species of bacteria and archaea (Coenye and Vandamme 2003). Ribosomal RNAs are integral

elements of the protein-synthesizing apparatus, the basic components of which are present in all primary kingdoms, and are among the most highly conserved cellular molecules (Devereux and Wilkinson 2004).

A better understanding of assembly and specificity of bacterial communities surviving with Millepora will provide new avenues as a preliminary for further study of the adaptation mechanisms and the uniqueness of metabolites that may be produced by these surviving bacteria as the potential sources for biotechnology and pharmaceuticals purposes. Therefore, the aim of this recent research is to isolate and characterize culturable surviving *M. intricata*-associated bacteria based on 16S rRNA gene marker.

MATERIALS AND METHODS

Sample collection

Sampling was performed by snorkeling at 2-3 meters depths in Morela coastal waters, Maluku, Indonesia, spotted at $3^0$31'25.57"S (Latitude) and $128^0$12'53.19" E (Longitude) (Figure 1). *M. intricata* fragments (3-5 cm) were taken from coral colony carefully and preserved with 10% glycerol, then transferred to laboratory and stored at -20^0C. During sampling, water temperature, salinity and pH were measured.

Cultivation of *M. intricata*-associated bacteria

The coral skeletons were crushed by using a sterilized pestle and mortar containing 0,85% NaCl. A dilution series was performed until 10^{-5} (P1), 10^{-6} (P2), and 10^{-7} (P3) then 100 µL suspension of each dilution was poured and flattened carefully in Nutrient Agar medium (Oxoid^{TM}) dissolved with seawater, incubated for 1x24 hours at 30^0C. Sub-culture and isolates purification was performed using streak plate method in consistant medium (Cappuccino and Welsh 2018). Morphological characteristics and cell forms of colonies were observed. Gram staining also performed to observe and distinguish particular colonies during isolates purification, based on differences in the composition and structure of cell walls (Pelczar and Chan 1986).

Genome isolation, PCR-amplification and sequencing

Bacterial genome from selected pure isolates was extracted by using Genomic DNA Purification Kit (Promega^{TM}), according to the manufacturer's instructions and resuspended in 50 µL Nuclease Free Water (NFW), visualized with 0,8% gel agarose electrophoresis stained with GelRed (Biotum^{TM}), and stored at -20^0C until required.

Primer pair 27F (5'-AGAGTTTGATCMTGGCTCAG-3') and 1492R (5'-TACGGYTACCTTGTTACGACTT-3'), especially targeting a 1.465 bp fragment of the genomic bacterial 16S rRNA gene (Lane 1991), were used for PCR amplification of DNA. The PCRs include 1X GoTaq Green Master Mix (Promega^{TM}), 10 pmol of each primer, adjusted to a final volume of 25 µL with NFW. The reaction conditions were as follows: 95^0C for 120 sec; followed by 30 cycles of 95^0C for 45 sec, 51^0C for 60 sec, and 72^0C for 60 sec; then a final extension of 72^0C for 5 min. Amplified PCR products were visualized by electrophoresis on 1% agarose gel stained with GelRed (Biotum^{TM}). All PCR products were sent to 1st Base^{TM} in Singapore to be sequenced using Sanger method.

Figure 1. Map of sample collection site (showed by a red node and arrow) at Morela Coastal Waters, Maluku, Indonesia

BLAST and phylogenetic analysis

DNA sequences of 16S rRNA fragments of selected isolates were proceed using BioEdit™. The resulting sequences are then identified by aligning the sequences using Basic Local Alignment Search Tool/ BLAST™, available on NCBI (www.ncbi.nlm.nih.gov), and compared with the reference sequences. Phylogenetic analysis was carried out using MEGA™ 7.0 software. All sequences were aligned using ClustalW™ program. Trees were constructed using Neighbor-joining methods and assessed with 1000 bootstrap replicates.

RESULTS AND DISCUSSION

Colony morphology and cell types of isolated *M. intricata*-associated bacteria

Nine pure colonies were obtained from 3 dilution series (P1, P2, and P3). The majority of colonies showed similar characteristics, according to Leboffe and Perce (2012) (Table 1, Figure 2).

Pelczar and Chan (1986) stated that 95% of marine bacteria are Gram-negative bacteria. The complex structure of Gram-negative bacteria's cell wall makes this group of bacteria able to withstand extreme environmental conditions such as in the ocean environment.

Table 1. Morphological characteristics of colonies and cell types

Isolate name	Colony morphology			Cell type	
	Elevation	Margin	Form	Form	GRAM
MI.P1.B	Convex	Smooth, entire	Round	Rod	Negative
MI.P2.C	Raised	Irregular	Irregular	Rod	Negative
MI.P2.D1.K	Flat	Lobate	Irregular	Spherical	Negative
MI.P2.D1.P	Convex	Irregular	Irregular	Rod	Negative
MI.P2.D2.K	Flat	Smooth, entire	Irregular	Rod	Negative
MI.P2.D2.P	Convex	Irregular	Irregular	Spherical	Negative
MI.P3.E1	Convex	Smooth, entire	Round	Spherical	Negative
MI.P3.E2	Convex	Smooth, entire	Round	Rod	Negative
MI.P3.F	Convex	Smooth, entire	Irregular	Rod	Negative

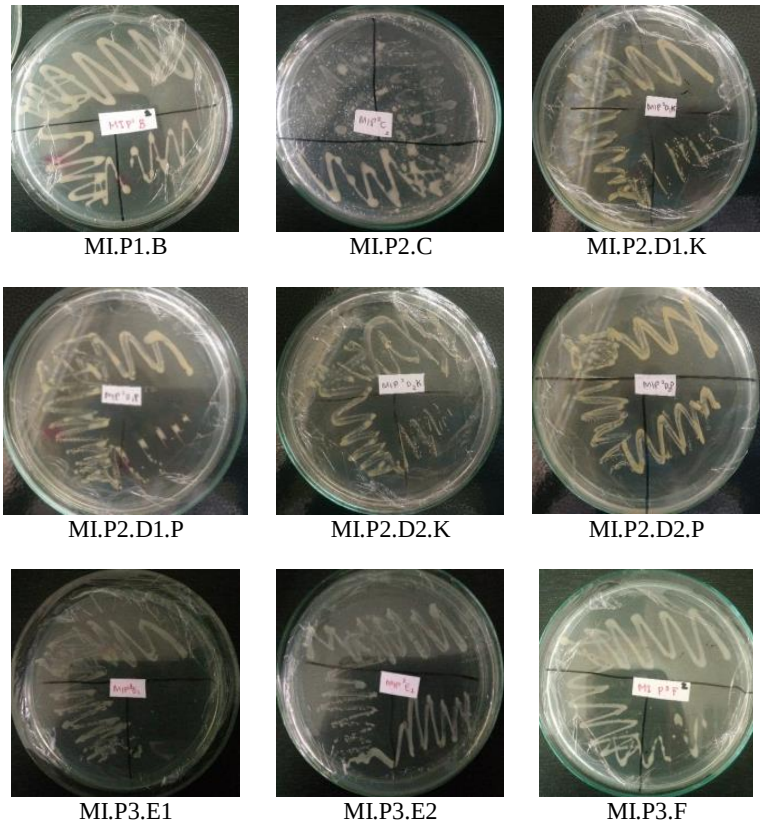

Figure 2. Morphological appearance of isolates on Nutrient Agar (NA) media

Based on the results of Gram staining, two different forms of bacterial cell types were obtained, rod (*bacillus*) and spherical (*coccus*). The *coccus* bacteria do not have flagellum as a tool for its movement, and this group is possible to be associated with *M. intricata*. This is reinforced by the statement of Hutchings and Saenger (1987) that the *coccus* bacteria are generally bound or joined to form a solid surface, because of the mucus material so that the cells are bound together and cause the bacteria to live in algae, seaweed, seagrass, and coral reefs. Meanwhile, the *bacillus* bacteria have a flagellum so that their life defense mechanism by moving in the waters. According to Sidharta (2000), the flagellum allows bacteria to move towards favorable environmental conditions or avoid an environment that is detrimental to their lives.

Bacterial genome and 16S rRNA amplicon

Three of nine pure isolates were selected based on their morphological differences and were administrated for molecular identification. Three bands with size upper than 10 kb were obtained (Figure 3a). Genomes concentration was measured. And three bands spotted around 1500 bp were obtained after PCR amplification (Figure 3b) indicates successful 16S rRNA gene fragments amplification using 27F and 1492R primer pair.

According to the gel electrophoresis visualization, the genomic DNA has been successfully isolated showed by bands rose above 10.000 bp compared to DNA Ladder (Figure 2a). The thickness of bands was varied between three samples and indicated the difference in DNA concentration (Agung et al. 2020). Thus, the 16S rRNA gene amplification showed that the three isolates had a single band that was about 1.500 bp, corresponds to the expected product size of 27F and 1492R primer pair, which is ± 1,465 bp. Amplification of 16S rRNA encoding gene has become a standard for studying the phylogenetic and diversity of marine bacteria (Radjasa and Sabdono 2003). The 27F and 1492R primer pair are the most widely used primers for amplification of the 16S rRNA bacterial gene (Frank et al. 2008).

BLAST™ analysis and phylogenetic tree construction

DNA sequencing results of the three selected isolates then be aligned to compare with 16S rRNA database using BLAST™ that was available in NCBI (Table 5). The result showed the high identity of isolates compared with NCBI database of 16S rRNA. And according to the results, all isolates have similarity with bacteria comes from marine environment.

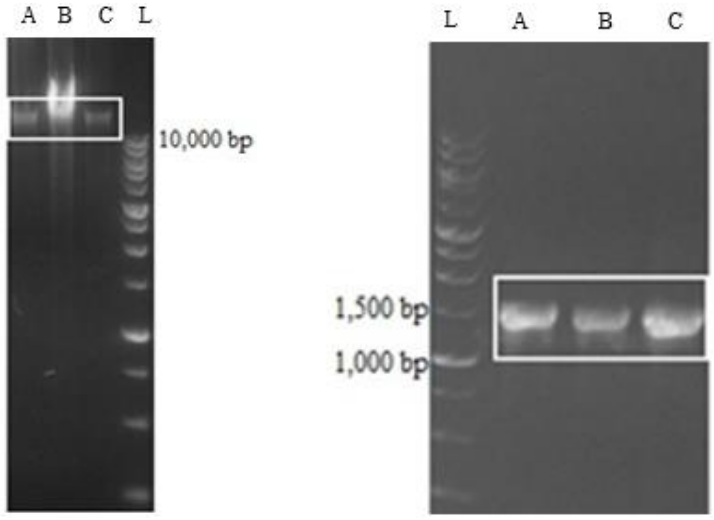

Figure 3. Gel electrophoresis visualization of **(A)** genome DNA and **(B)** 16S rRNA gene fragments of *Millepora intricata*-associated bacteria performed in 1% agarose gel, **L**: 1 Kb DNA ladder (Fermentas™), **A**: isolate of MI.P1.B, **B**: isolate of MI.P2.C, **C**: isolate of MI.P2.D2.K

Table 2. BLAST™ analysis of 16S rRNA sequences of *M. intricata*-associated bacteria

Isolate Codes	Closest taxonomically related strain	Taxonomic description (class)	Sequence identity (%)	Query cover (%)	NCBI Acc. no
MI.P1.B	*Pseudoalteromonas arabiensis* strain k53	Gammaproteobacteria	98	96	NR_113220.1
MI.P2.C	*Halomonas aquamarina* strain DSM 30161	Gammaproteobacteria	98	95	NR_042063.1
MI.P2.D2.K	*Halomonas zhanjiangensis* strain JSM 078169	Gammaproteobacteria	99	92	NR_104283.1

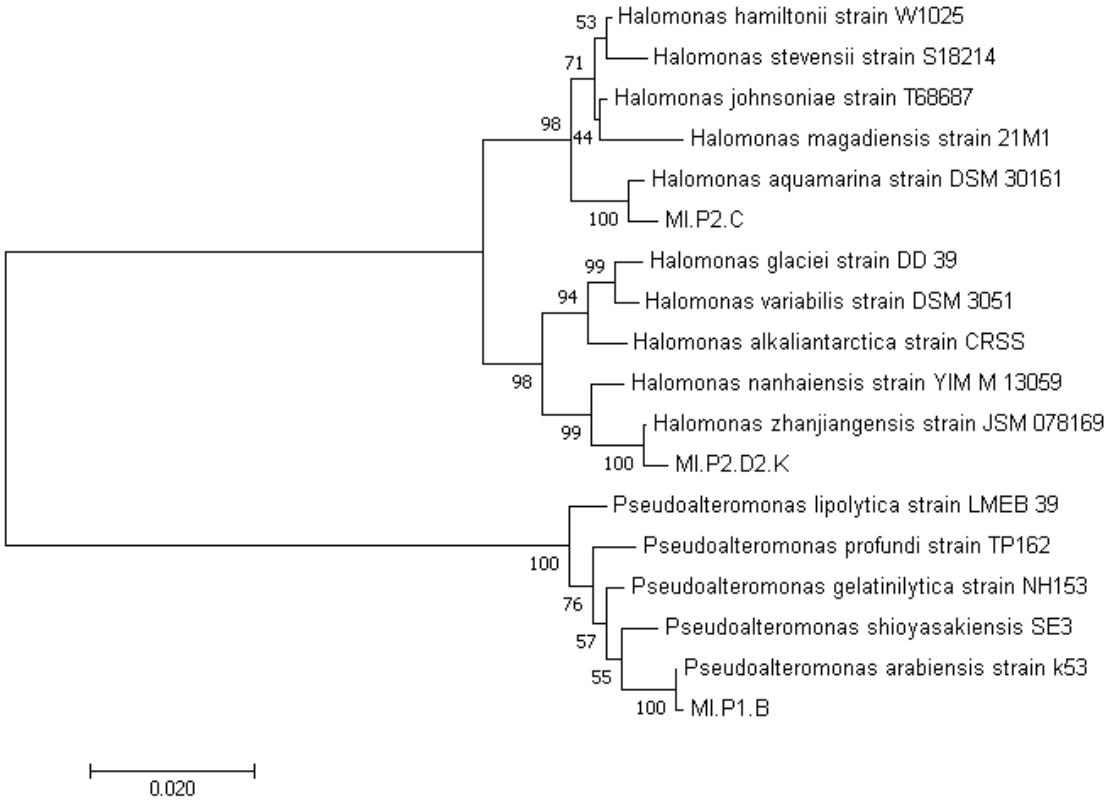

Figure 4. Neighbor-joining tree of 16S rRNA Genes of *Millepora intricata*-associated bacteria (1000x bootstrapping)

The three isolates obtained from *M. intricata* have belonged to the same class of Gammaproteobacteria. Some genus belongs to Gammaproteobacteria have been reported to associate with a large diversity of marine organisms, including cnidarians, poriferans, mollusks, annelids, tunicates, and fish (Morrow et al. 2012). Phylogenetic analysis aims to properly reconstruct the relationship between organisms and estimate differences that occur from one ancestor to their offspring (Li et al. 1996).

According to the phylogenetic tree above, isolate MI.P1.B has a very close relationship with *Pseudoalteromonas arabiensis* strain k53. This is indicated by the bootstrap value between the two sequences which is high at 100%. The percentage of 100% bootstrap means that of the 1,000 times the construction of this phylogenetic tree, the sequence MI.P1.B has a 100% genetic relationship with *P. arabiensis* strain k53. According to Hillis and Bull (1993) bootstrap values ≥ 70% indicate the possibility of ≥ 95% of these organisms have a high level of genetic relationship and can be trusted.

Bacterial species *P. arabiensis* strain k53 was first isolated by Matsuyama et al. (2013) from sediments in the Arabian Sea using a culture method. This species grows at temperatures around 6-35ºC with optimum pH 7-8. This is similar to the culture approach carried out in this research, cultivation of the sample MI.P1.B also performed at 30ºC. This species is an aerobic, Gram-negative bacterium, not an endosporic-forming bacterium, is motile, its cell type is bacillic, has smooth colonies, convex, circular, and entire. This species belongs to the genus of Pseudoalteromonas and the class of Gammaproteobacteria. The genus Pseudoalteromonas is a genus consisting of aerobic, Gram-negative marine bacteria and has a flagellum to push or attract bacterial cells in a liquid medium (Madigan et al. 2015) Based on a study conducted by Atencio et al. (2018), the genus Pseudoalteromonas is widely distributed in the marine environment and associated with marine organisms.

The isolate MI.P2.C has a very close relationship with the *H. aquamarina* bacterial species strain DSM 30161 with a bootstrap value of 100%. Based on data on the Integrated Taxonomic Information System (ITIS), the species of *H. aquamarina* strain DSM 30161 belong to the genus Halomonas and the Gammaproteobacteria class. The species is an aerobic, Gram-negative bacterium isolated from seawater and can live in environments that have a wide range of salinity (euryhaline) (Dobson and Franzmann 1996). According to Arahal et al. (2002), this species is a bacillic bacterium, is motile, has a flagellum around its cells, can grow at temperatures around 5-40ºC with a pH between 5-9.

Meanwhile, the isolate MI.P2.D2.K has a very close relationship with the *H. zhanjiangensis* bacterial species strain JSM 078169 with a 100% bootstrap value. Based on research by Chen et al. (2009) *H. zhanjiangensis* bacteria strain JSM 078169, was first isolated from the species of sea urchin *Hemicentrotus pulcherrimus* in the tidal zone at the Naozhou Island waters, south of Zhanjiang city, China. This bacterium is a halophilic, aerobic, Gram-negative, bacillic, flat surface, circular edge, motile, has a flagellum

around the cell, and is yellow. This species can grow at a pH of about 6-10.5 (optimum 7.5) and a temperature of 4-40ºC (optimum 25-30ºC). Antibiotics that can inhibit the growth or kill of these bacterial species at certain concentrations include ampicillin, carbenicillin, gentamicin, nalidixic acid, polymixin, rifampicin, and streptomycin (Chen et al. 2009).

***Millepora intricata*-bacteria interactions**

The coral holobiont is comprised of the coral animal and its associated microorganisms consisting of bacteria, archaea, fungi, viruses, and protists including the dinoflagellate algae *Symbiodinium* (Rohwer et al. 2002). However, the interactions between coral and bacteria have not been well studied because the bacterial assemblages on corals are complex and dynamic (Ritchie 2012). Research to date indicates that bacterial associates of corals may have critical roles in protecting the host (Rosenberg et al. 2007), supporting its growth, including fixation and passage to the coral host of nitrogen and carbon (Kimes et al. 2010) and stabilizing the coral holobiont as a whole (Zang et al. 2015).

Genus of Millepora has been reported secreting a protein toxin called Milleporin (Radwan and Aboul-dahab 2005) and may be used as chemical defenses against fouling and potentially pathogenic microorganisms. Since host metabolites are a strong selective force for controlling its microbiome composition (Foster et al. 2017), bacteria use a range of appendages to attach to a surface that can mediate host specificity (Klemm and Schembri 2000). According to this recent study, *P. arabiensis*, *H. aquamarina*, and *H. zhanjiangensis* were successfully isolated from *M. intricata* based on classical culture method. These three isolates may have developed special mechanisms for both interacting with the host and contributing some beneficial roles to support the host survival.

Pseudoalteromonas arabiensis has significant roles in reducing nitrate to nitrite and producing various types of enzymes including trypsin (Matsuyama et al. 2013). *P. arabiensis* which is isolated from the tissues and layers of the Octocoralia mucus is capable of producing exopolysaccharide (EPS), a bioactive molecule that acts as an antifungal. These bioactive molecules make this bacteria able to help corals againts pathogenic invasions and be resistant to disease infections (Atencio et al. 2018).

Halomonas aquamarina also plays an important function to reduce nitrate in the marine environment and and produce urease (Mata et al. 2002). Suantika et al. (2013) reported that *H. aquamarina* is able to inhibit pathogenic bacteria *Vibrio harveyi* in white shrimp intestine, by producing exoenzyme and organic compounds and release it to the intestine mucus as defensive agents. *H. aquamarina* can also secrete bacteriocin to inhibit the growth of other pathogenic bacteria. This bacterial species can produce *aquachelin siderophore* molecules which are Fe^{3+} complex compounds or specific iron chelating, which are useful for hiding iron elements in the environment so that the iron is not available for the growth of pathogenic bacteria.

The discovery of compounds or mechanisms carried out by Genus of Halomonas to inhibit pathogenic bacterial growth, indicates that *H. aquamarina* and *H. zhanjiangensis* successfully adapt and survive in an environment filled with pathogens or toxins, such as in the *M. intricata* holobiont.

Finally, a detailed understanding of the mechanism and functional role of bacteria in the *M. intricata* holobiont and their ecological role would be valuable both for the management of coral reefs and for the biotechnological prospects for the development of pharmacological bioactive compounds.

ACKNOWLEDGEMENTS

This work is financially supported by Universitas Padjadjaran through the Grant of Fundamental Research (RFU) year of 2018. The authors would like to acknowledge M. Fahrul Barcinta from the University of Pattimura for help with instrumentation during sampling. The limited fragments of coral *M. intricata* were taken only for research purposes.

REFERENCES

Agung MUK, Maqbul I, Astuty S, Mulyani Y. 2020. Bacterial community composition among coral diseases in Biawak Island using denaturing gradient gel electrophoresis. Res J Chem Environ 24 (1): 93-98. DOI: 10.13140/RG.2.2.12216.29445

Arahal DR, Wolfgang L, Karl HS, Antonio V. 2002. Phylogeny of the family *Halomonadaceae* based on 23S and 16S rDNA sequences analyses. Intl J Syst Evol Microbiol 52: 241-249. DOI: 10.1099/00207713-52-1-241.

Atencio LA, Francesco DG, Giannina OY, Ronnie G, Hector MG, Imke S, Luis CM, Marcelino G. 2018. Antimicrobial-producing Pseudoalteromonas from the marine environment of Panama shows a high phylogenetic diversity and clonal structure. J Basic Microbiol 58: 747-769. DOI: 10.1002/jobm.201800087

Cappuccino JG, Welsh C. 2018. Microbiology a Laboratory Manual. 11th ed. Pearson, England.

Chen YG, Yu-Qin Z, Heng-Yu H, Hans-Peter K, Shu-Kun T, Ke H, Qi-Hui C, Xiao-Long C, Wen-Jun L. 2009. *Halomonas zhanjiangensis* sp. nov., a halophilic bacterium isolated from a sea urchin. Intl J Syst Evol Microbiol 59: 2888-2893. DOI: 10.1099/ijs.0.010173-0

Coenye T, Vandamme P. 2003. Diversity and significance of *Burkholderia* species occupying diverse ecological niches. Environ Microbiol 5 (9): 719-729. DOI: 10.1046/j.1462-2920.2003.00471.x.

Devereux R, Wilkinson SS. 2004. Amplification of Ribosomal RNA Sequences. Kluwer Academic Publisher, Netherlands.

Dobson SJ, Franzmann PD. 1996. Unification of the genera *Deleya* (Baumann et al. 1983), *Halomonas* (Vreeland et al. 1980), and *Halovibrio* (Fendrich 1988) and the species *Paracoccus halodenitrificans* (Robinson and Gibbons 1952) into a single genus, *Halomonas*, and placement of the genus *Zymobacter* in the family *Halomonadaceae*. Intl J Syst Bacteriol 46 (2): 550-558. DOI: 10.1099/00207713-46-2-550.

Espiritu RA, Raymond SM, Consolacion YR. 2016. Chemical constituents of *Millepora dichotoma.* Der Pharm Chem 8 (3): 245-248.

Fatkhurrochman. 2017. Aktivitas Antibakteri dari Bakteri Asosiasi Karang Api (*Millepora* sp.) Terhadap Bakteri Patogen pada Karang yang Terkena Black Band Disease (BBD). [Hon. Thesis]. Universitas Padjadjaran, Bandung. [Indonesian]

Foster KR, Schluter J, Coyte KZ, Rakoff-Nahoum S. 2017. The evolution of the host microbiome as an ecosystem on a leash. Nature 548 (7665): 43-51 DOI: 10.1038/nature23292.

Frank JA, Claudia IR, Shobha S, Jon SW, Brenda AW, Gary JO. 2008. Critical evaluation of two primers commonly used for amplification

of bacterial 16S rRNA genes. Appl Environ Microbiol 74 (8) 2461-2470. DOI: 10.1128/AEM.02272-07.

Hillis DM, James JB. 1993. An empirical test of bootstrapping as a method for assessing confidence in phylogenetic analysis. Syst Biol 42 (2): 182-192.

Hong M-J, Yu Y-T, Chen CA, Chiang PW, Tang SL. 2009. Influence of species specificity and other factors on bacteria associated with the coral *Stylophora pistillata* in Taiwan. Appl Environ Microbiol 75 7797-7806. DOI: 10.1128/AEM.01418-09

Hutchings P, Saenger P. 1987. Ecology of Mangroves. University of Queensland Press, St Lucia, Qld.

Integrated Taxonomic Information System (ITIS). Available: http://www.itis.gov. [28 September 2018]

Kimes NE, Van Nostrand JD, Weil E, Zhou J, Morris PJ. 2010. Microbial functional structure of *Montastraea faveoata*, an important Caribbean reef-building coral, differs between healthy and yellow-band diseased colonies. Environ Microbiol 12 (2): 541-556.

Klemm P, Schembri MA. 2000. Bacterial Adhesin: function and structure. Intl J Med Microbiol 290: 27-35

Lane DJ. 1991. 16S/23S rRNA sequencing. In: Stackebrandt E, Goodfellow M (eds). Nucleic Acid Techniques in Bacterial Systematics. Wiley & Sons, New York.

Leboffe MJ, Pierce BE. 2012. Microbiology Laboratory Theory & Application: Brief. 2nd ed. Morton Publishing Company, Englewood.

Lee STM, Davy SK, Tang S, Kench PS. 2016. Mucus sugar content shapes the bacterial community structure in thermally stressed *Acropora muricata*. Front Microbiol 7: 371. DOI: 10.3389/fmicb.2016.00371

Li J, Chen Q, Long L-J, Dong J-D, Yang J, Zhang S. 2014. Bacterial dynamics within the mucus, tissue and skeleton of the coral *Porites lutea* during different seasons. Sci Rep 4: 7320. DOI: 10.1038/srep07320

Li S, Dennis KP, Hani D. 1996. Phylogenetic tree construction using Markov Chain Monte Carlo. https://pdfs.semanticscholar.org/7cfb/3b0dfde70d1b25c97d888a908e5a637b678b.pdf

Madigan MT, Martinko JM, Bender KS, Buckley DH, Stahl DA. 2015. Brock Biology of Microorganisms. 14th ed. Pearson, England.

Mahmoud HM, Kalendar AA. 2016. Coral-associated actinobacteria: Diversity, abundance, and biotechnological potentials. Front Microbiol 7: 204. DOI: 10.3389/fmicb.2016.00204

Mata JA, Jose MC, Emilia Q, Victoria B. 2002. A detailed phenotypic characterisation of the type strains of *Halomonas* species. Syst Appl Microbiol 25 (3): 360-375. DOI: 10.1078/0723-2020-00122.

Matsuyama H, Hideki M, Hirokazu K, Yoshihisa K, Masafumi M, Isao Y. 2013. *Pseudoalteromonas arabiensis* sp. nov., a marine polysaccharide-producing bacterium. Intl J Syst Evol Microbiol 63: 1805-1809 DOI: 10.1099/ijs.0.043604-0.

Morrow KM, Moss AG, Chadwick NE, Liles MR. 2012. Bacterial associates of two Caribbean coral species reveal species-specific distribution and geographic variability. Appl Environ Microbiol 78: 6438-6449. DOI: 10.1128/AEM.01162-12

Pelczar MJ, Chan ECS. 1986. Dasar Dasar Mikrobiologi Jilid 1. UI Press, Jakarta. [Indonesia]

Radjasa OK, Sabdono A. 2003. Screening of secondary metabolite-producing bacteria associated with corals using 16S rDNA-based approach. J Coast Dev 7 (1): 11-19.

Radwan FFY and Aboul-Dahad HM. 2005. Milleporin-1, a new phospholipase A_2 active protein from the fire coral *Millepora platyphylla* nematocysts. Comp Biochem Phys C Toxicol Pharmacol 139: 267-272.

Razak TB, Hoeksema BW. 2003. The Hydrocoral genus *Millepora* in Indonesia. Zool Verh Leiden 345: 313-336

Ritchie KB. 2011. Bacterial Symbionts of Corals and Symbiodinium. Chap 9. In: Rosenberg E, Gophna U (eds.) Beneficial Microorganisms in Multicellular Life Forms. Springer, Berlin. DOI: 10.1007/978-3-642-21680-0_9.

Rohwer F, Seguritan V, Azam F, Knowlton N. 2002. Diversity and distribution of coral-associated bacteria. Mar Ecol Prog Ser 243: 1-10 DOI: 10.3354/meps243001.

Rosenberg E, Koren O, Reshef L, Efrony R, Zilber-Rosenberg I. 2007. The role of microorganisms in coral health, disease and evolution. Nat Rev Microbiol 5: 355-362.

Sidharta BR. 2000. Pengantar Mikrobiologi Kelautan. Universitas Atmajaya, Yogyakarta. [Indonesian]

Suantika G, Pingkan A, Dea IA, Zarah FK. 2013. The Use of Indigenous probiotic *Halomonas Aquamarina* and *Shewanella algae* for White Shrimp (*Littopenaeus vannamei* Boone) hatchery productivity in zero water discharge system. J Aquac Res Dev 4: 194. DOI: 10.4172/2155-9546.1000194.

Suharsono. 2008. Jenis-jenis Karang di Indonesia. Coremap Program. LIPI Press, Jakarta. [Indonesian]

Veron J. 2000. Corals of the World Vol. 3. Australian Institute of Marine Science, Townsville Australia.

Woese CR, Fox GE. 1977. Phylogenetic structure of the prokaryotic domain: The primary kingdoms. Proc Natl Acad Sci USA. 74 (11): 5088-5090.

Zhang YY, Ling J, Yang QS, Wang YS, Sun CC, Sun HY, Feng JB, Jiang YF, Zhang YZ, Wu ML, Dong JD. 2015. The diversity of coral-associated bacteria and the environmental factors affect their community variation. Ecotoxicology. DOI: 10.1007/s10646-015-1454-4.

INDO PAC J OCEAN LIFE
Volume 5, Number 1, June 2021
Pages: 8-13

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o050102

Coral reef ecosystem health status of Paladan Islands, Indonesia: An assessment criteria using coral cover percentage

EKA REZA S. WIDODO[1♥], ABUBAKAR SIDIK KATILI[2,3], MUSTAMIN IBRAHIM[2,3]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo. Jl. Prof. Dr. Ing. B. J. Habibi, Tilongkabila, Bone Bolango 96554, Gorontalo, Indonesia. Tel./fax.: +62-435-821125, ♥email: ekarezas.widodo23@gmail.com.

[2]Lecturer in Biology Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo. Jl. Prof. Dr. Ing. B. J. Habibi, Tilongkabila, Bone Bolango 96554, Gorontalo, Indonesia.

[3]Center of Coastal Ecology Studies Based on Local Wisdom, Department of Biology, Universitas Negeri Gorontalo. Jl. Prof. Dr. Ing. B. J. Habibi, Tilongkabila, Bone Bolango 96554, Gorontalo, Indonesia, Gorontalo Province, Indonesia

Manuscript received: 23 November 2020. Revision accepted: 5 April 2021.

Abstract. *Widodo ERS, Katili AS, Ibrahim M. 2021. Coral reef ecosystem health status of Paladan Islands, Indonesia: An assessment criteria using coral cover percentage. Indo Pac J Ocean Life 5: 8-13.* This study aims to analyze the health of coral reef ecosystems in Paladan Island waters, Tojo Una-una District, Central Sulawesi, Indonesia. This research is a quantitative descriptive study using roaming data collection techniques and measuring the overall length of coral reef cover in a 5x5 meter^2 plot. The research was conducted for 4 months using survey methods. The percentage of live coral cover and mortality index was calculated and categorized according to coral reef health criteria reported from literature. The result showed that coral reefs in the Paladan Island waters exhibit 72.9% life coral cover with an IMK value of 0.09. A comparison of this result with the standardized coral reef health criteria indicates that the percentage coral cover is within a healthy range (50-100%) with an IMK value of ≤ 0, suggesting that coral reef conditions have not changed or deteriorated. Based on the value of coral cover obtained, it is suggested that the coral reef of Paladan island is still in good condition. The rapid assessment criteria reported here may be useful for monitoring of coral reef ecosystem health.

Keywords: Community activities, coral reef cover percentage method, coral reef ecosystem health, Paladan island

INTRODUCTION

Biodiversity is a potential that enriches an area with biological resources. It has become a fact that the Indonesian region has a great biodiversity potential of which coastal environment is an important component. Based on data from the Indonesian Minister of Marine Affairs and Fisheries in 2020, Indonesian waters' total area is approximately 3,110,000 km^2. This large area of water has made Indonesia one of the countries rich in natural marine resources including coral reefs.

Coral reef is a dynamic ecosystem with rich biodiversity and high productivity, therefore, the role of coral reefs is very important in preserving the coastal ecosystem. (Suryanti et al. 2011) demonstrate that, the important role of coral reef ecosystems includes spawning ground and, housing and foraging for various types of fish species. Coral reefs can also be a wave buffer, protecting the coast from erosion, coastal flooding, and other destructive events caused by the phenomenon of seawater (Amin 2009).

The role of coral reef ecosystems is very strategic in supporting the availability of fishery resources and is one of the main pillars that contribute to the existence of coastal communities. According to Amrullah (2014), the dominant livelihood of coastal communities is fishermen who depend on coral reef resources for food and as source of income. Degraded coral reefs affect fish populations and as well as the livelihood of the coastal communities.

The coral reef ecosystem is currently one of the most threatened ecosystems because coral reef creatures have a very low tolerance ability to environmental stressors, and they can only survive in places where the conditions are favorable. The ecological boundaries of coral reefs are currents, sunlight, water clarity, depth and salinity (Zewanto et al. 2017).

Indonesia's coral reefs are under threat by human activities and natural phenomena. Human activities that damage coral ecosystem are fishing using bombs, cyanide, as well as several other types of destructive fishing gears. In contrast, the damage by natural phenomena involves earthquakes, tsunamis, drastic water temperature changes, and the abundance of coral-eating organisms such as the Acanthaster planci (Sahetapy et al. 2017).

Damage to coral reefs in Indonesia, one of which occurred in East Luwu District according to Ayyub et al. (2018), the estimated coral cover was 37%, impact that can occur due to the damage to coral reefs is the damage to the dwellings of the fish that live around coral reefs and can reduce the catch of reef fish by fishermen. meaning that the health of coral reefs is moderate (Reference). The damage reported herein was caused by activities of the coastal community of East Luwu District by catching fish using destructive fishing, bombing fish, and anesthesia.

Coral fringing reefs surround Paladan Island, so the Paladan archipelago is known as a rock fishing spot in the Tojo Una Una area, however, the unregulated use of fishing gears such as trawls and explosive bombs have

resulted in several coral reef ecosystems around Paladan Island experiencing the threat of damage (Suryanti et al. 2011), this is appropriate with the statement of Abrar et al (2012), where the decline in coral reefs in Indonesia is caused by various factors, including sedimentation, pollution originating from land such as industrial and domestic waste disposal, coral mining for building materials or other physical damages such as overexploitation of marine resources, and distractive fishing practices.

Based on observations made by researchers, the management of tourist attractions for Paladan Island is faced with various threats from ecological aspects, namely a decrease in environmental quality due to pollution and damage to coastal ecosystems. This fact shows that the management of natural tourism areas that do not pay attention to ecological aspects can affect the stability of the ecosystem, especially the coral reef ecosystem in the Paladan Islands by calculating the percentage of coral reef cover around the island. The method of calculating the percentage of coral reef cover has become the standard in determining the health of coral reefs (Ayyub et al. 2018).

MATERIALS AND METHODS

Study area

Paladan Island is one of the islands located in Tōjo Una-Una District which is used as a beautiful underwater park tour. The components of the coral reef ecosystem in Paladan Island waters consist of biotic and abiotic components. The biotic component consists of Acropora, Non-Acropora, algae and other fauna, while the abiotic component consists of dead coral, sand, scattered corals, water, and rocks. The condition of coral reefs in the waters of Paladan Island has never before been assessed on the health of coral reef ecosystems. The need for an assessment of the health of coral reefs because there are tourism activities that can affect the condition of coral reefs. Human activities that can negatively impact waste (anchor) of ships, disposal of ship fuel into the sea, and disposal of waste from tourist canteens to the sea. Coral reefs are the measurement criteria to determine how the coral reef ecosystem is, namely measuring the cover of live coral reefs and dead coral reefs. Can be seen on the location map.

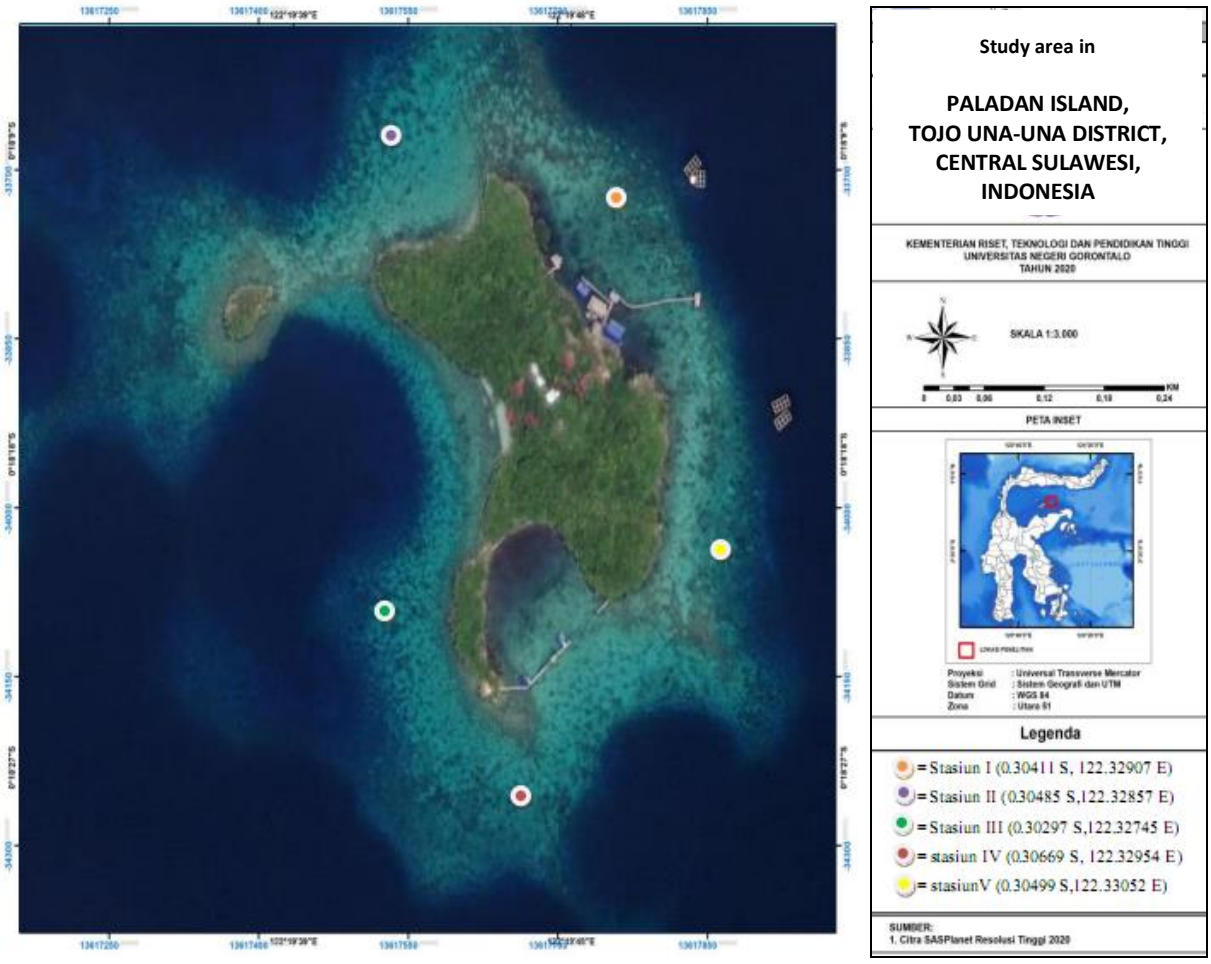

Figure 1. Study area in Paladan Island, Tojo Una-una District, Central Sulawesi, Indonesia with survey station (I-V)

Procedures

The survey started from interviews to find out about community activities, observe the community's core activities in conserving coral reefs, and collect coral reef data to see the health status of coral reefs. At each sampling station, a 50m Roll Meter is placed and transect measurements are taken. Scuba diving equipment was used for the underwater survey and data was recorded using an underwater blackboard and pencil. Underwater cameras are used for documentation, boats for transportation, handfractometers, used to measure salinity, GPS is used to determine the location of research stations, thermometers for measuring temperature, compasses for determining cardinal directions.

The data collection technique is carried out using the line transect technique, with the following work procedures: (i) At each station, a transect line is made from the shoreline to the sea along the length of 50 M using a meter which is given a ballast so that the meter is under the surface of seawater and above coral reefs; (ii) Make a plot of 5m x 5m placed in a zigzag manner so that it can represent every coral reef in the observation location; (iii) Measure the length of coral cover and record the length of coral cover within the plot; (iv) Physicochemical data collection was carried out in the morning, afternoon and evening at each observation station.

Coral reef cover

Primary data

For coral reef conditions, a survey method is used by making a line transect of 100m and making a plot measuring 5m x 5m and measuring the total length of the coral reef plotted. The advantage of this method is that it makes it easier to collect data in the field because it can represent the samples taken by the researcher.

Calculation of the percentage of live corals. The percentage of coral cover (%) is known using the Cox formula (1967), which is as follows:

Persentage of coral reefs (%) = Colony size length (cm) / Transect length (cm)

The mortality index was determined using the formula of (English et al, 1997), which is as follows:

$$IM = \frac{DC}{(LC + DC)}$$

Where, IM = Mortality Index; DC = Percentage of dead coral cover; LC = Percentage of live coral cover.

Secondary data

The secondary data were obtained from coral reef substrate components reported in previous studies and related agencies of the Coastal and Marine Resources Management Agency.

Measurement of physicochemical parameters

The physicochemical parameters of the waters around Paladan Island were collected. The water temperature was measured with a thermometer, salinity with a, pH with a color litmus paper. The current velocity was measured by pimpong ball method.

Community activities

Describe community activities as primary data to support other causes of damage to coral reefs caused by community activities described in the discussion.

Data analysis

Physical-chemical parameters of waters

The physicochemical parameters (salinity, temperature, pH, current velocity) for the water were analyzed descriptively and presented in form of tables or graphs and then evaluated base on KEPMEN LH No. 51 of 2004 of water quality standards for Indonesian marine waters (Table 1).

Live coral cover

The percentage of coral cover obtained from this study was categorized base on the coral reef health criteria in table 2. The health of coral reef ecosystems was categorized according to the Minister of Environment Decree No.4 of Year (2004), where the coral cover value within the range of 50-100% is declared healthy while below this range is declared unhealthy or damaged. The dead coral reefs were identified base on the calculated IMK value $\leq$ 0.0, which indicates either non-existent or experience little damage. The IMK value close to 1.0 indicates no change in the status of the coral reefs (English et al, 1997). All secondary data were obtained from previous studies on coral reef ecosystems. The field data were presented descriptively in form of figures and tables. The secondary data related to standards protocol were mentioned on a case-by-case basis to validate the research findings.

Table 1. Indonesian marine water quality standards

Physico-chemical parameters	Value
Salinity	30-34 ‰
Temperature	28-30 °C
pH	7-8.5
Strong currents	0.28-0.45 M/Scnd

Note: Keputusan Menteri LH No.51 Tahun 2004

Table 2. Categories of coral reefs

Coral reef category (%)	
Bad	0-24.9
Moderate	25-49.9
Healthy	50-74.9
Very Healthy	75-100

Note: Keputusan Menteri LH No.4 Tahun 2004

RESULTS AND DISCUSSION

Percentage of coral reef cover and mortality index in Paladan Island Waters

Based on the results of coral reef observations on the island of Paladan, the following coral reef cover and mortality index were obtained in Table 3.

The average coral reef cover value obtained, was 72.9% for all transect. This value is in a good category because it is in the range of 50-75%, in accordance with the Minister of Environment Decree No. 4 of 2004. While the dead coral cover in Paladan Island waters from stations I, II, III, IV, and V is in the range of 0-19.7%. If averaged, the value of dead coral cover was 9.9%.

The coral reef condition in Paladan Island waters was 72.9% life coral reef. This value is within the healthy category (50-100%). The dead coral reefs account for only 9.9% of all sampling stations. The total percentage of coral cover is less than 100% suggested. This is due to the different geographical conditions at each station and the shape of the coral reefs that resemble small islands below sea level, so that the total value of each station does not reach 100%.

The IMK value of coral reef conditions in Paladan Island is 0.12. This mortality index value is classified as low, suggesting that the health condition of coral reefs is not affected.

Physical-chemical factors of coral reefs in Paladan Island Waters

Based on the observations made at five stations for measuring physicochemical parameters, there are several influences on the research location, namely rain during chemical physics data collection. The chemical physics data obtained the following results.

The average physicochemical factor measurement can be explained as follows, the circulating salinity state is 30.08%. Furthermore, the pH value in Paladan Island waters was 8.12%. The current strength in Paladan Island waters is 0.049 m/sec. The temperature in Paladan Island waters is 32.2ºC. Referring to the Decree of the Minister of Environment No. 51 of 2004 concerning the Quality Standards for Indonesian Marine Waters that the physical conditions of Paladan Island waters for salinity, pH, and current strength in normal conditions of salinity are 30-34%, pH 7-8.5, and current strength is 0.28-45 m/sec. Meanwhile, the temperature is still in the normal range.

Discussion

The coral reef cover found estimate for stations I, II, III, and V is in the range of 51.1-87.7% (Figure 2). The average coral reef cover value obtained, was 72.9% for all transect. This value is in a good category because it is in the range of 50-75%, in accordance with the Minister of Environment Decree No. 4 of 2004. While the dead coral cover in Paladan Island waters from stations I, II, III, IV, and V is in the range of 0-19.7%. If averaged, the value of dead coral cover was 9.9%.

Table. 3 Percentage of coral reefs and coral reef mortality index in Paladan Island, Tojo Una-una District, Central Sulawesi, Indonesia

Location of coral reefs	Percentage of live coral reefs (%)	Percentage of dead coral reefs (%)	IMK
Island Paladan St I	87.1	10.6	0.11
Island Paladan St II	76.6	5.7	0.07
Island Paladan St III	84.8	0	0
Island Paladan St IV	64.7	13.6	0.17
Island Paladan St V	51.1	19.7	0.28
Average	72.9	9.9	0.12

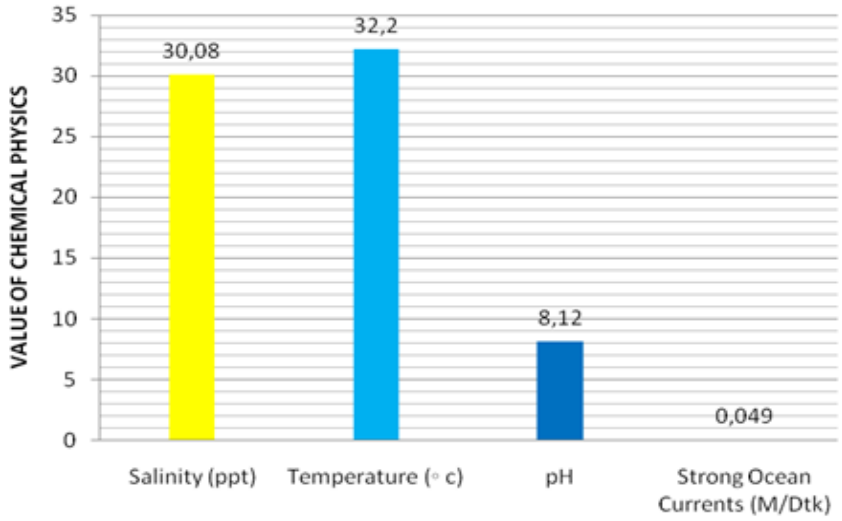

Figure 2. Physiochemical properties of the seawater in Paladan Island, Tojo Una-una District, Central Sulawesi, Indonesia

The condition of coral reefs at station I is close to boat moorings, station II is a favorite place for fishing tourism, station III is a location that is difficult to reach by tourists because it is located behind Paladan Island, while stations IV and V are at boat moorings and locations. diving for tourists. From the previous explanation, the condition of coral reefs facing the threat of damage, namely at stations I, II, IV, and V.

Based on the survey result for each station, the overall percentage of live coral was 72.9%. This figure suggests that the health of the coral reef ecosystem in Paladan Island in stable condition. According to research by Ampou et al. (2020), coral cover within the range of 50-100% indicates healthy coral reef condition.

In calculating the mortality index, for the total cover value of dead coral, the mortality index value was 0.12. This value is classified as a mortality index value close to 0 or almost no dead coral reefs are found around the waters of Paladan Island. It can also be said that there is no change in the condition of living coral reefs. According to the statement of Ampou et al. (2020), a mortality index value that is close to 1 indicates a healthy coral reef system.

The forms of colonies in Palada Island waters are ACB (Acropora branching), ACS (Acropora submassive), ACE (Acropora Encrusting), CM (Coral massive), and CB (Coral Branching). This is following research conducted by Afni (2017) where this type of coral growth is in a sandy substrate with a depth of three-five meters above sea level. While the dead corals found in Paladan Island waters are coral reefs that are experiencing bleaching.

The low number of dead coral reefs in Paladan Island waters is influenced by the low threat experienced by the coral reef ecosystem. One of the biggest threats that can contribute greatly to the health of coral reef ecosystems is community activity. Farid et al. (2018) reported that community activities can contribute negatively to coral growth especially fish trawling activities. Additionally, the authors general observation was that the activities of residents in utilizing these waters are still minimal, since most of the residents of Paladan Island were engaged in gardening activities than those who are fishermen. According to the data obtained from the local government, the number of households in the supply village directly adjacent to Paladan Island is 975 households. It was also reported that 25 families are active farmers while 875 families are farm laborers who would earn a sum of 50 KK as ASN workers (Village Government Supply Data 2019). Based on the facts from the data, it is clear that the condition of the waters in the Paladan island area does not receive much influence from the activities of the residents.

Conversely, other threats could exist. In accordance with the author's observation, the presence of waste disposal from tourism activities on the island of Paladan could be a future threat if it is not properly managed. The garbage on Paladan Island is thought to impact and threaten existing coral reefs in the form of visible damage, although currently, it is still on a small scale. Garbage on the water surface may have negative consequences for coral reef creatures by preventing light from penetrating through the water surface (Farid et al. 2018). Yuliani et al. (2016) stated that garbage floating on the sea surface prevents light from entering the seawater, consequently reducing metabolic activities that may result in coral death where such case was reported in the Lhokseudu area, Leupung sub-district, Aceh Besar district.

Further, underwater snorkeling and diving can threaten the existing coral cover conditions, especially for unregulated activities. Another threat that might occur is the damage to the morphological structure of the coral reef from the activities related to coral reef trade where corals are used as commercial objects. This fact is in line with the research presented by Ayyub et al. (2018) that uncontrolled human activities such as exploiting coral reefs for economic purposes can negatively impact coral reef ecosystems. Activities such as snorkeling and diving can accidentally cause damage to coral reefs especially by stepping on live corals fragile. According to the research of Akhmad et al. (2018), the snorkeling around tourism area of Karimunjawa National Park could increase vulnerability of corals trembling and leading to damage.

Another threat that is certain to occur is global warming. Global warming could be a major threat to coral reefs in the waters of Paladan Island. According to Latuconsina's (2010) statement, the global warming process begins by trapping greenhouse gas emissions such as carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NOx), chlorofluorocarbons (CFCs), and other excess gases in the atmosphere, so that some of the geothermal heat is trapped and can cause an increase in temperature at the earth's surface which is called global warming. The impact that can occur due to an increase in the earth's surface temperature according to Salim's research (2016), an increase in the earth's surface temperature can cause coral bleaching due to the death of zooxanthellae algae which function as food providers for corals. This statement is evidenced by an increase in water surface temperature, namely 32.2^{o}C, over time this temperature increase will continue due to human activities that can increase carbon dioxide emissions.

Based on the discussion, it can be concluded that the health status of coral reefs in the waters of Paladan Island is in good condition, indicated by the low mortality index value, suggesting that the coral reefs in Paladan Island waters are not being damaged. Based on the measurement of physicochemical parameters, it can be concluded that salinity, pH, current strength, and temperature are in good condition to support coral reef life. Threats that can slowly destroy the coral reef ecosystem in Paladan Island waters are garbage, irresponsible visitor activity, and global warming.

REFERENCES

Abrar M, Bachtiar I, Budiyanto A. 2012. Community structure and disease in corals (Scleractinia) in Lembata Waters, East Nusa Tenggara. Ilmu Kelautan 17 (2): 63-73. DOI: 10.14710/ik.ijms.17.2.109-118. [Indonesian]

Afni N. 2017 Coral Reef Condition in Samatellu Pedda Island, Liukang Tupabbiring District, Pangkep District, South Sulawesi. [Thesis]. Science dan Technology Faculty, UIN Alaudin, Makassar. [Indonesian]

Akhmad DS, Supriharyono, Purnomo PW. 2018. Community structure and disease in corals (Scleractinia) in Lembata Waters, East Nusa Tenggara. Ilmu dan Teknologi Kelautan Tropis 10 (2): 419-429. DOI: 10.29244/jitkt.v10i2.21495. [Indonesian]

Amin. 2009. Coral reefs; Threatened Assets (Problems and Alternative Solutions to Rescue them). Region I (2): 1-12 [Indonesian]

Ampou E, Widagti N, Nugroho S, Sangaji I. 2020. Status of coral reefs and reef fish in Gili Matra, Nusa Tenggara Barat. Ecotrophic 14 (1): 14-27. [Indonesian]

Amrullah, Amrullah. 2014. Analysis of Coral Reefs Condition with Remote Sensing Approach in Liukang Tuppabiring District, Pangkep South Sulawesi. Biotek 1 (1): 1-14 [Indonesian].

Ayyub FR, Rauf A, Asni A. 2018. Management Strategy of Coral Reef Ecosystem in the Coastal Area of East Luwu District.Pendidikan Teknologi Pertanian, Vol. 4 (2018) : S56-S65 [Indonesian].

Cox GW. 1967. Laboratory Manual of General Ecology. MC Brown Company Publishers, Dubuque, Iowa.

Decree of the Minister of Environment Number 4 of 2004 concerning Standard Criteria for Damage to Coral Reefs.

English S, Wilkinson C, Baker V. 1997. Survey Manual for Tropical Marine Resources. ASEAN-Australian Marine Science Project: Living Coastal Resources. Australian Institute of Marine Science, Townsville, Australia.

Farid M, Wahyu P, Supriharyono. 2018. Changes of coral reef cover in terms based of tourists number in Tanjung Gelam, Karimunjawa Islands using oil Landsat 8 satellite imagery. J Maquares 7 (1): 18-27. [Indonesian]

Indonesian Minister of Marine Affairs and Fisheries Data. 2020. Indonesian Outer Sea Data 2020.

Latuconsina H. 2010. The impact of global warming on coastal and ocean ecosystems. Agrikan Agribisnis Perikanan 3: 30-37. DOI: 10.29239/j.agrikan.3.1.30-37. [Indonesian]

Sahetapy D, Widayati S, Sangadji. 2017. The impact of community activities on the coral reef ecosystem in the Katapang coastal area, western Seram District. Triton 13 (2): 105-114. [Indonesian]

Salim D. 2016. Management of coral reef ecosystems due to bleaching and damage. Kelautan 5 (2): 1907-9931. DOI: 10.21107/jk.v5i2.870. [Indonesian]

Suryanti, Supriharyono, Indrawan W. 2011. Coral reef conditions with Chaetodontidae fish as indicators in Sambangan Island, Karimun Jawa Islands, Jepara, Central Java. Oseanografi Marina 1 (1): 106-119. DOI: 10.14710/buloma.v1i1.2988. [Indonesian]

Village Government Data Supply. 2019. Job Data and Number of Households.

Yuliani W, Ali MS, Saputri M. 2016. Community management of coral reef ecosystems in the Lhokseudu area, Leupung District, Aceh Besar District. Jurnal Ilmiah Mahasiswa Pendidikan Biologi 1 (1): 1-9. [Indonesian]

Zewanto I, Nasir M, Kurnianda V. 2017. Percentage of coral cover at Ulee Kareung Beach, Simpang Mamplam District, Bireuen District. Jurnal Ilmiah Mahasiswa Kelautan dan Perikanan Unsyiah 2 (2): 302-309. [Indonesian]

INDO PAC J OCEAN LIFE
Volume 5, Number 1, June 2021
Pages: 14-21

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o050103

Pioneer assessment on megabenthic community suggest the recent ecological condition of coral reef in Senggigi Beach, Western Lombok Island, Indonesia

MUHAMMAD IRSYAD ABIYUSFI GHAFARI[1,2,♥], VITA FITRIANTI[2,♥♥]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia. Tel./fax.: +62-411-585188, ♥email: irsyad.ghafari@gmail.com

[2]Student Club for Marine and Fisheries Research, Universitas Mataram. Jl. Majapahit No.62, Mataram 83115, West Nusa Tenggara, Indonesia. Tel./fax.: +62-370-636041, ♥♥email: vitafitrianti99@gmail.com

Manuscript received: 18 April 2021. Revision accepted: 16 June 2021.

Abstract. *Ghafari MIA, Fitrianti V. 2021. Pioneer assessment on megabenthic community suggests the recent ecological condition of coral reef in Senggigi Beach, Western Lombok Island, Indonesia. Indo Pac J Ocean Life 5: 14-21.* Megabenthic communities are among the excellent bioindicator used nowadays. This study was the first to conduct in Senggigi Beach and provide preliminary useful information regarding the condition of coral reef ecosystem on-site, through assessing the megabenthic community from 2019-2020 to 202-2021. Benthos Belt Transect (BBT) method was used to collect data from 6 different observation sites. There are 3 groups of targeted megabenthic fauna assessed: the bioindicator group (sea urchin and blue starfish), the corallivorous group (drupella snail and crown-of-thorns starfish), and the commercially valued group (edible sea cucumber, giant clam, spiny lobster, and commercial top shells). Sea urchin was found to dominate all stations, indicating a decreasing live coral cover after bleaching. Presence of corallivorous megabenthos was very rare, as it is not a potential threat to corals. There is a trend of increasing density of edible sea cucumber and giant clam by 30% and 50% respectively, with a mass giant clam recruit in 2021. We suspect less or no impact of anthropogenic activity to megabenthic community dynamic in Senggigi Beach to date, but their community dynamic is purely influenced by the decline condition of coral reef ecosystem due to recent 2016 mass bleaching.

Keywords: Benthos Belt Transect (BBT), bioindicator, coral bleaching, megabenthic community, Senggigi Beach

INTRODUCTION

Megabenthos is the largest bottom-dweller of marine organisms that are often used as bioindicator for their excellent sensitivity to represent the condition of their aquatic environment, especially for the coral reef ecosystem health status. The life of benthic invertebrates is directly related to the nutrient and waste cycle in the bottom sediment (Mehdipour et al. 2018; Belal 2019), and it is the main reason for their high sensitivity to small changes in their environmental parameter (Young et al. 2014; Patang et al. 2018). Environmental changes can be easily detected based on the dynamics abundance, species, and spatial distribution of benthic organisms (Ali 2014; Custodio et al. 2018). Unlike any other benthic organisms, megabenthos are the largest type among the benthic community with average size of >10 mm (Maximov et al. 2014), making them easier to observe by naked eyes. Ecological surveys on the coral reefs conducted by several coral reefs monitoring programs such as the Reef Check MAQTRAC program, the Australian Institution of Marine Science Long-Term Monitoring Program (AIMS LTMP), Atlantic and Gulf Rapid Reef Assessment (AGGRA), the Caribbean Coastal Marine Productivity Program (CARICOMP), or the Coral Reef Rehabilitation and Management Program (COREMAP) have used megabenthic fauna as 'indicator species' to interpret the ecological data they obtain (Hill and Wilkinson 2004; Giyanto et al. 2014).

Senggigi Beach is one of the most popular tourist destinations on Lombok Island (Indonesia), where the coastal ecosystem could suffer from potential threats. The average number of domestic and foreign tourists visiting Senggigi Beach from 2014 to 2020 was quite high, reached 412,575 visitors·year^{-1} (West Lombok Regency Tourism Office 2021). The existence of a fast boat jetty in Senggigi Beach for inter-island crossing allows the mobilization of large numbers of visitors from Bali. Senggigi Beach is also a place for local people to catch fish traditionally, where the majority of angling and spearfishing is done during low tide. Apart from that, various human activities may potentially become anthropogenic stress that threatens the sustainability of the coral reef ecosystem on the beach. On the other hand, we observed that the coral reefs there have suffered the 2016 bleaching episode, along with other coral reefs in the west coast of Lombok as reported by Bachtiar and Hadi (2019) and Wouthuyzen et al. (2018). The historical background of coral bleaching that has occurred in the area can elevate the chances of decreasing the stability of the coral reef ecosystem on Senggigi Beach.

As best we know, there are no scientific records or ecological monitoring activities that have been carried out in Senggigi Beach. No ecological data available resulted in our nescience on how much human activity and the recent

mass bleaching has stressed the coral reef ecosystem there. In fact, information related to the condition of the coral reef ecosystem is very crucial for the environmental management efforts and the development of environmentally friendly tourism on Senggigi Beach in the future. Assessment of the coral reef ecosystem conditions by utilizing the presence of megabenthic fauna allows us to understand the condition of coral reef ecosystem at Senggigi Beach. Therefore, this study is the first to describe the condition of coral reef ecosystems in Senggigi Beach based on the composition, abundance and distribution of megabenthic communities.

MATERIALS AND METHODS

Study location

The study was conducted consecutively in November 2019 and February 2020 (represent the data series of last 2019-early 2020, first data set), as well as in November 2020 and March 2021 (represent the data series of last 2020-early 2021, second data set) at the coral reef area of Senggigi Beach within 6 observation sites that have been determined, as shown in Figure 1. Senggigi Beach is situated in a bay called 'Senggigi Bay', on the west coast of Lombok Island. This strategic place is annually affected by very strong currents and waves during the west monsoon. The middle part of the Senggigi Beach is a gap that characterized by turbid water and mud-rich bottom due to the discharged sediment through a small river. A jetty was built in this part. The existence of a gap zone in Senggigi Beach causes the formation of 2 different reef areas, later refers to as the northern and the southern coral reef region.

Data collection

The data collection was carried out using Benthos Belt Transect (BBT) method referring to Arbi and Sihaloho (2017) with minor modifications. The transect is laid along 50 m parallel to the shoreline at a depth of 3-5 m. Each station consists of one transect. Observations on megabenthic fauna were done within 1 meter to the left and 1 meter to the right of the transect line, made up the total observation area of 100 m^2 per transect. There are 8 types of targeted megabenthic fauna included in 3 functional groups based on Arbi and Sihaloho (2017), as shown in Table 1. The individual number of targeted megabenthic fauna encountered was recorded on a slate and documented using an underwater digital camera.

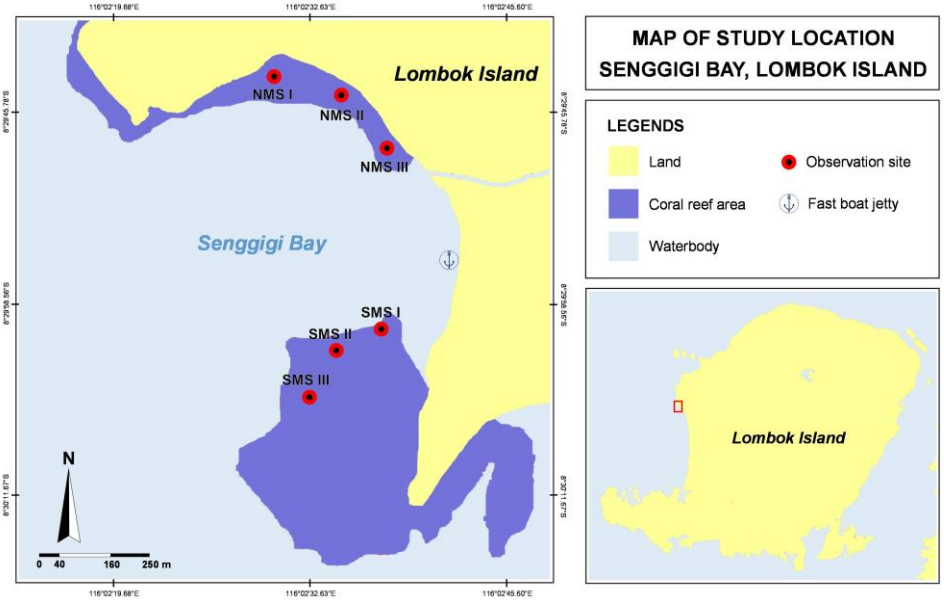

Figure 1. A map of study location showing 6 observation sites in Senggigi Beach, Western Lombok Island, Indonesia: 3 sites (NMS) on the northern coral reef region and 3 others (SMS) on the southern coral reef region

Table 1. Targeted megabenthic fauna on this survey (Arbi and Sihaloho 2017)

Functional group	Megabenthic fauna	Phylum (higher classification)
Bioindicator group	Sea urchin (class Echinoidea)	Echinodermata
	Blue starfish (*Linckia laevigata*)	Echinodermata
Corallivorous group	Crown-of-thorns (COT) starfish (*Acanthaster* spp.)	Echinodermata
	Drupella snail (*Drupella* spp.)	Mollusca
Commercially valued group	Edible sea-cucumber (family Holothuriidae)	Echinodermata
	Giant clam (*Hippopus* spp; *Tridacna* spp.)	Mollusca
	Spiny lobster (family Palinuridae)	Arthropoda
	Commercial top shell (*Tectus* spp; *Trochus* spp.)	Mollusca

Data analysis

Data analysis were performed using Microsoft Excel 2010 software. Data analysis included analysis of megabenthic composition (percentage), analysis of megabenthic density per square meter (ind·m^{-2}) and per hectare (ind·ha^{-1}) for the entire station (which makes up the total area observation of 600 m^2), as well as analysis of megabenthic distribution in the entire station per period (ind·period^{-1}). A data set comprised of the average of the last and early data of the represented year. Analysis result from the two represented years of survey is then compared and visualized in the form of diagrams and pie charts.

RESULTS AND DISCUSSION

Results

Composition and distribution of megabenthic fauna

In general, the composition of the megabenthic community remained relatively unchanged the first and the second set of observations, as shown in Figure 2. All targeted megabenthic fauna exist in Senggigi Beach, as documented in Figure 3. The composition of bioindicator group was dominated by sea urchins, while blue starfish is very rare. Sea urchin distributed in all stations and makes up more than 70% of the entire composition of megabenthic community during 2 periods of survey. The corallivorous group, especially the COT, appears only in SMS III with very low percentage. Comparing the two sets of observation results, the majority of commercially valued megabenthos seems to have lost in several stations, such as in NMS II and SMS II. Another station seems to have a very dynamic change in their commercially valued group composition. The presence of commercially valued megabenthos increasing in the megabenthos composition of SMS I.

Megabenthic community from southern coral reef region seems more varied compared to their northern counterpart. This can be related to the different types of coral complexity between the two coral reef regions, where the southern coral reef region has a denser coral cover with a typical of vast reef flat, while the northern part exhibits patchy reef and dominated by both macroalgae and massive corals, as shown in Figure 4. Different composition of megabenthic community between the two coral reef areas is more likely due to the differences substrate types and habitat complexity (Cappenberg and Mahulette 2019; Tatipata and Mashoreng 2019; Olii and Paramata 2020) between the two reef region, rather than the influence of different ecological stressor.

Density of megabenthic fauna

Overall result shows that the overall abundance of megabenthic community has dropped by 0.047 ind·m^{-2} (or 467 ind·ha^{-1}) over the past 2 years. A declining abundance of megabenthos communities may indicate a decrease in live coral cover (Wulandari et al. 2020). It is also found that the fluctuations of the environmental parameter are strongly correlated with changes in benthic community abundance (Coyle et al. 2007; Ghafari et al. 2020). Based on Figure 5, there is a slight decrease in density of bioindicator and corallivorous group and it might be correlated with the decrease of overall megabenthos abundance. Although the abundance of megabenthos community has decreased, the density of most of commercially valued group has increased, which indicate that this group may not be subjected to significant anthropogenic or ecological stresses.

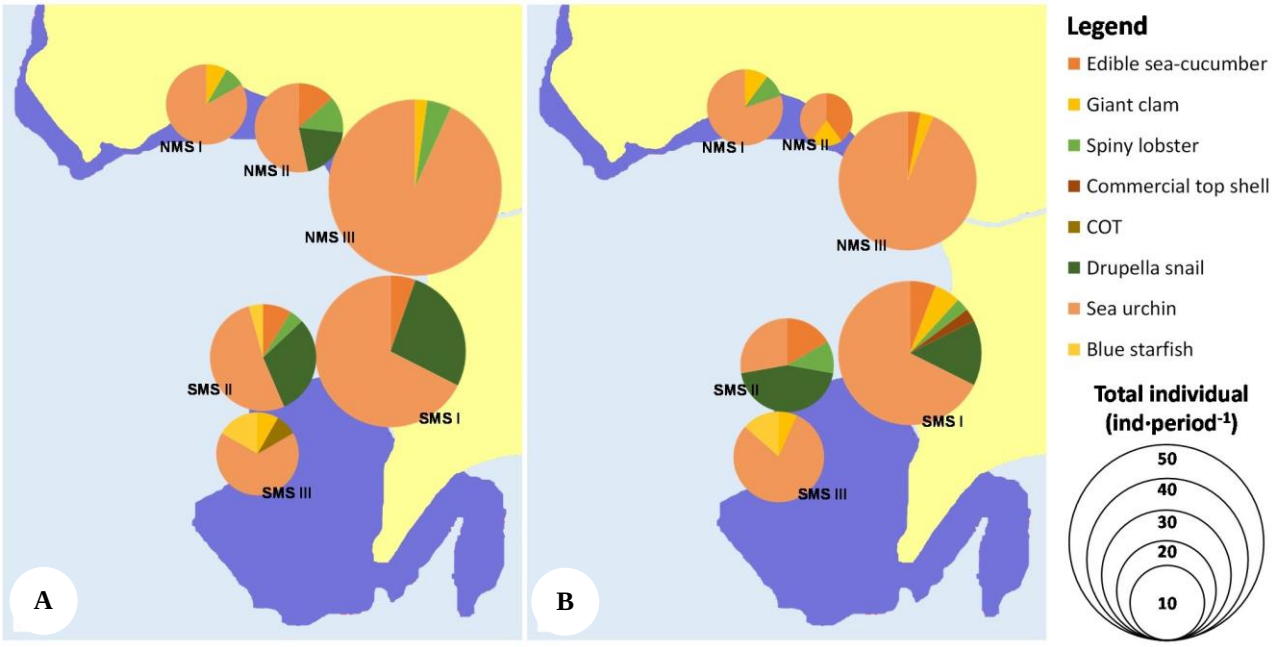

Figure 2. Comparation of megabenthic composition, total abundance (number of individuals collected per period) and distribution from A. 2019-2020 to B. 2020-2021 in all observation sites of Senggigi Beach, Western Lombok Island, Indonesia

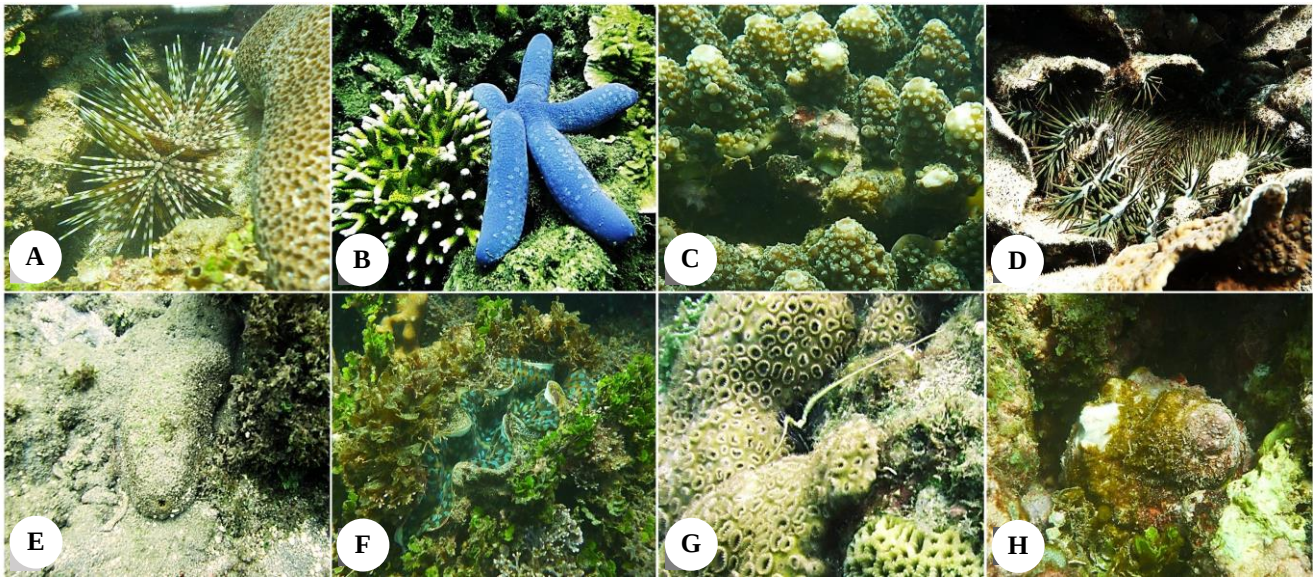

Figure 3. Various megabenthic fauna found in Senggigi Beach, Western Lombok Island, Indonesia during 2 years survey: A. Sea urchin; B. Blue starfish; C. Drupella snail; D. COT; E. Edible sea cucumber; F. Giant clam; G. Spiny lobster; and H. Commercial top shell

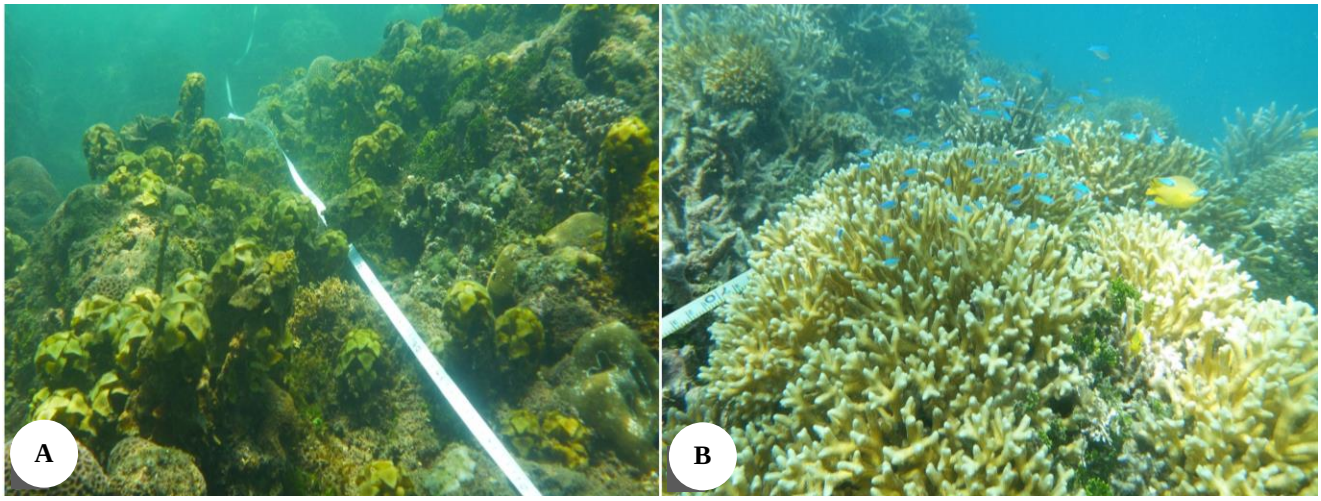

Figure 4. The typical coral reef complexity between 2 reef regions: A. northern coral reef; B. southern coral reef

Discussion

Bioindicator group

Sea urchins appear to dominate all station. The dominance of sea urchins in coral reef areas was also reported by Sese et al. (2018), Akbar et al. (2019), Mutaqin et al. (2020) and Wulandari et al. (2020). In contrast, Ghafari et al. (2020) reported that the condition of the megabenthic community in the nearest area, namely Sekotong bay, shows a trend of blue starfish domination during the 5 years of survey conducted by LIPI (Indonesian Institute of Sciences).

Sea urchin domination among the megabenthic community in Senggigi Beach is thought to be related to decreasing live coral cover as the effect of the recent 2016 bleaching episode, which is simultaneously supported by the overall trend of declining megabenthic abundance during the twice set of observations. Nevertheless, this assumption needs to be proven through direct evaluation of coral cover. Sea urchin domination over the reef is generally associated with the increasing benthic algae on the substrate as a result of the post-bleaching algal-coral shift phase (Jompa and Cook 2003; Vercelloni et al. 2020). The increasing abundance of planktonic and benthonic algae can lead to the aggregation of sea urchins as the main algae consumers (grazers) and algae controllers on the reef (Ishikawa et al. 2016; Ghafari et al. 2019). Sea urchins are also reported to dominate and become the main grazer in heavily fished coral reef areas (McClanahan and Shafir 1990; O'Leary et al. 2013). However, the density of sea urchins at Senggigi Beach during the 2 years of survey is still less than 0.80 ind·m^{-2} (as standard indication of sea urchin aggregation in heavily fished areas mentioned by McClanahan and Shafir (1990), meaning that sea urchin population in Senggigi Beach does not indicate the heavily fished condition.

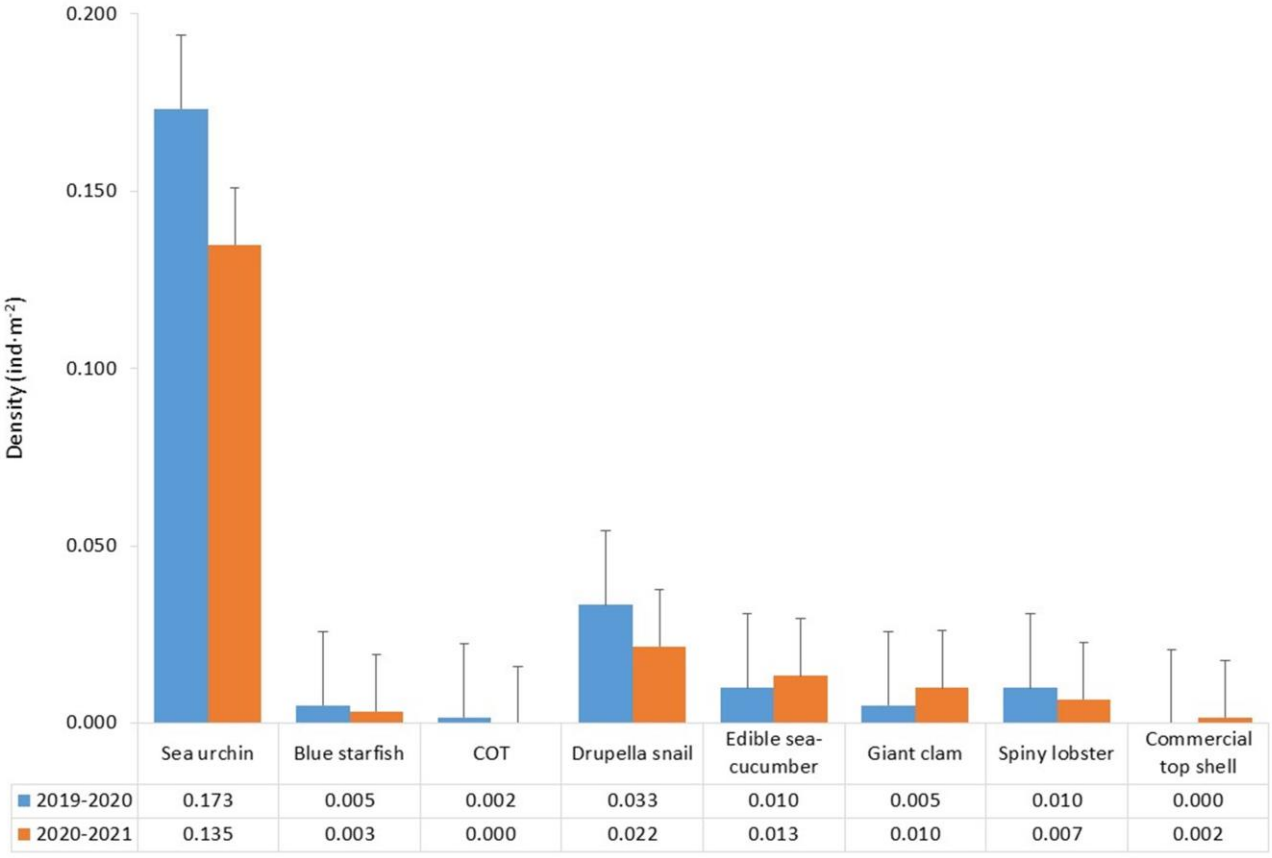

Figure 5. Comparation of average megabenthic density per period (ind·m^{-2}·period^{-1}) in Senggigi Beach from the two sets of observation. Each vertical bars represent the standard error

Under normal circumstances (if sea urchins are not in aggregation state), sea urchins can increase coral resilience and recovery by consuming a large amount of benthic algae. A population of sea urchin in an area could potentially reduce algae cover by 30 to 60%, facilitating the attachment of coral juveniles by opens up a living space for coral recruitments (Dang et al. 2020a; Nozawa et al. 2020). Although several studies reported that the dominance of sea urchins in waters has the potential to reduce the space for coral attachment through a bioeroder mechanism (Peyrot-Clausade et al. 2000), the density of sea urchins in Senggigi Beach cannot yet be categorized as potentially damaging the settlement space for coral recruitment as the threatening aggregation of sea urchin supposed to be more than 16 ind·m^{-2} (Dang et al. 2020b).

Blue starfish was rare and found in small numbers. Blue starfish is found only at 2 outer stations on southern coral reefs (SMS II and III). Blue starfish often occurs in healthy coral reef, even though their direct role for coral resilience is still unknown (Bos et al. 2008). Blue starfish is very sensitive to environmental changes, so it is rarely found in high anthropogenic stress or polluted waters (Ghafari et al. 2019). Blue starfish favor the area with strong current and low sedimentation rate (Aziz 1996). It could be the reason for blue starfish only appears on the outermost station during the 2 years of the survey, because the wave currents and proximity from the shoreline bring about low levels of sedimentation and pollution in that area. In a reasonable population size, blue starfish live in confined spaces on the surface of rubble or coralline algae among good healthy corals (Laxton 1974; Arbi et al. 2020) and acts as a grazer that controls the algae population, indirectly facilitate the open space for coral recruit attachment (Zamani 2015). Therefore, it can be said that the coral reef ecosystem conditions in the 2 outer stations are better than the other stations.

Corallivorous group

Drupella snail is one of the coral predators encountered in Senggigi Beach. The majority of drupella snail was found at stations in southern reef, and only found in a few number (n=3) at 1 station in northern reef during 2020 survey. Drupella snail is coral-eating (corallivorous) gastropods (Arbi 2009) and they prefer acroporid or pocilloporid rather than any other coral species (Schoepf et al. 2010). These types of branching corals are only common in the southern coral reef region and it explained the majority of drupella snail presence in that area.

Drupella snail makes up the second-highest density among other megabenthic fauna in Senggigi Beach with an average density of 0.0275 ind·m^{-2}·year^{-1}. Arbi et al. (2017) stated that the aggregation of drupella snail that potentially

threatening live coral is supposed to be at least 50 ind·m^{-2} or more. Thus, the presence of drupella snail in Sengigi Beach is still far from potentially threatening the corals. The density of drupella snail population in Senggigi Beach is much lower than those from Perlang village waters, Bangka Belitung (Akbar et al. 2019), Kendari waters (Arbi et al. 2020), or East Sumba waters (Cappenberg and Akbar 2020). However, the density of drupella snail in Senggigi Beach is slightly higher than the drupella's density from the nearest waters, which is in Sekotong Bay (Ghafari et al. 2020), or from other areas such as from Buton Island (Cappenberg and Mahulette 2019) and Waworaha waters (Wulandari et al. 2020). The low drupella's density in Senggigi Beach could be due to degraded coral cover after previous bleaching (Saponari et al. 2021), or due to the presence of coral guards, such as deterring hydrozoans (Montano et al. 2017) and coral crab *Trapezia cymodoce* (Samsuri et al. 2018), which was unable to observe in this study.

It should be noted that the high predation rate of drupella snail against coral polyps could reach up to 1.16 ± 1.1 cm^{2}·ind^{-1}·day^{-1} (Bessey et al. 2018) and their aggregation among healthy coral reef could potentially reduce live coral cover by 70-80% (Baird 1999; Scott et al. 2017). The declining number of reef fish that prey on drupella snail, such as balistid, diodontid, labrid, lutjanid (McClanahan 1994) and protected Napoleon fish (*Cheilinus* spp.) (Ratianingsih et al. 2017), or other factors, such as the presence of El-Niño, increased water temperature and salinity (Lam et al. 2007), stress and disease in corals (Morton et al. 2002; Shafir et al. 2008) could lead to the drupella's outbreak on a reef.

COT is a coral predator megabenthos that is found in very small numbers, where only 1 individual was found during the 2020 survey. COT, along with commercial top shell, has the lowest density among other megabenthic fauna during the 2 years survey. COT populations are considered to be a threat to coral reefs if their density reaches more than 0.014 ind·m^{-2} (equivalent to 140 ind·ha^{-1}) (Reichelt et al. 1990). The number of COT found in the coral reefs of Senggigi Beach was 0.001 ind·m^{-2}·year^{-1}, so it is still categorized as safe for coral reefs. In healthy coral reefs, COT has limited movement space with a selective dietary preference for fast-growing corals such as acroporids and pocilloporids only (Pratchett 2007). This COT's dietary preference is very useful to compensate for population growth between slow- and fast-growing corals. COT generally comprises 0-1% of megabenthos communities in healthy coral reefs, as confirmed by survey data reported by Cappenberg and Mahulette (2019), Satyawan and Artiningrum (2019), Cappenberg and Akbar (2020), and Wulandari et al. (2020). COT outbreaks are mainly triggered by a declining population of their natural predators, such as the large endangered triton snail (*Charonia tritonis*) (Bose et al. 2017), and various reef fish like pomacanthid, lethrinid, chaetodontid, balistid, tetraodontid, and labrid. (Babcock et al. 2016; Cowan et al. 2017). Other factors that can drive a COT's outbreak are an extreme elevated water temperature (Grossman 2014), algal blooms, and eutrophication (Birkeland 1982; Babcock et al. 2016).

Commercially valued group

Commercially valued megabenthos made up 10-16% of the composition of the megabenthos findings during the 2 years of the survey. Surprisingly, there is a tendency for an increase in the density of edible sea cucumbers and giant clams by 30% and 50%, respectively. The distribution of edible sea cucumbers, giant clams and spiny lobsters is always above 50%, while commercial top shells are only found at 1 station in 2021 (n = 1, SMS I). The even distribution and the increasing density of the majority of commercially valued megabenthos may suggest that the anthropogenic stress through fishing activities may have less or no impact to the megabenthic community or coral reef ecosystem. In the 2021 survey, we observed the presence of juvenile giant clams in several locations within and outside of transect, which indicates mass recruitment of clams in these waters. Juvenile giant clams greatly contribute to enhance NPP (Net Primary Productivity) due to their nature as fast-growing individuals (Neo et al. 2015). Recruitment of juvenile giant clam indicates that the condition of coral reefs is somehow improving from the latest mass bleaching impact in 2016. The improved condition of coral reefs has certainly contributed to the increasing number of commercially valued megabenthos, especially for clams, spiny lobsters, and sea cucumbers in Senggigi Beach.

The existence of commercially valued megabenthos in nature must be preserved because of their important role in maintaining the health of coral reef ecosystems, even though that many of them do not belong to keystone species. Adult giant clam plays an important role as natural water purification, provider of nurseries area, and contributes to build topographic heterogeneity of the reefs (Cabaitan et al. 2008; Neo et al. 2015). Other types of commercially valued megabenthos, such as spiny lobsters, edible sea cucumbers, and commercial top shells, play a role as consumers and recycle nutrients in coral reef ecosystems and contribute to keeping the coral reef healthy.

In conclusion, the condition of coral reefs in the southern reef region is much better than in the north, as evidenced by more diverse composition of megabenthic communities in the south. The domination of sea urchins at all stations shows that there has been a decline in the condition of the coral reef ecosystem in Senggigi Beach. The dynamics of the megabenthos community in Senggigi Beach are thought to be purely influenced by the bleaching episode which causes changes in the overall condition of the coral reef ecosystem. Although the density of the entire surveyed megabenthos is decreasing, there is a trend towards an increase in the density of commercially valued groups that indicates the absence of significant anthropogenic pressure effects. In addition, the low threat of coral predators provides hope for the acceleration of coral reef recovery in Senggigi Beach. We suggest that future monitoring programs should be implemented for the area.

ACKNOWLEDGEMENTS

The author declares that this study has no conflict of interest. We would like to thank Eman Sulaeman, Rifan Ely, Rojiman Ariadi, and Anugrah Aprian Ademullah for their remarkable favor during field survey. Special thanks to Namira R.P. Muquita for assisting us in manuscript translation and grammar checking.

REFERENCES

Akbar AH, Adibrata S, Adi W. 2019. Kepadatan megabentos pada ekosistem terumbu karang di perairan Desa Perlang Bangka Tengah, Bangka Belitung. Akuatik 13 (2): 173-177. DOI: 10.33019/akuatik.v13i2.1621. [Indonesia]

Ali TS. 2014. Spatial and temporal variations of marine benthic in-fauna community in northern and southern areas of the Kingdom of Bahrain. Arab Gulf J Sci Res 32 (1): 80-92.

Arbi UY. 2009. *Drupella* spp. (Muricidae: Moluska): Siput pemakan karang. Oseana 34 (3): 19-24. [Indonesia]

Arbi UY, Sihaloho HF. 2017. Panduan Pemantauan Megabenthos Edisi 2. Media Sains Nasional, Jakarta. [Indonesia]

Arbi UY, Aji LP, Susetiono. 2017. Modul Pelatihan Penilaian Kondisi Megabenthos B: Pengambilan Data Megabenthos. LIPI Press, Jakarta. [Indonesia]

Arbi UY, Sawonua PH, Cappenberg HA. 2020. Fluktuasi kepadatan megabentos di perairan Kendari, Sulawesi Tenggara. Berita Biologi 19 (3B): 477-489. DOI: 10.14203/beritabiologi.v19i3B.3902. [Indonesia]

Aziz A. 1996. Habitat dan zonasi fauna ekhinodermata di ekosistem terumbu karang. Oseana 21 (2): 33-43. [Indonesia]

Babcock RC, Dambacher JM, Morello EB, Plagányi EE, Hayes KR, Sweatman HP, Pratchett MS. 2016. Assessing different causes of crown-of-thorns starfish outbreaks and appropriate responses for management on the Great Barrier Reef. Plos One 11 (12): e0169048. DOI: 10.1371/journal.pone.0169048

Bachtiar I, Hadi TA. 2019. Differential impacts of 2016 coral bleaching on coral reef benthic communities at Sekotong Bay, Lombok Barat, Indonesia. Biodiversitas 20 (2): 570-575. DOI: 10.13057/biodiv/d200237

Baird A. 1999. A large aggregation of *Drupella rugosa* following the mass bleaching of corals on the Great Barrier Reef. Reef Res 9 (2): 6-7.

Belal AA. 2019. Macrobenthic invertebrates as a bio-indicator for water and sediment quality in Suez Bay, Red Sea. Egypt J Aquat Res 45 (2): 123-130. DOI: 10.1016/j.ejar.2019.03.003

Bessey C, Babcock RC, Thomson DP, Haywood MD. 2018. Outbreak densities of the coral predator *Drupella* in relation to in situ *Acropora* growth rates on Ningaloo Reef, Western Australia. Coral Reefs 37 (4): 985-993. DOI: 10.1007/s00338-018-01748-7

Birkeland C. 1982. Terrestrial runoff as a cause of outbreaks of *Acanthaster planci*. Mar Biol 69 (2): 175-185. DOI: 10.1007/BF00396897

Bos AR, Alipoyo JCE, Cardona LT, Gumanao GS, Salac FN. 2008. Population structure of common Indo-Pacific sea stars in the Davao Gulf, Philippines. UPV J Nat Sci 13: 11-24.

Bose U, Wang T, Zhao M, Motti CA, Hall MR, Cummins SF. 2017. Multiomics analysis of the giant triton snail salivary gland, a crown-of-thorns starfish predator. Sci Rep 7 (1): 6000. DOI: 10.1038/s41598-017-05974-x

Cabaitan PC, Gomez ED, Alino PM. 2008. Effects of coral transplantation and giant clam restocking on the structure of fish communities on degraded patch reefs. J Exp Mar Biol Ecol 357 (1): 85-98. DOI: 10.1016/j.jembe.2008.01.001

Cappenberg HAW, Akbar N. 2020. Kondisi megabenthos di Perairan Kabupaten Sumba Timur, Provinsi Nusa Tenggara Timur. Jurnal Ilmu Kelautan Kepulauan 3 (2): 130-146. DOI: 10.33387/jikk.v3i2.2582.g1738. [Indonesia]

Cappenberg HAW, Mahulette RT. 2019. Sebaran dan kepadatan megabentos di perairan Pulau Buton, Sulawesi Tenggara. Bawal 11 (2): 79-93. DOI: 10.15578/bawal.11.1.2019.79-93

Cowan Z-L, Pratchett M, Messmer V, Ling S. 2017. Known predators of crown-of-thorns starfish (*Acanthaster* spp.) and their role in mitigating, if not preventing, population outbreaks. Diversity 9 (1): 1-19. DOI: 10.3390/d9010007

Coyle KO, Konar B, Blanchard A, Highsmith RC, Carroll J, Carroll M, Denisenko SG, Sirenko BI. 2007. Potential effects of temperature on the benthic infaunal community on the southeastern Bering Sea shelf: Possible impacts of climate change. Deep-Sea Res Part II Top Stud Oceanogr 54 (23-26): 2885-2905. DOI: 10.1016/j.dsr2.2007.08.025

Custodio M, Chaname F, Pizzaro S, Cruz D. 2018. Quality of the aquatic environment and diversity of benthic macroinvertebrates of high Andean wetlands of the Junín region, Peru. Egypt J Aquat Res 44 (3): 195-202. DOI: 10.1016/j.ejar.2018.08.004

Dang VD, Fong C-L, Shiu J-H, Nozawa Y. 2020a. Grazing effects of sea urchin *Diadema savignyi* on algal abundance and coral recruitment processes. Sci Rep 10: 20346. DOI: 10.1038/s41598-020-77494-0

Dang VD, Cheung P-Y, Fong C-L, Mulla AJ, Shiu J-H, Lin C-H, Nozawa Y. 2020b. Sea urchins play an increasingly important role for coral resilience across reefs in Taiwan. Front Mar Sci 7 (581945): 1-8. DOI: 10.3389/fmars.2020.581945

Ghafari MIA, Fitrianti V, Ademullah AA, Ariadi MR. 2020. Kondisi komunitas megabenthos terumbu karang di Teluk Sekotong Kabupaten Lombok Barat. In: Bachtiar I, Jufri AW (eds). Kesehatan Terumbu Karang dan Ekosistem Terkait Lainnya di Teluk Sekotong Kabupaten Lombok Barat. Mataram University Press, Mataram. [Indonesia]

Ghafari MIA, Hadiprayitno G, Ilhamdi ML, Satyawan NM. 2019. Struktur komunitas Echinodermata di Kawasan Intertidal Gili Meno, Lombok Utara. Al-Kauniyah Jurnal Biologi 12 (2): 181-188. DOI: 10.15408/kauniyah.v12i2.10871

Giyanto, Manuputty AE, Abrar M, Siringoringo RM, Suharti SR, Wibowo K, Edrus IN, Arbi UY, Cappenberg HAW, Sihaloho HF, Tuti Y, Zulfianita D. 2014. Panduan Monitoring Kesehatan Terumbu Karang. COREMAP-CTI LIPI, Jakarta. [Indonesia]

Grossman LA. 2014. The Impact of Sea Surface Temperature on Outbreaks of *Acanthaster planci* on the Great Barrier Reef. [Senior Thesis]. Claremont Colleges, Claremont.

Hill J, Wilkinson C. 2004. Methods for Ecological Monitoring of Coral Reefs. Australian Institute of Marine Science, Townsville.

Ishikawa T, Maegawa M, Kurashima A. 2016. Effect of sea urchin (*Diadema setosum*) density on algal composition and biomass in cage experiments. Plankton Benthos Res 11 (4): 112-119. DOI: 10.3800/pbr.11.112

Jompa J, McCook LJ. 2003. Coral-algal competition: Macroalgae with different properties have different effects on corals. Mar Ecol Prog Ser 258: 87-95. DOI: 10.3354/meps258087

Lam K, Shin PK, Hodgson P. 2007. Severe bioerosion caused by an outbreak of corallivorous *Drupella* and *Diadema* at Hoi Ha Wan Marine Park, Hong Kong. Coral Reefs 26 (4): 893-893. DOI: 10.1007/s00338-007-0288-9

Laxton JH. 1974. A preliminary study of the biology and ecology of the blue starfish *Linckia laevigata* (L.) on the Australian Great Barrier Reef and an interpretation of its role in the coral reef ecosystem. Biol J Linn Soc 6 (1): 47-64. DOI: 10.1111/j.1095-8312.1974.tb00713.x

Maximov AA, Golubkov SM, Petukhov VA. 2014. Distribution of energy flow in bottom community between different size groups of zoobenthos (using the example of Neva Bay). Inland Water Biol 7 (4): 372-380. DOI: 10.1134/S1995082914040099

McClanahan TR. 1994. Coral-eating snail *Drupella cornus* population increases in Kenyan coral reef lagoons. Mar Ecol Prog Ser 115 (1-2): 131-137. DOI: 10.3354/meps115131

McClanahan TR, Shafir SH. 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 83 (3): 362-370. DOI: 10.1007/BF00317561

Mehdipour N, Gerami MH, Nemati H. 2018. Assessing benthic health of hard substratum macrobenthic community using soft bottom indicators and their relationship with environmental condition. Iran J Fish Sci 17 (4): 641-656. DOI: 10.22092/ijfs.2018.116991

Montano S, Fattorini S, Parravicini V, Berumen ML, Galli P, Maggioni D, Arrigoni R, Seveso D, Strona G. 2017. Corals hosting symbiotic hydrozoans are less susceptible to predation and disease. Proc R Soc B 284 (1869): 20172405. DOI: 10.1098/rspb.2017.2405

Morton B, Blackmore G, Kwok CT. 2002. Corallivory and prey choice by *Drupella rugosa* (Gastropoda: Muricidae) in Hong Kong. J Molluscan Stud 68 (3): 217-223. DOI: 10.1093/mollus/68.3.217

Mutaqin BW, Yuendini EP, Aditya B, Rachmi IN, Fathurrizqi MI, Damayanti SI, Ahadiah SN, Puspitasari NNA. 2020. Kelimpahan megabenthos sebagai indikator kesehatan karang di perairan Bilik, Taman Nasional Baluran, Indonesia. Jurnal Enggano 5 (2): 181-194. DOI: 10.31186/jenggano.5.2.181-194. [Indonesia]

Neo ML, Eckman W, Vicentuan K, Teo SL-M, Todd PA. 2015. The ecological significance of giant clams in coral reef ecosystems. Biol Conserv 181: 111-123. DOI: 10.1016/j.biocon.2014.11.004

Nozawa Y, Lin C-H, Meng P-J. 2020. Sea urchins (Diadematids) promote coral recovery via recruitment on Taiwanese reefs. Coral Reefs 39: 1199-1207. DOI: 10.1007/s00338-020-01955-1

O'Leary JK, Potts D, Schoenrock KM, McClahanan TR. 2013. Fish and sea urchin grazing opens settlement space equally but urchins reduce survival of coral recruits. Mar Ecol Prog Ser 493: 165-177. DOI: 10.3354/meps10510

Olii AH, Paramata AR. 2020. Community structure of macrozoobenthos in Lake Limboto. NIKè 8 (3): 60-69. DOI: 10.37905/nj.v8i3.9858

Patang F, Soegianto A, Hariyanto S. 2018. Benthic macroinvertebrates diversity as bioindicator of water quality of some rivers in East Kalimantan, Indonesia. Intl J Ecol: 1-11. DOI: 10.1155/2018/5129421

Peyrot-Clausade M, Chabanet P, Conand C, Fontaine MF, Letourneur Y, Harmelin-Vivien M. 2000. Sea urchin and fish bioerosion on La Réunion and Moorea reef. Bull Mar Sci 66 (2): 477-485.

Pratchett MS. 2007. Feeding preferences of *Acanthaster planci* (Echinodermata: Asteroidea) under controlled conditions of food availability. Pac Sci 61 (1): 113-120. DOI: 10.1353/psc.2007.0011

Ratianingsih R, Ismawati N, Puspita JW, Jaya AI. 2017. The role of top-predator in the preservation of coral reefs ecosystem. Commun Biomath Sci 1 (1): 54-61. DOI: 10.5614/cbms.2017.1.1.5

Reichelt RE, Bradbury RH, Moran PJ. 1990. The crown-of-thorns starfish, *Acanthaster planci*, on the Great Barrier Reef. Math Comput Model 13 (6): 45-60. DOI: 10.1016/0895-7177(90)90008-b

Samsuri AN, Kikusawa YP, Taira D, Sam SQ, Sim WT, Ng CSL, Afiq-Rosil L, Wee TWD, Ng NK, Toh TC, Chou LM. 2018. The effectiveness of *Trapezia cymodoce* in defending its host coral *Pocillopora acuta* against corallivorous *Drupella*. Mar Biol 165: 70. DOI: 10.1007/s00227-018-3330-2

Saponari L, Dehnert I, Galli P, Montano S. 2021. Assessing population collapse of *Drupella* spp. (Mollusca: Gastropoda) 2 years after a coral bleaching event in the Republic of Maldives. Hydrobiologia 848 (11): 2653-2666. DOI: 10.1007/s10750-021-04546-5

Satyawan NM, Atriningrum NT. 2019. Kondisi eksisting fauna megabenthos di Perairan Labuhan Pandan Lombok Timur pasca gempa bumi Lombok 7.0 Skala Richter. Jurnal Biologi Tropis 19 (2): 172-179. DOI: 10.29303/jbt.v19i2.1303. [Indonesia]

Schoepf V, Herler J, Zuschin M. 2010. Microhabitat use and prey selection of the coral-feeding snail *Drupella cornus* in the northern Red Sea. Hydrobiologia 641 (1): 45-57. DOI: 10.1007/s10750-009-0053-x

Scott CM, Mehrotra R, Hein MY, Moerland MS, Hoeksema BW. 2017. Population dynamics of corallivores (*Drupella* and *Acanthaster*) on coral reefs of Koh Tao, a diving destination in the Gulf of Thailand. Raffles Bull Zool 65 (68): 68-79.

Sese MR, Annawaty, Yusron E. 2018. Keanekaragaman echinodermata (echinoidea dan holothuridea) di Pulau Bakalan, Banggai Kepulauan, Sulawesi Tengah, Indonesia. Scr Biol 5 (2): 73-77. DOI: 10.20884/1.SB.2018.5.2.812. [Indonesia]

Shafir S, Gur O, Rinkevich B. 2008. A *Drupella cornus* outbreak in the northern Gulf of Eilat and changes in coral prey. Coral Reefs 27 (2): 379-379. DOI: 10.1007/s00338-008-0353-z

Tatipata KP, Mashoreng S. 2019. The impact of coral conditions on the structure of the megabenthos community associated with the coral reefs of the Spermonde Islands. Torani 3 (1): 37-50.

Vercelloni J, Liquet B, Kennedy EV, González-Rivero M, Caley MJ, Peterson EE, Puotinen M, Hoegh-Guldberg O, Mengersen K. 2020. Forecasting intensifying disturbance effects on coral reefs. Glob Chang Biol 26 (5): 2785-2797. DOI: 10.1111/gcb.15059

West Lombok Regency Tourism Office. 2021. Data kunjungan wisatawan ke Lombok Barat 2014-2020. http://dispar.lombokbaratkab.go.id/article/data-kunjungan-wisatawan-ke-lombok-barat-2014-2020

Wouthuyzen S, Abrar M, Lorwens J. 2018. A comparison between the 2010 and 2016 El-Ninō induced coral bleaching in the Indonesian waters. In: Mukti M, Yuniati MD, Setiadi B (eds). Global Colloquium on GeoSciences and Engineering 2017; IOP Conference Series: Earth and Environmental Science 118. LIPI, Bandung, 18-19 October 2017. [English]

Wulandari AT, Sadarun B, Palupi RD. 2020. Hubungan kelimpahan relatif karang hidup dengan kepadatan megabentos di perairan Waworaha Sulawesi Tenggara. Sapa Laut 5 (2): 131-138. DOI: 10.33772/jsl.v5i2.12167. [Indonesia]

Young S-S, Yang H-N, Huang D-J, Liu S-M, Huang Y-H, Chiang C-T, Liu J-W. 2014. Using benthic macroinvertebrate and fish communities as bioindicators of the Tanshui River Basin around the Greater Taipei Area - Multivariate analysis of spatial variation related to levels of water pollution. Intl J Environ Res Public Health 11 (7): 7116-7143. DOI: 10.3390/ijerph110707116

Zamani NP. 2015. Kondisi terumbu karang dan asosiasinya dengan bintang laut (*Linckia laevigata*) di perairan Pulau Tunda, Kabupaten Seram, Provinsi Banten. Jurnal Teknologi Perikanan Kelautan 6 (1): 1-10. DOI: 10.24319/jtpk.6.1-10. [Indonesia]

INDO PAC J OCEAN LIFE
Volume 5, Number 1, June 2021
Pages: 22-28

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o050104

Genetic variations of *Cheilopogon nigricans* in the Makassar Strait, Indonesia

INDRAYANI INDRAYANI[1,♥], MUHAMMAD NUR FINDRA[1], ADY JUFRI[2], HERLAN HIDAYAT[3], ARMAN PARIAKAN[4]

[1]Faculty of Fisheries and Marine Science, Universitas Halu Oleo. Jl. H.E.A. Mokodopit, Kambu, Kendari 93561, Southeast Sulawesi, Indonesia. Tel.: +62-823-4267-8801, email: elaaindraa@gmail.com

[2]Faculty of Animal Husbandry and Fisheries, Universitas Sulawesi Barat. Jl. Prof. Dr. Baharuddin Lopa, S.H., Lingkungan Talumung, Majene 91214, West Sulawesi, Indonesia

[3]Faculty of Forestry and Environmental Sciences, Universitas Halu Oleo. Jl. Syaikh Muhammad Al-Khidhir, Kambu, Kendari 93561, Southeast Sulawesi, Indonesia

[4]Faculty of Agriculture, Fisheries and Animal Husbandry, Universitas Sembilanbelas November. Jl. Pemuda, Tahoa, Kolaka 93561, Southeast Sulawesi, Indonesia

Manuscript received: 23 April 2021. Revision accepted: 22 June 2021.

Abstract. *Indrayani I, Findra MN, Jufri A, Hidayat H, Pariakan A. 2021. Genetic variations of* Cheilopogon nigricans *in the Makassar Strait, Indonesia. Indo Pac J Ocean Life 5: 22-28.* This study reports DNA Barcoding results (sequencing of cox 1 mitochondrial gene fragments) of four Makassar Strait flying fish species belonging to the Exocoetidae family. Sampling was collected from around the Makassar Strait waters in West Sulawesi. This research was carried out by molecular identification using DNA barcoding of the cytochrome oxidase 1 (COI) gene, the Wizard Promega CO1 primer kit. The molecular identification results showed that the collected fish had 100% and 99.10% genetic similarities with the species *Cheilopogon nigricans* from the South China Sea. The genetic variations of flying fish in the Makassar Strait are in the same group as flying fish originating from the South China Sea.

Keywords: Cheilopogon, DNA, Exocoetidae, flying fish, Indonesia

INTRODUCTION

Makassar Strait plays an important role related to marine science and operational fisheries oceanography. It provides the unique ocean structures such as variability of the topographic feature, the main path of the Indonesia Throughflow (ITF) (Gordon 2005; Gordon et al. 2008), important upwelling zone associated with the southeast monsoon winds (Hendiarti et al. 2005; Atmadipoera and Widyastuti 2014) and dynamics of the oceanic fronts (Hidayat et al. 2019). This area is also characterized by spatial distribution locations of both cyclonic and anti-cyclonic eddy (Hidayat et al. 2019). South Sulawesi Province, Indonesia is an exporter of single flying fish eggs *Hirundicthys oxycephalus* and *Cheilopogon cyanopterus*, thus making this commodity one of the prima donna of the sector. Fish in addition to shrimp production, since 1969 the export of *H. oxycephalus* and *C. cyanopterus* flying fish eggs from Sulawesi to Japan has been started, and until now these eggs have become increasingly popular and are considered one of the special foods. Production of flying fish eggs *H. oxycephalus* and *C. cyanopterus* in the period 1977 to 2000 ranged from 72.2 to 87.5 tons, with an average production of 308.1 tons per year. Egg collection is increasing due to higher demand, resulting in decreased egg production and fish production (Syahailatua 2006).

Flying fish (Exocoetidae) are economically important fish in the Indonesian capture fisheries sector with high species diversity. The high diversity causes difficulties in the identification process of each species. Generally, flying fish have a standard length of 38 cm. Flying fish, including pelagic fish, which live on the open ocean's surface, can jump out of the water and glide for great distances. Flying fishes are members of the family Exocoetidae (Parin 1996; Carpenter and Niem 1999; Carpenter and Niem 2001), composed of 71 valid species (Wu et al. 2017), 18 of which were found in Indonesia (Robins and Ray 1986; Shen 1993; Sommer and Poutiers 1996; Parin 1999; Carpenter and Niem 2001; Riede 2004; Febyanty and Syahailatua 2008; Ferdiansyah and Syahailatua 2010; Fricke and Wantiez 2011). Flying fish, is one of important species in South Sulawesi waters, especially in Makassar Strait and Flores Sea. This species is familiar to the local coastal communities as one of fish protein sources and its highly valued eggs for export. On the contrary, the wild stock species has been left unmanaged and tends to show signs of overfishing, indicated by the decrease of population, abundance, and catch per unit of effort (CPUE) (Nessa et al. 1993; Ali 2005). Other indications of its population stress are shown by the changing of biological reproduction such as the decrease of body length, increase the fecundity but decrease the egg diameter, and earlier spawning period (Ali 2005).

Based on previous research, there were several flying fish species found in the waters of the Makassar Strait, namely *Hirundichthys oxycephalus* (Ali 2005; Febyanty and Syahailatua et al. 2008; Indrayani et al. 2020), *Parexocoetus mento* (Febyanty and Syahailatua 2008),

Cheilopogon cyanopterus (Febyanty and Syahailatua 2008), *Cheilopogon spilopterus*, *Cheilopogon abei*, *Cypselurus poecilopterus* (Indrayani et al. 2020). The distribution of different flying fish is highly influenced by ecology. For example, one flying fish species and another are prefer a different or the same coastal ecosystem due to reproductive biology, egg, larvae morphology, etc. (Parin 1961; Parin 1968; Collette et al. 1984). However, several studies that have been carried out in the Makassar Strait waters on the types of flying fish that have been collected, have not been determined morphologically and meristically. So, errors from identifying flying fish species can occur due to the many morphologically similarities between species. The individual fish of the same species at the age stage different species often differ from each other apart from individuals of different species at the same age stage (Jayakumar et al. 2019). Research on flying fish DNA has been carried out in several countries including Jayakumar et al. (2019), this study reports the first findings of *Cypselurus opisthopus* based on DNA identification with CO1 primers in the southeast Arabian Sea based on one specimen caught by commercial trawlers (Lewallen et al. 2016) molecular identification of Exocoetidae based on Cytochrome B Mitochondria (1137bp) and RAG2 (882 bp) in Australian waters; (Gordeeva and Shakhovskoi 2017) reported the results of a study of 5 species from the Exocoetidae family in South Atlantic waters with CO1 primary. Based on this, we use molecular markers as one way to identify the types of flying fish caught in the Makassar Strait.

Genetic variation is an important feature of a population not only for short-term fitness of individuals but also for long-term survival of the population by which it allows adaptation of fish to a changing environmental condition. Genetic diversity is also similarly important for farmed populations which allows selective breeding and preventing loss of fitness due to inbreeding depression. Genetic variability can be determined by morphological characters (morphometric analysis), allozyme electro-phoresis (protein pattern), and DNA fingerprinting. The genetic variations of four-wing samples of flying fish H. affinis have been studied at molecular DNA level (Gomes et al. 1998; Gomes 2000).

Currently, DNA fingerprinting technique is extremely efficient for detection of molecular genetic markers that may be utilized in assessment of genetic variation in fish, differentiation of stocks or populations and fisheries management. In more recent development in the detection of genetic polymorphisms is random amplified polymorphic DNA (RAPD). This technique, which is based on the polymerase chain reaction (PCR), amplifies random genomic segments with a single oligonucleotide primer of arbitrary sequence (Williams et al. 1990). In contrast to isozymes, RAPD provides a more arbitrary sample of the genome and generates essentially unlimited numbers of loci for use in genetic analysis (Fritsch and Rieseberg 1996). Genetic differentiation based on RAPD analysis in various fish species has been noted in many studies (Bielawski and Pumo 1997; Coccone et al. 1997; Koh et al. 1999; Liu et al. 1999; Imron et al. 2009; Imron et al. 2010; Moria et al. 2010; Mulyasari et al. 2010; Iskandariah et al. 2011; Lante et al. 2011; Nugroho et al. 2011).

The current study aims to provide a reference for the identification and validation of flying fish from the Exocoetidae family based on the results of the DNA barcode sequencing of the mitochondrial fragment of the cytochrome oxidase 1 (cox 1) gene in flying fish from the Indonesian Makassar Strait. We used the 650 bp region of mtDNA cytochrome oxidase. Subunit I gene (COI) to equalize the CO1 fragment was used in a previous note by Jayakumar et al. (2019). These findings will be practically used for species validation and identification references in the future. The absence of a flying fish gene Exocoetidae from the genus *Cheilopogon* originating from Indonesia in GenBank provides an opportunity for this study to produce the first record. A good management strategy and the initiation of breeding program of the flying fish perhaps can be suggested as the solutions to these ever-growing problems. For that reason, the genetic data of this species is very important as baseline data for its future management.

MATERIALS AND METHODS

Study area

Flying fish specimens were collected from the local fishermen in Majene District, West Sulawesi Province, Indonesia. The location of random sampling is based on the fishing position of gillnet fishermen in the Makassar Strait.

Sample preservation procedure

Sample preservation

Twenty (20) individuals were collected from the Makassar Strait fishing area, each of them with morphological characteristics for the flying fish Exocoetidae. Five good fish specimens were randomly taken for DNA isolation. Then the whole body of specimen was stored in 96% ethanol until it reached the laboratory (Hasan and Tamam 2019). All taken samples were stored under -20º C temperature in the Ichthyology Laboratory of Brawijaya University.

DNA isolation

A small portion of the right pectoral fin was excised and retained in TNESU8 buffer for molecular studies. DNA extraction used TNESU8 buffer containing a high concentration of urea and SDS from DNase to digest DNA in the sample. Four hundred (400) l of TNESU8 was added with 100 mg of fish fin samples in a sterile microtube (Kusuma et al. 2016). Genomic DNA was extracted using the phenol method, a procedure described by Asahida et al. (1996). Twenty (20) µl of 20 mg/ml proteinase K slock solution was added to the DNA sample suspension, and the sample was shaken at 150 rpm at 37°C overnight. Subsequently, 50 µl of NaCl5M and 500 µl of phenol/chloroform (1:1) were added, and sample vortexed for 5 minutes. The suspension was centrifuged at 12000 rpm at cold temperature for 10 minutes. Three hundred (300) µl of chloroform/isoamyl alcohol (24:1) was added to 100 µl of the supernatant, and the result was centrifuged for

10 minutes at 12000 rpm at cold temperature. DNA binding was carried out by adding 1000 µl of cold 96% ethanol to 100 µl of supernatant. The suspension was vortexed for 5 minutes and inserted into a GD column, which was already attached to the collection tube. The suspension was centrifuged for 1 minute at 5000 rpm at a cold temperature. Precipitation was completed by removing the filtrate from the collection tube. The collection tube was washed with 800 µl of cold 70% ethanol and dried before reattaching to the GD column. Subsequently, the collection tube was centrifuged at 12000 rpm at a cold temperature for 5 minutes. In the results of this last centrifugation, remaining liquid was taken by removing the collection tube. The resulting pellets were dissolved in 200 µl Tris- EDTA buffer and stored in a freezer.

DNA sequencing

Molecular confirmation of the species identification was carried out by using partial mtDNA cytochrome oxidase sub-unit I gene (COI). Genomic DNA was extracted by using Wizard Promega Purification Kit as per manufacturer's protocol. The partial COI gene was amplified by using universal primers COI F (5'-TCAACCAACCACAAAGACATTGGC AC-3') and COI R (5'-TAGACTTCTGGG TGGCCAAAGAATCA-3') (Ward et al. 2005). The amplifications were performed in 25 µL reactions containing 10× assay buffer (100 mM Tris, 500 mM KCl, pH 9.0) with 20 mM MgCl2, 10 pmoles of each primer, 200 µM of each dNTP, 0.25 U TaqDNA polymerase and 25 ng of template DNA. PCR conditions were used as follows: initial denaturation at 95°C for 5 min, denaturation 94°C for 30s, annealing 54°C or 45s, extension 72°C for 1 min (30 cycles) followed by a final extension for 10 min at 72°C. PCR products were sequenced bidirectionally.

Data analysis

The sequence data were translated into amino acids to confirm the absence of premature stop codons. The forward and reverse sequences were edited by using the Chroma 2.6.6 program, the consensus was drawn up by using the Ugene 1.32 program, and the comparison sequences were applied by using the Mesquite program. DNA sequences developed in the present study and already available sequences for the species and related species in NCBI were aligned and edited by using MEGA version 10 (Kurniawan et al. 2021). Phylogenetic and molecular evolutionary were analyzed by using Kimura 2-parameter method (Kimura 1980) and were conducted by using MEGA version 7.0 (Kumar et al. 2016). The sequence of Decapterus ruselli was used as outgroup for phylogenetic analysis.

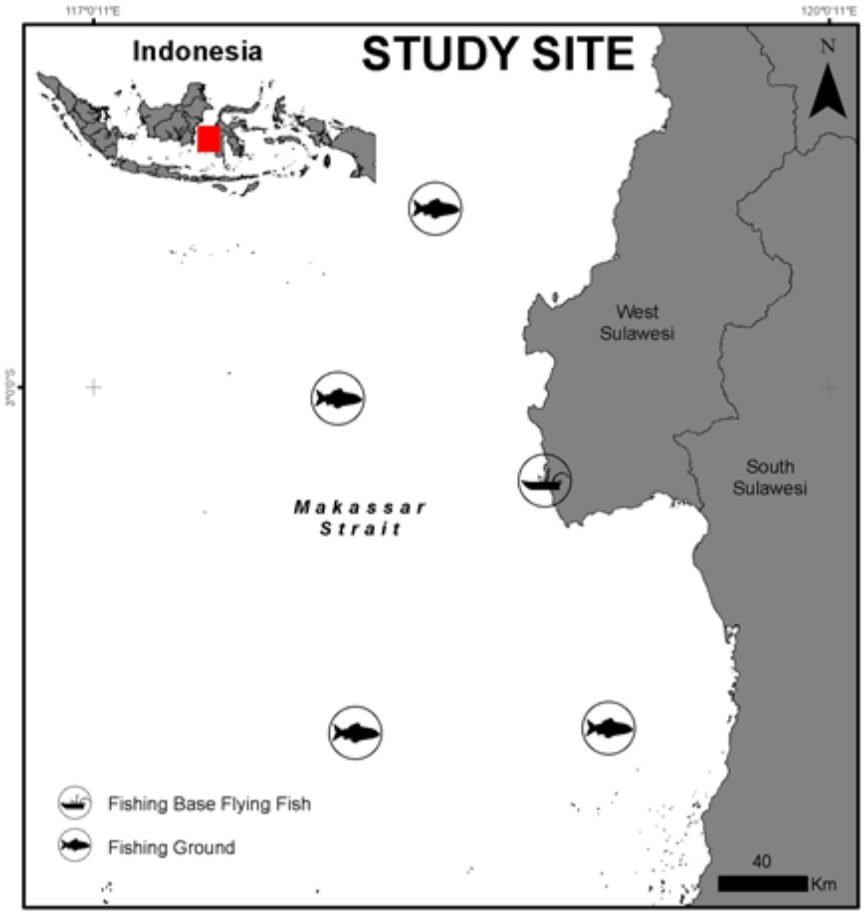

Figure 1. Location of sampling in Majene District, West Sulawesi Province, Indonesia

RESULTS AND DISCUSSION

Molecular identification and barcoding DNA

The molecular identification of flying fish originating from the Makassar Strait showed that the collected samples had 99.10% and 100% similarities with the species *Cheilopogon nigricans* (Table 1) originating from the South China Sea. The alignment analysis result showed that the amplicon sample sequence had similarities with the *C. nigricans* CO1 gene sequences of 100% (Accession no. MH638695.1) and 99.10% (Accession no. KU360275.1). Based on these similarity figures, it can be concluded that it is true that the sample used in this study is the CO1 oxidase gene from flying fish (*C. nigricans*).

Tree phylogeny

Reconstruction of the phylogeny tree was made from the gene *control region* mtDNA sequences downloaded from *GenBank* (Table 2). The data which were downloaded from *GenBank* came from various locations. This was done to determine the distribution of flying fish caught in the waters of the Makassar Strait, and the reconstruction of phylogeny trees was also carried out to determine the genetic relationship between species. Genetic and phylogenetic identification of the CO1 gene from each fish specimen was successfully amplified, resulting in a clear and band-specific appearance. There are currently seven nucleotides for the species *C. nigricans* recorded on NCBI, with four records from the South China Sea and three records from the South Atlantic (Table 2). This suggests that *C. nigricans* nucleotide records from the Makassar Strait are the first records. The CO1 sequences were truncated to the same length as those from GenBank, so the final dataset for phylogenetic reconstructions consisted of sequences of 650 bp for 8 specimens.

To determine the level of kinship between flying fish samples which was used in this study, tree analysis was carried out phylogenic. Phylogenic Tree can represent hypothesized evolutionary relationships among groups of organisms. Phylogenic tree was reconstructed by aligning the study sample sequences (2 samples). The reconstruction of phylogenic tree using the MEGA program with the UPGMA model (Figure 3). The phylogenic tree analysis results showed that the MKS1 and MKS2 samples were in the same group with a genetic distance of 0.0062, which showed that the two isolates had a very close kinship.

Table 1. Similarity specimen

Sample	Query cover	Identity	Species validation	Accession
Makassar 1	95%	100%	*Cheilopogon nigricans*	MH638695.1
Makassar 2	96%	99.10%	*Cheilopogon nigricans*	KU360275.1

Table 2. Genetic record of *Cheilopogon nigricans* in GenBank (NCBI 2020)

GenBank accession number	Gene	NCBI Released time	Location
MH638695.1	cytochrome oxidase subunit I (COI)	02 June 2019	South China Sea
MH638713.1	cytochrome oxidase subunit I (COI)	02 June 2019	South China Sea
KU360275.1	cytochrome oxidase subunit I (COI)	28 February 2017	South Atlantic
JF493131.1	cytochrome oxidase subunit I (COI)	25 July 2016	South Atlantic
MH638747.1	cytochrome oxidase subunit I (COI)	02 June 2019	South China Sea
KU360277.1	cytochrome oxidase subunit I (COI)	28 February 2017	South Atlantic

Table 3. The distance of *Cheilopogon nigricans* sequences from Makassar strait with other species in *Cheilopogon* genus on CO1 gene

Spesies	1	2	3	4	5	6	7	8
*C.nigricans*_Mks (1)								
*C.nigricans*_Mks (2)	0.0062							
MH638695.1 *C.nigricans*	0.0046	0.0031						
KU360275.1 *C.nigricans*	0.0062	0.0046	0.0015					
MN392929.1 *Decapterus russelli*	0.1973	0.1953	0.1913	0.1933				
MH638713.1 *C.nigricans*	0.0062	0.0046	0.0015	0.0031	0.1933			
KU360277.1 *C.nigricans*	0.0078	0.0062	0.0031	0.0046	0.1893	0.0046		
JF493131.1 *C.nigricans*	0.0093	0.0078	0.0047	0.0031	0.1892	0.0062	0.0078	
MH638747.1 *C.nigricans*	0.0093	0.0078	0.0047	0.0062	0.1892	0.0062	0.0078	0.0093

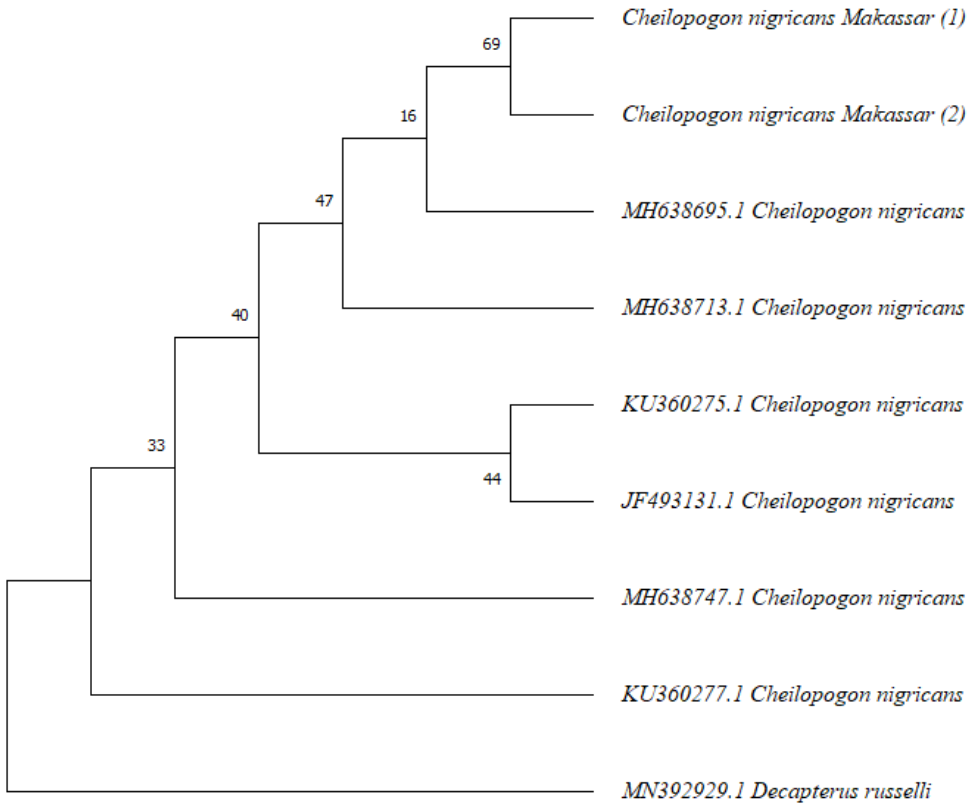

Figure 2. Maximum likelihood phylogenetic tree with 1000 bootstrap replicates. Specimens from the Makassar Strait were grouped together with a strong bootstrap value (100%). Species *Decapterus ruselli* used as an outgroup

Discussion

The taxonomy of flying fishes is ambiguous due to limits of diagnostic characters which distinguish genera, overlapping diagnostic characters between certain species, morphological differences of juveniles from adults of the same species, especially in color pattern and presence of barbels and probability of species yet to be described (Gordeeva and Shakhovskoy 2017). In order to support the limited information on taxonomic features of the species, molecular analysis is incorporated. Mitochondrial DNA (mtDNA) is widely used for phylogenetic studies because its evolution is faster than evolution of nuclear DNA, and it can be used for differentiating closely related species (Tamura et al. 1993). Hebert et al. (2003) demonstrated the utility of the COI gene in species delineation. COI gene sequence is appropriate for this role because, its mutation rate is often fast enough to differentiate closely related species and also because its sequence is conserved among congeners. It should be noted, however, that Gordeeva and Shakhovskoy (2017) were not able to distinguish two closely related species of flying fishes using COI. In the present study, molecular analysis using mitochondrial COI gene revealedthat the collected specimen belongs to *C. opisthopus*. The genetic divergence values of present specimen and GenBank specimens of *C. opisthopus* are within well acceptable level for intraspecific variation in fish species (Jayakumar et al. 2019).

The morphological characters of flying fish in Makassar Strait have a total length which is not different too much from those in other waters. De Croos (2009) found the length distribution of flying fish with an average total length of 19.5 cm to 39.2 cm in Kandakuliya, Sri Lanka. The maximum total length of flying fish can reach 45 cm and generally reaches 38 cm (Carpenter and Niem 1999). If we look further, the total length of the flying fish in the Makassar Strait is still small fish that are experiencing growth and development. The flying fish in the waters of the Makassar Strait in this study proved to be fish from the Exocoetidae family. The value of the genetic distance between species with data from GenBank is still very low, so it can be concluded that the used samples of isolate flying fish still have a very close relationship with *C. nigricans* species from the South China Sea. According to Tallei et al. (2016), the less the value of the genetic distance between two organisms, the closer the relationship between them. Akbar and Aris (2018b) said that the linked genetics, among other things, shows that all populations are closely related. The closeness of the kinship between populations may be caused by interpopulation having the same parentage and genetic proximity (Kusuma et al. 2016; Akbar and Aris 2018b). The evolutionary distance is calculated using the Maximum Composite Likelihood method (Tamura et al. 2011) and is in units of the number of basic substitutions per site. The phylogeny tree analysis results show that the Indonesian Makassar Strait specimens are in the same group as *C. nigricans* from the South China

Sea while *C. nigricans* from the North Atlantic are in a different group. The difference in genetic distance between the two sample groups is presumed because geographically, there are boundaries that allow it to occur. Separation of groups from one another, for example, straits or islands (Kurniawan et al. 2021) or perhaps migration due to environmental suitability and food availability. The cytochrome gene's success was amplified from flying fish samples with a nucleotide length of 650 bp. The amplicon sample sequence was similar to the CO1 gene sequence of *C. nigricans* isolates by 99.10% and 100% through BLAST alignment analysis and the close relationship between flying fish samples. Flying fish obtained in the Makassar Strait showed low genetic distance values in the phylogenic tree analysis, namely 0.000-0.005. The genetic variation of flying fish (*C. nigricans*) in the Indonesian Makassar Strait waters consists of the same population group as the *C. nigricans* specimens from the South China Sea. Regarding the results of this study, this flying fish species is included in the IUCN Red list database in a near-threatened status so that it requires immediate action in capture fisheries management and conservation actions. Domestication can be done to support efforts to save endangered species through ex-situ conservation strategies. In addition, further studies on habitat and biological characteristics are also urgently needed to support fisheries management efforts and in-situ conservation activities.

ACKNOWLEDGEMENTS

This work was supported by BPPDN (Educational Fund Management Institution) in scholarship and research funding, Suci, Widya, Septiana, Messrs Faiq, and Azam in the laboratory assistance, Ari in the field assistance, and Ardiansyah Kurniawan in the analysis discussion

REFERENCES

Akbar N, Labenua R. 2018. Diversity skipjack tuna (*Katsuwonus pelamis*) in the waters of the Maluku Sea North. Depik 7 (2): 164-176. DOI: 10.13170/depik.7.2.11156

Ali SA. 2005. Stock Conditions and Population Diversity of Flying Fish (*Hyrundichthys oxycephalus*) in the Flores Sea and Makassar Strait. [Dissertation]. Hasanuddin University, Makassar.

Atmadipoera AS, Widyastuti P. 2014. A numerical modeling study on upwelling mechanism in Southern Makassar Strait. Jurnal Ilmu dan Teknologi Kelautan Tropis 6 (2): 355-371. DOI: 10.29244/jitkt.v6i2.9012

Asahida T, Kabayashi T, Saitoh K, Nakayama I. 1996. Tissue preservation and total DNA extraction from fish store at ambient temperature using buffer containing high concentration of urea. Fish Sci 62 (5): 727-730. DOI: 10.2331/fishsci.62.727

Bielawski JP, Pumo DE. 1997. Ramdomly Amplified Polymorphic DNA (RAPD) analysis of Atlantic coast striped bass. Heredity 78: 32-40. DOI: 10.1038/hdy.1997.4

Carpenter KE, Niem VH. 1999. The Living Marine Resources of the Western Central Pacific Volume 4, Food and Agriculture Organization of the United Nations. Department of Biological Sciences Old Dominion University Norfolk, Virginia, USA and Marine Resources Service Species Identification and Data Programme FAO Fisheries Department, Rome.

Carpenter KE, Niem VH. 2001. 2 FAO Species Identification Guide for Fishery Purposes: The Living Marine Resources of the Western Central Pacific. FAO Fisheries Department, Rome.

Coccone A, Allegrucci G, Fortunade C, Sbordoni V. 1997. Genetic differentiation within the European sea bass (Dicentrachuslabrax) as revealed by RAPD-PCR assays. J Heredity 88: 316-324. DOI: 10.1093/oxfordjournals.jhered.a023109

Collette BB, McGowen GE, Parin NV, Mito S. 1984. Beloniformes: Development and relationships. International Symposium Dedicated to the Memory of Elbert Halvor Ahlstrom Ontogeny and Systematics of Fishes. La Jolla, California, 15-18 August 1983.

De Croos MDST. 2009. Gillnet selectivity of three flying fish, *Cheilopogon nigricans* (Bennett, 1846), *Cypselurus poecilopterus* (Valenciennes, 1846) and *Cheilopogon suttoni* (Whitle and Colefax, 1938) off the northwestern coast of Sri Lanka. Sri Lanka J Aquat Sci 14: 15-28. DOI: 10.4038/sljas.v14i0.2190

Febyanty F, Syahailatua A. 2008. Kebiasaan makan ikan terbang, *Hirundicthys oxycephalus* dan *Cheilopogon cyanopterus*, di perairan Selat Makassar. Jurnal Penelitian Perikana Indonesia 14 (1): 123-131. DOI: 10.15578/jppi.14.1.2008.123-131. [Indonesia]

Ferdiansyah F, Syahailatua A. 2010. Fekunditas dan diameter telur ikan terbang di perairan selat makassar dan utara bali. Bawal 3: 191-197. DOI: 10.15578/bawal.3.3.2010.191-197

Fricke R, Kulbicki M, Wantiez L. 2011. Checklist of the fishes of New Caledonia, and their distribution in the Southwest Pacific Ocean (Pisces). Stuttgarter Beiträge zur Naturkunde A, Neue Serie 4: 341-463.

Fritsch P, Rieseberg LH. 1996. The use of rRndom Amplified Polymorphic DNA (RAPD)in conservation genetics. In: Smith TB, Wayne RK (eds). Molecular Genetic Approaches in Conservation. Oxford University Press, New York.

Gomes C, Dales RB, Oxendford HA. 1998. The application of RAPD marked in stock dis-crimination of the four wing flying fish, *Hirundichthys affinis* in the Central Western Atlantic. Mol Ecol 7: 1029-1039. DOI: 10.1046/j.1365-294x.1998.00427.x

Gomes C, Oxendford HA, Dales RB. 2000. Restriction site mapping of the mitochondrial DNA of the four-wing flyingfish, *Hirundichthys affinis*. DNA Sequence 11 (3-4): 277-280. DOI: 10.3109/10425170009033243

Gordeeva NV, Shakhovskoi IB. 2017. Efficiency of DNA barcoding for phylogenetic analysis and species identification in flying fish (Exocoetidae). J Ichthyol 57 (2): 287-296. DOI: 10.1134/s0032945217020096

Gordon LA. 2005. Oceanography of the Indonesian seas and their throughflow. Oceanogr 18: 14-27. DOI: 10.5670/oceanog.2005.01

Gordon RJ, Lowy FD. 2008. Pathogenesis of methicillin-resistant *Staphylococcus aureus* infection. Clin Infect Dis 46 (5): S350-S359. DOI: 10.1086/533591.

Hasan V, Tamam MB. 2019. First record of the invasive Nile Tilapia, *Oreochromis niloticus* (Linnaeus, 1758) (Perciformes, Cichlidae), on Bawean Island, Indonesia. Check List 15 (1): 225-227. DOI: 10.15560/15.1.225

Hebert PDN, Ratnasingham S, de Waard JR. 2003. Barcoding animal life: Cytochrome C oxidase subunit 1 divergences among closely related species. Proc R Soc Lond Ser B: Biol Sci 270: 96-99. DOI: 10.1098/rsbl.2003.0025

Hendiarti N, Suwarso, Aldrian E, Amri K, Andiastuti R, Sachoemar SI, Wahyono IB. 2005. Seasonal variation of pelagic fish catch around Java. Oceanogr 18 (4): 112-123. DOI: 10.5670/oceanog.2005.12

Hidayat R, Zainuddin M, Safruddin S, Mallawa A, Farhum SA. 2019. Skipjack Tuna (*Katsuwonus pelamis*) catch in relation to the thermal and chlorophyll-a fronts during May - July in the Makassar Strait. IOP Conf Ser Earth Environ Sci 253: 012045. DOI: 10.1088/1755-1315/253/1/012045

Imron, Sunandar D, Susilowati R, Suprapto R, Khasani I. 2009. Randomly Amplified Polymorphic DNA (RAPD) fingerprinting ofsix Indonesian populations of giant fresh-water prawn, *Macrobrachium rosenbergii*. Indon Aquacult J 4 (2): 93-100. DOI: 10.15578/iaj.4.2.2009.93-100

Imron, Sunandar D, Suprapto R, Listyowati N. 2010. The application of RAPD finger-printing to assess inbreeding levels in the cultured populations of giant freshwater prawn, *Macrobrachium rosenbergii*. Indon Aquacult J 5 (1): 73-82. DOI: 10.15578/iaj.5.1.2010.73-82

Indrayani, Sambah AB, Kurniawan A, Pariakan A, Jufri A, Wiadnya DGR. 2020. Determination spesies flying fishes (Exocoetidae) in

Makassar strait. IOP Conf Ser Earth Environ Sci 441: 012110. DOI: 10.1088/1755-1315/441/1/012110

Iskandariah, Kusmini II, Arifin OZ, Gustiana R. 2011. Variasi genetik hasil persilangan nila BEST dengan red nifi dan nirwana menggunakan penanda RAPD. Jurnal Riset Akuakultur 6 (3): 363-371. DOI: 10.15578/jra.6.3.2011.363-371. [Indonesia]

Jayakumar TTZ, Shakhovskoy IB, Prasoon NPK, Kathirvelpandian A, Ajith KTT, Lal KK. 2019. The first record of the rear fin flying fish, *Cypselurus opisthopus* (Exocoetidae), from the water of South India, with the assessment of flying fish species occurring in the Indian exclusive economic zone. J Ichthyol 59 (5): 697-706. DOI: 10.1134/S0032945219050059

Kimura M. 1980. A simple method for estimating evolutionary rate of base substitutions through comparative studies of nucleotide sequences. J Mol Evol 16 (2): 111-120. DOI: 10.1007/BF01731581

Koh TL, Khoo G, Fan LQ, Phang VPE. 1999. Genetic diversity among wildforms and cultivated varieties of discus (*Symphysodon* spp.) as revealed by Random Amplified Polymorphic DNA (RAPD) finger printing. Aquac 173: 485-497. DOI: 10.1016/s0044-8486(98)00478-5

Kumar R, Mahadani P, Kishore R, Meitei AL, Singh DR. 2016. Technical Bulletin: DNA Barcoding of Indian Orchids. ICAR-National Research Centre for Orchids, India.

Kurniawan A, Hariati AM, Kurniawan A, Wiadnya DGR. 2021. First genetic record and the phylogenetic relationship of *Osteochilus spilurus* (Cyprinidae: Labeoninae) originating from Bangka and Belitung Islands, Indonesia. Biodiversitas 22 (2): 794-802. DOI: 10.13057/biodiv/d220233

Kusuma ABK, Bengen DG, Maduppa H, Subhan B, Arafat D. 2016. Keanekaragaman genetik karang lunak *Sarcophyton trocheliphorum* pada populasi laut Jawa, Nusa Tenggara dan Sulawesi. Jurnal Enggano 1 (1): 89-96. DOI: 10.31186/jenggano.1.1.89-96. [Indonesian]

Lante S, Tenriulo A, Parenrengi A, Rachmansyah, Malina AC. 2011. Keragaman genetik populasi ikan beronang (*Siganus guttatus*) di Selat Makassar dan Teluk Bone menggunakan metode Random Amplified Polymorphic DNA. Jurnal Riset Akuakultur 6 (2): 211-224. DOI: 10.15578/jra.6.2.2011.211-224. [Indonesia]

Lewallen EA, van Wijnen AJ, Bonin CA, Lovejoy NR. 2016. Flyingfish (Exocoetidae) species diversity and habitats in the eastern tropical Pacific Ocean. Mar Biodivers 48: 1755-1765. DOI: 10.1007/s12526-017-0666-7

Liu ZJ, Li P, Argue BJ, Dunham RA. 1999. Random amplified polymorphic DNA markers: Usefulness for gene mapping and analysis of genetic variation of catfish. Aquac 174: 59-68. DOI: 10.1016/s0044-8486(99)00007-1

Mulyasari, Soelistyowati DT, Kristanto AH, Kusmini II. 2010. Karakteristik genetik enam populasi ikan nilem (*Osteochilus hasselti*) di Jawa Barat. Jurnal Riset Akuakultur 5 (2): 175-182. DOI: 10.15578/jra.5.2.2010.175-182. [Indonesia]

Moria SB, Setiawati KM, Haryanti, Wardana IK. 2010. Karakter genetik induk (F-0) danturunannya (F-1) pada ikan hias laut clown (*Amphiprion percula*) menggunakan marker DNA (Random Amplified Polymorfism DNA). Jurnal Riset Akuakultur 5 (2): 183-190. DOI: 10.15578/jra.5.2.2010.183-190. [Indonesia]

Nessa MN, Mallawa A, Najamuddin, Sadarang A, Ali SA, Arifin MF, Alamsyah PM, Mardiana, Latif SS. 1993. Penelitian Pengembangan Potensi Sumberdaya Laut Selat Makassar, Laut Flores dan Selat Makassar Sulawesi Selatan. Lembaga Pengabdian pada Masyarakat, Hasanuddin University, Makassar, South Sulawesi.

Nugroho E, Sundari S, Jatnika. 2011. Variasi genetik hibrida ikan gurami dianalisis dengan menggunakan marker RAPD. Jurnal Riset Akuakultur 6 (1): 1-6. DOI: 10.15578/jra.6.1.2011.1-6. [Indonesia]

Parin NV. 1961. Principles of classification of the flying fishes (families Oxyporhamphidae and Exocoetidae). Tr Inst Okeanol Im PP Shirshova Akad Nauk SSSR 43: 92-183.

Parin NV. 1968. Ikhtiofauna Okeanskoi Epipelagiali (Ichthyofauna of The Ocean Epipelagic Zone). Nauka, Moscow.

Parin NV. 1996. On the species composition of flying fishes (Exocoetidae) in the West-Central Part of Tropical Pacific. J Ichthyol 36: 357-364.

Parin NV. 1999. *Exocoetidae* (Flyingfish). In: Carpenter KE, Nien VH. The Living Marine Resources of The Westere Central Pacific. FAO, Rome.

Riede K. 2004. Global Register of Migratory Species - from Global to Regional Scales. [Final Report]. Federal Agency for Nature Conservation, Bonn, Germany.

Robins CR, Ray GC. 1986. A Field Guide to Atlantic Coast Fishes of North America. Houghton Mifflin Company, Boston, United States.

Shen SC. 1993. Fishes of Taiwan. Department of Zoology, National Taiwan University, Taipei.

Sommer C, Schneider W, Poutiers JM. 1996. FAO Species Identification Field Guide for Fishery Purposes. The Living Marine Resources of Somalia. FAO, Rome.

Syahailatua A. 2006. Perikanan ikan terbang di Indonesia: Riset menuju pengelolaan. Oseana 31 (3): 21-31.

Tallei TE, Rembet RE, Pelealu JJ, Kolondam BJ. 2016. Sequence variation and phylogenetic analysis of *Sansevieria trifasciata* (Asparagaceae). Biosci Res 13 (1): 1-7.

Tamura K, Nei M. 1993. Estimation of the number of nucleotide substitution in the control region of mitochondrial DNA in humans and chimpanzees. Mol Biol Evol 10: 512-526. DOI: 10.1093/oxfordjournals.molbev.a040023

Tamura K, Peterson D, Peterson N, Stecher G, Nei M, Kumar S. 2011. MEGA5: Molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. Mol Biol Evol 22: 2731-2739. DOI: 10.1093/molbev/msr121

Ward RD, Zemlac TC, Innes BH, Last PR, Hebert PDN (2005) DNA barcoding Australia's fish species. Phil Trans R Soc B 360: 1847-1857.

Williams JGK, Kubelik AR, Livak KJ, Rafalski JA, Tingey SV. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic marker. Nucleic Acids Res 18: 6531-6535. DOI: 10.1093/nar/18.22.6531

Wu L, Liu X, Fu P, Xu L, Wang X, Sun Y, Yeling. 2017. Identification and stable isotop analyses of flying fish scales from ornithogenic sediments at three islands in the South China Sea. Mar Ecol Prog Ser 585: 175-183. DOI:10.3354/meps12382

INDO PAC J OCEAN LIFE
Volume 5, Number 1, June 2021
Pages: 29-41

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o050105

The significance of community-based management in the structure and sustainability of the fisheries in Cross River Estuary, Nigeria

AMBO ANTIGHA ANTIGHA, AYAA KOJO ARMAH♥, ELVIS NYARKO
Department of Marine and Fisheries Sciences, University of Ghana. P.O.BOX GP1115, Nungua, Legon Boundary, Accra, Ghana.
Tel./fax.: +233-30-2213850. ♥email: akarmah@ug.edu

Manuscript received: 4 May 2021. Revision accepted: 29 June 2021.

Abstract. *Antigha AA, Armah AK, Nyarko E. 2021. The significance of community-based management in the structure and sustainability of the fisheries in Cross River Estuary, Nigeria. Indo Pac J Ocean Life 5: 29-41.* Given the unsustainable fishing practices in the Cross River estuary, this study examined its fisheries' structure and sustainability. Water quality and fish health in the research area were evaluated by analyzing the water's physicochemical parameters. Surface measurements included pH, DO, turbidity, salinity, alkalinity, phosphate, and nitrate levels. In addition, researchers looked into the exploitation rates, fish sizes, and socioeconomic elements in the estuary's multispecies gillnet fishery to ascertain its susceptibility to human and environmental influences. The turbidity of the water in the area varied significantly between the study sites, with values ranging from 21.8 to 52.2 NTU (normalized turbidity units) at Esuk Anansa, 30.3 NTU at Esuk Okon, and 21.8 NTU at Esuk Anantigha. Nevertheless, fish could tolerate the water quality during the research period. Sampled monthly catches averaged 21.2 kilograms in weight (range 15.3 kg to 27.0 kg). CPUE averaged 7.1 kg per vessel per journey. *Pseudotolithus elongatus* made up 56.69% of the catch by weight, followed by *Ethmalosa fimbriata* at 30.28% and *Chrysichthys nigrodigitatus* at 7.53%. The study found that certain fish species are in danger because of unsustainable fishing practices that result in the taking of predominantly small fish (less than 15 cm in length). To update knowledge on socioeconomic indices, fishing equipment, and prime captures of the fishes in the area and to propose management methods for the fisheries and environment, the socioeconomic situation of artisanal fishermen, traders, and mangrove loggers in the estuary were determined. The study suggests implementing a community-based coastal resource management strategy for the long-term health of the region's fisheries and ecology.

Keywords: Fishing, health status, physicochemical, water

INTRODUCTION

Compared to other ecosystems, such as forests, grasslands, or agricultural land, estuaries are among the most fertile on Earth. As a result, unique ecosystems of plants and animals suited for living at the sea's edge thrive in the tidal, protected waters of estuaries. Shallow open seas, freshwater and salt marshes, swamps, sandy beaches, mud and sand flats, rocky coasts, oyster reefs, mangrove forests, river deltas, tidal pools, and seagrasses can all be found in and around estuaries (USEPA 1998).

Since estuarine ecosystems are subject to constant or periodic external forcing (such as tides, storms, and river discharges), they will be significantly impacted by human-induced climate change. It is often physically variable, sometimes to the extreme (for example, exposed to high or low salinity, temperature, oxygen, or moisture) (Officer 1976; Kennedy 1984; Hobbie 2000; Valiela 2006). As a critical transition zone with steep gradients in energy and physicochemical qualities at the interface of land and sea, they are naturally a focal point of influences from both landward and seaward sides. During periods of global upheaval, they serve as a focal point for the stresses that human activity and climate change place on the world's oceans and continents. As a result, ecosystem services and economic potential can be severely diminished for any creature or activity dependent on estuarine stability (Jennerjahn and Mitchell 2013).

Estuaries have been recognized for a long time as crucial locations for fish because of the multiple functions they serve: as nurseries, migration corridors, feeding grounds, and shelter areas (Mc. Lusky and Elliot 2004; Rezai et al. 2011; Tumiran et al. 2011; Hossain et al. 2012; Zaleha et al. 2013; Rahim et al. 2014; Saifullah et al. 2014; Paturej et al. 2017; Eugenia et al. 2019; Aiman et al. 2020). Furthermore, to ensure their safety and long-term maintenance, it's essential to have a firm grasp on the ecosystem process (i.e., the operation of these transitional environments) (Franco et al. 2008). Fish are a sustainable aquatic resource. Advantages include reversing a downward trend toward overexploitation by employing prudent management and techniques. In addition, the stock's renewability idea facilitates the fish population's dynamics. Therefore, studying population dynamics in fisheries is gaining popularity as a valuable resource for conservation and management (Mosepele 2000).

Many types of fish and crustaceans are considered estuary dependent due to the crucial role estuaries play in their life cycles (Potter et al. 1990; Holt and Miller 2011). Consequently, there has been a lot of focus on the need to conserve estuarine ecosystems as nurseries to ensure the survival of critical fisheries since many of the bigger marine species that use estuaries as nursery regions are of

economic and recreational importance (Elliot et al. 1990; Pomfret et al. 1991).

Restoring the ecological services of damaged tropical estuaries has received little attention (Twiley et al. 1996). While efforts to improve water quality through pollution control have received much attention, restoring habitats like mangroves received very little effort. However, managing and conserving tropical estuaries are becoming challenging as devastation proceeds and fisheries yields decline. Several nations have already launched pilot programs to examine the viability of mangrove reforestation (Blaber et al. 2000). Protecting tropical estuaries is crucial because little rehabilitation effort has been made.

Humans have become an integral element of the ecology of the Cross River estuary due to its frequent closeness to population centers, biological diversity, high fisheries productivity, and recreational value (Oribhabor et al. 2013). Indiscriminate mangrove harvesting, garbage disposal, multi-faceted pollution, and unsustainable fishing practices are all human-caused factors degrading the estuary's ecosystem.

The study aims to analyze the fisheries' framework so that adequate measures may be taken to protect the estuary's aquatic life in the long run. The objectives are (i) to precisely evaluate the quality of the water in the cross-river estuary and the condition of the fish that live there by examining the water's physicochemical characteristics; (ii) to determine the diversity of fish species, the frequency with which they are caught, and the effects of human and environmental variables on their populations; (iii) to evaluate the catch sizes and exploitation rates of target species in the estuary.

MATERIALS AND METHODS

Survey of the study area

Before starting data collecting, a preliminary reconnaissance survey was conducted. The GPS coordinates of each research site in Nigeria's Cross River Estuary have been recorded. In addition, social, environmental, and economic problems were discovered through on-the-ground observational walks and boat cruises.

Description of the study area

Southeastern Nigeria is home to the estuary of the Cross River. Located between 04º10′ and 05º10′ north latitude and 08015 and 08035 east longitude, this Cross River State coastal region is adjacent to Cameroon. Also, it includes a portion of Akwa Ibom State and Rivers State to the east of the Niger Delta. The estuary has the distinction of being the largest in the entire Gulf of Guinea. The estuary serves as a meeting place for three major rivers that flow south to the Atlantic Ocean. Countries like Nigeria and Cameroon share this estuary (Nwosu et al. 2005). Its origin can be traced back to the Cameroun Mountains. As it makes its way westward into Nigeria, it winds through the country's high rainforests until finally emptying into the Atlantic. Mangrove forest replaces other types of flora in the lower brackish parts of the river (Ama-Abasi 2002).

Climate and vegetation

The climate of the research area is characterized by a long wet season from April to October and a dry season from November to March. The mean yearly rainfall is roughly 2,000 mm. During the wet season, around August/September, there is a prolonged drought known as the August drought. The harmattan is a period of extreme cold, dryness, and dust that often occurs between December and January. The average temperature is 22°C during the wet season and 35°C during the dry season, and the average relative humidity is above 60% year-round, approaching 90% during the wet season (Akpan 1993). The hydrodynamic circumstances change the salinity of the coastal waters and flood the floodplain, which affects both marine and freshwater fisheries in the area (Moses 1990). *Rhizophora racemosa, Rhizophora mangle, Rhizophora harrissonii, Languncularia racemosa,* and *Avicennia marina (africana)* are the five kinds of mangroves found in the region, together with the invasive exotic nipa palm (*Nypa fruticans*). Plankton, crustaceans, molluscs, fin fishes, reptiles, birds, and mammals are some of the many species that call this region home (Nwosu 2005).

Locations of study

The research was conducted in the Cross River estuary in Nigeria, namely on the Bakassi Peninsula and in the Calabar South Local Government Area. Because of the abundance of fish landings in the region, these spots were chosen.

A peninsula in the Gulf of Guinea, Bakassi is a place. The estuaries of the Cross River (near Calabar) and the Rio del Ray (to the east) form its boundaries. The peninsula is located at 04°25′N 05°10′W (or longitudes 08°20′E and 09°08′E). Area-wise, it's about 665 km^2, and its islands are all low and covered in mangroves. Bakassi is estimated to have a population of between 150,000 and 300,000. The warm east-flowing Guinea current (known as Aya Efiat in Efik) meets the chilly north-flowing Benguela current in Bakassi, located at the easternmost point of the Gulf of Guinea (called Aya Ubenekang in Efik). Submarine shoals rich in fish, shrimp, and a wide variety of other marine species are formed due to the interaction between these two ocean currents, and enormous, foamy breakers ceaselessly advance toward the shore. Because of this, the waters around Bakassi are teeming with fish. The primary economic activity is fishing (Gill et al. 2003). Coordinates for the Calabar South LGA are latitudes 04° 95' and 05° 15'N and longitudes 08° 32' and 08° 45'E. In addition, Anantigha is home to its administrative hub. As of the 2006 Census, its population was 191,630, and its land area was 264 square kilometers. Most of the locals make their living off the sea and the mangrove forests.

The following are the three locations at which the research was conducted:

Station 1: Esuk Anansa lies in the town of Ikang, between latitudes 04° 47' and 05º 20'N and longitude 08° 30′ and 08° 42' E. Calabar, the state capital, is around 5 km away, and Station 2 (Esuk Okon) is about 1 km away from the town. In this station, the high population density has led to widespread deforestation, littering, and surface runoff

pollution caused by residential wastes, especially during the wet season. Palm trees (*Elaeis guineensis*), bamboo (*Bambusa africana*), plantain and banana (*Musa* spp.), and mangroves (*R. racemosa*, *R. mangle*, and *A. africana*) compose the majority of the local flora. Okra (*Abelmoschus esculentus*), Water Leaf (*Talinum triangulare*), Fluted Pumpkin (*Telfairia occidentalis*), and Maize (*Zea mays*) are the most common crops grown in the riparian zones. Silty sediments describe the biotope or beach at this location.

Station 2: Esuk Okon is situated between latitudes 04º 49′ and 05° 22' N and longitudes 08° 33 ′ and 08° 40' E, on the outskirts of Ikang in the Bakassi Local Government Area of Cross River State, Nigeria. Calabar Municipality, the state capital of Cross River State, is around 6 kilometers from the settlement. About 200 households call this area home; most are fishermen, but the area lacks essential services and infrastructure, such as a hospital, school, access road, power, hotels, and a market. These conveniences are unavailable in the village itself. Therefore, residents must travel to Ikang, the nearest central town, only approximately 1 km away. The predominant plants and crops at this location are similar to those at station 1. In addition, the beach at this location is characterized by muddy sediment composed of silt.

Station 3: Esuk Anantigha is situated between latitudes 04° 55′ and 05° 10'N and longitudes 08° 22′ and 08° 34'E, in the southern section of the capital of Cross River State (Calabar South). With a higher population density than Station 1, this station has seen widespread deforestation, erosion, flooding, and widespread pollution from sources as diverse as human waste and urban and agricultural runoff during the rainy season. Flora, fauna, and farmed crops are similar to those at the other stations, except for a higher concentration of nipper palms and a smattering of fish and poultry farms. Mangrove wood is a home fuel used for fish smoking, cooking, baking, and construction, and this station is the primary landing site/market for this product. This biotope is distinguished by its muddy substrate and bank root structure (Figure 1).

Research design and sampling methods

Either primary or secondary data were used in the analysis. Taking water samples once a month at each site and analyzing them in a lab was the primary source of information. pH, dissolved oxygen (DO), turbidity, salinity, alkalinity, phosphate (PO_4- P), and nitrate (NO_3- N) were among the water quality characteristics tested for in the study. In addition, in-situ measurements of water temperature and turbidity were taken. Water samples were taken monthly from each station at a distance of 100 meters from the beach and at a depth of 1 meter using one-liter polyethylene bottles that had been washed, rinsed, and dried in a laboratory. Samples of water were kept cold in a cooler containing ice chips. The Institute of Oceanography at the University of Calabar in Nigeria tested the water and wastewater using the American Public Health Association's (APHA) standard technique (APHA 2005).

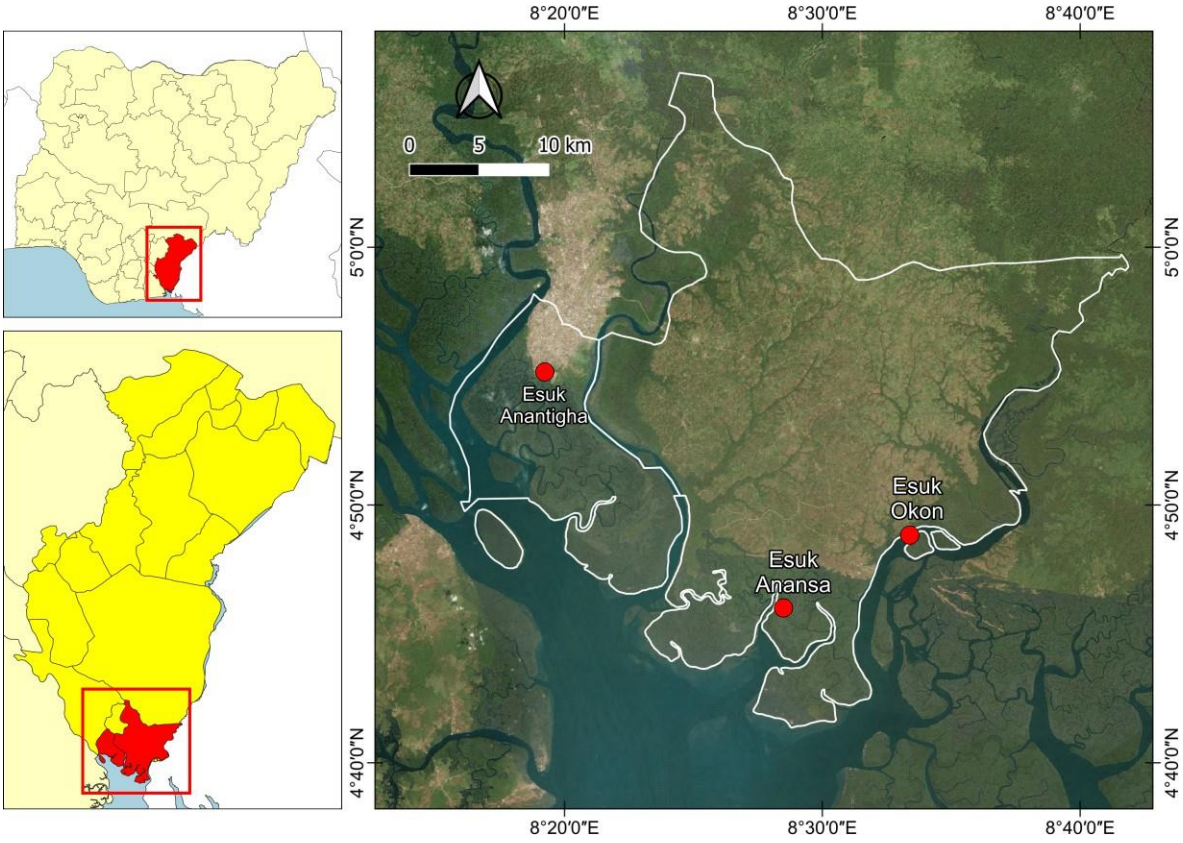

Figure 1. Map of the study area showing the three stations of Esuk Anansa, Esuk Okon Esuk Anantigha of Cross River State, Nigeria

The landings of multispecies artisanal gillnet fishing in the study area were evaluated during the study. Traditional methods were used to measure the length of 1,814 fish within 0.1 cm, from the point of snout to the tip of the caudal fin. The arriving boats were chosen randomly to reduce the potential for bias. It was accomplished by taking daily boat samples at each location. In addition, once a month, at various landing days during flow tide, samples were taken from each station (landing periods). Near-surface and near-bottom gillnets of around 100 m in length and of stretched mesh size range from 2.9 cm to 5.0 cm (average 3.8 cm) were the most common fishing gears in the area. These were used to catch bonga (*E. fimbriata*) and demersal fish, respectively (Holzlohner et al. 2007). Other methods included artificial shelters, basket traps, and fish fences in addition to the traditional hook-and-line way.

One hundred forty-two respondents from the three study sites provided socioeconomic data. There were 70 responses from fishermen, mangrove loggers, fish processors/ traders, and farmers, 50 from Esuk Anantsa, and 22 from Esuk Okon. A census of each station's inhabitants was used to compile this data. Most people live in Esuk Anantigha, although there are also many people in Esuk Anansa. Rainfall data was received from the Department of Meteorology of the Nigerian Airport Authority in Calabar, Cross River State. A map of the research region was obtained from the Geography and Regional Planning Department of the University of Calabar, Nigeria.

According to Holzlohner et al. (2007), fish were sampled by weighing every fish caught in a single boat expedition. The capture rate was calculated by adding the weight of all fish taken from each boat on each trip and expressing it as kilograms per boat. During the study period, six boats were sampled at each station, with one being sampled every month for six months. Overall, 18 boats were sampled from a total of 149 at each location. Esuk Anantigha has the most boats (62), followed by Esuk Okon (34) and Esuk Anansa (53) in terms of overall numbers. Because of storage limitations, we only sorted the total catch from each boat sample for the three most common fish in the area: *Pseudotolithus elongatus* (West African croaker), *Ethmalosa fimbriata* (Bonga), and *Chrysichthys nigrodigitatus* (estuarine catfish). It is because fishermen focused on catching these species to meet consumer demand. Due to their low commercial value, a few additional species caught in the landings were considered by-catches.

The following formula was utilized to get the catch per unit effort:

$$\text{CPUE} = \frac{Catch\ per\ Trip}{Effort} \quad \text{……..……(1)}$$

CPUE, or catch per unit effort, is the average catch divided by the average effort during the study period.

Once the monthly totals were tallied, the relative abundance of each species was calculated as a percentage of the month's total landings by weight, as shown below:

$$\textbf{Percentage Weight}\ (\%) = \frac{Species\ weight}{Total\ Weight} \times 100 \quad \text{…….(2)}$$

Sokal and Rohlf (1981) and Cochran (1977) used biostatistics to determine the mean length, variance, and standard deviation.

The following equation determined the mean length of each sample:

$$\times = [x(1) + x(2) + \cdots + x(n)] = \frac{1}{n} * \sum_{i=1}^{n} x(i) \quad \text{…….. (1)}$$

Where: n = sample of a particular fish species caught from one boat and

x(i) = length of fish no i., and I = 1,2,……..,n.

The variance, which is the variability about the mean value, is given by the following equation:

$$S^2 = \frac{1}{n-1} * [(x(1) - \times)^2 + (x(2) - \times)^2 + \cdots + (x(n) - \times)^2] = \frac{1}{n-1} * \sum_{i-1}^{n} [x(i) - \times]^2$$

……..……..(2)

Thus the variance, S^2, is the sum of squares deviation from the mean divided by the number minus one.

$$S^2 = \frac{1}{n-1} * [\sum_{i=1}^{n} x(i)^2 - \frac{1}{n} * |\sum_{i=1}^{n} x(i)]^2 \quad \text{…..…(3)}$$

The square root of the variance is the standard deviation. The relative standard deviation or coefficient of the mean is the standard deviation divided by the mean, i.e.

$$\frac{S}{X} \quad \text{……...…...…….. (4)}$$

The growth parameters L∞ (asymptotic length) and K (stress factor) of the species were examined with the FISAT II software package. The total mortality Z was calculated as follows:

Z = F + M……..……(5)

Where F = fishing mortality and M = Natural mortality. The exploitation rate (E) was calculated as follows:

$$\text{E} = \frac{F}{Z} \text{……...……..……(6)}$$

Data sources

Focused group discussions (a semi-structured discussion with groups of fishermen, mangrove loggers, and traders to identify their impression of the environment), questionnaires, water samples for physicochemical parameter analysis, and the catch composition of gillnet fisheries in the research locations were utilized to obtain data from the field between December 2014 and May 2015. The Calabar, Nigerian Airport Authority (NAA.)

Meteorology Department provided precipitation totals for the study period. Knowledge gained from prior research was also incorporated.

The questionnaire included both open-ended questions, which provided respondents with the freedom to share their thoughts and feelings, and closed-ended questions, from which respondents could choose among a set of pre-coded replies designed to reduce the possibility of respondent bias. The questionnaire covered six distinct topics: respondent demographics, traditional fisheries management, other estuarine resources management, ethnicity, social life, and local government. Discussions with fishermen and women, shellfish harvesters, mangrove loggers, fish, and shellfish processors, and traders preceded the distribution of questionnaires. In addition, the stations' focal groups met twice before surveys were distributed.

Data analysis

Water samples were analyzed physicochemically following the procedures outlined in the American Physical Health Association (APHA 2005). The growth parameters were examined using the FISAT II fish statistics software package. The fish samples' catch per effort, catch composition, and length frequency was analyzed using pertinent statistics, including mean, variance, and standard deviation. The fish catch per unit effort and the water's physicochemical properties were statistically tested using a simple Analysis of Variance (ANOVA). Descriptive statistics were used to evaluate the questionnaire data (Statistical Package for Social Science software). There were also tables, charts, graphs, and pictures used.

RESULTS AND DISCUSSION

Physicochemical characteristics of water in the study area

Mean values for surface temperature, pH, dissolved oxygen, turbidity, salinity, alkalinity, and nutrients (PO_4-P and NO_3-N) are displayed in Table 1 for the research locations and time. The temperature of the water did not follow any discernible pattern. Across the board, average surface temperatures were between 29.25°C and 29.50°C. In this case, hydrogen ions (pH) concentration varied from 6.25 to 6.47. 5.15 mg/L is the average dissolved oxygen concentration. From 5.20 to 5.90 mg/L, that was the range. From December 2014 to January 2015, dissolved oxygen levels increased. Salinity averaged 7.65 ppt, and turbidity ranged from 21.80 to 52.50 NTU across all sites. Average phosphate and nitrate levels were between 0.0016 and 0.0048 Mg/L and 0.0023 and 0.0048 Mg/L, respectively, throughout the three stations of Anansa, Okon, and Anantigha, with alkalinity averaging 35.0 Mg/L. At all the stations, phosphate and nitrate concentrations rose over the study's drier months, but at Anantigha, they peaked in April, just as the wet season was beginning. The former was between 0.016 and 0.048 mg/L, whereas the latter was between 0.023 and 0.048 mg/L.

Catch assessment

The catch-per-effort of the multispecies gillnet fishery in the research areas is shown in Table 2. Anansa had 161.90 kg, Okon had 88.20 kilograms, and Anantigha had 131.00 kg of total landings throughout the research period (range from 88.20 kg to 161.90 kg). Sampled monthly landings (CPUE) had a mean weight of 21.20 kg/boat/trip (range 15.33 kg to 27.00 kg).

Pseudotolithus elongatus constituted 56.69%, by weight, of the total catch in the study areas, followed by *E. fimbriata* (30.28%), *C. nigrodigitatus* (7.53%), and other fishes (5.5%) (Figure 2). In addition, *Ilisha africana, Pseudotolithus typhus, Scomberomorus tritor, Liza falcipinnis, Caranx hippos, Polydactylus quadrifilis, Cynoglossus senegalensis, Arius parkii, Sphyraena sphyraena*, and *Schilbe mystus* were also discovered. Together, the bonga (*E. fimbriata*), the estuary catfish (*C. nigrodigitatus*), and the bobo croaker (*P. elongatus*) made up 94.50% of the total haul. The *P. elongatus* was found to be present in the catch every month, with the highest numbers being caught in January and April (82.29% and 85.34%, respectively). As with the other species, *E. fimbriata* was spotted from December to May, with the highest occurrence rates in February (37.32%) and March (74.57%). While *C. nigrodigitatus* was present throughout the research, it was most abundant in February and April, making up 15.86% and 8.56%, respectively.

Table 1. Physicochemical characteristics of water in the study area (Mean±S.D)

Location	Temp. (ºC)	pH	DO. (mg/L)	Turbidity (NTU)	Salinity (ppt)	Alkalinity (mg/L)	$PO4^-P$ (mg/L)	$NO3^-N$ (mg/L)
Anansa	29.5±0.2	6.25±0.2	5.90±0.3	52.20±1.2	10.63±0.8	36.25±0.25	0.0016±0.002	0.0048±0.003
Okon	29.7±0.1	6.47±0.2	5.80±0.5	30.33±0.7	7.65±1.5	35.00±1.25	0.0048±0005	0.0023±0.002
Anantigha	29.25±0.25	6.27±0.3	5.15±0.4	21.80±2.2	10.20±0.6	42.50±1.0	0.0018±0.001	0.0046±0.003

Table 2. Monthly distribution of the CPUE (kg/boat/trip) for the study locations

Location	Dec.2014	Jan.2015	Feb.2015	Mar.2015	Apr.2015	May2015
Anansa	20.50	26.50	37.30	34.00	22.40	21.20
Okon	10.30	12.20	16.20	15.70	18.30	15.50
Anantigha	15.20	18.40	27.50	25.20	24.60	20.10
Mean	15.33	19.03	27.00	24.97	21.77	18.93

Figure 3. Gear composition of the artisanal fishery for the study area

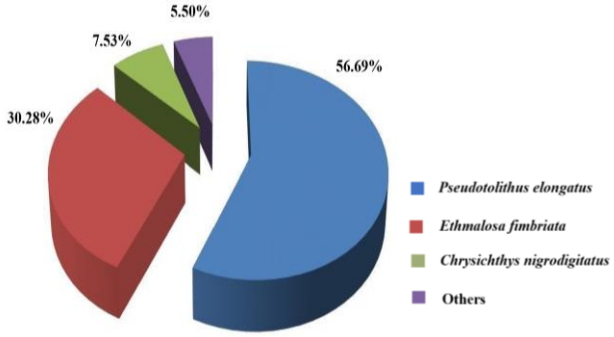

Figure 2. Catch composition (%) by weight of the gillnet fishery for the study period

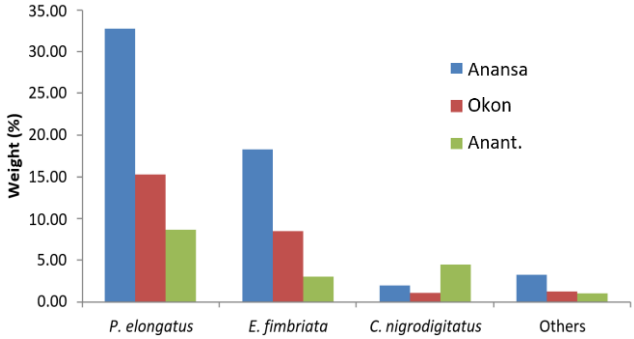

Figure 4. Catch composition (%) by weight for the study locations

Although some species were present throughout the period, others made a more noticeable impact in January and March. In December 2014, the value of the catch was at its lowest. In February 2015, the total catch averaged 127.00 kg, while the highest value was 81.0 kg.

Near-surface gillnets for bonga were around 100 meters long, and their stretched mesh sizes ranged from 2.9 to 5.0 cm; near-bottom drift nets for demersal fish were 4.0 to 6.6 cm. In addition, there were other methods, such as hook and line, and various traps like brush traps, basket pots, artificial shelters, basket traps, fish fences, and drums (Figure 3).

The species distribution of the fish caught in each of the three locations is displayed in Figure 4. The *P. elongatus* was found at a prevalence of 32.75% in Esuk Anansa, 15.32% in Esuk Okon, and 8.62% in Esuk Anantigha. The Esuk Anansa, Esuk Okon, and Esuk Anantigha percentages were 18.60%, 8.50%, and 2.98% for *E. fimbriata* and 1.98%, 1.05%, and 4.50% for *C. nigrodigitatus*. Esuk Anansa had 3.25%, Esuk Okon 1.23%, and Anantigha 1.02% of various species. The *P. elongatus* made up the majority of the catch composition (56.69%), followed by *E. fimbriata* Esuk (30.28%), and *C. nigrodigitatus* had the lowest percentage (7.53%), with respective catch compositions of 2.03% at Anansa, 2.03% at Esuk Okon, and 5.5% at Anantigha. At only 5.50% across the board, the miscellaneous fishes were most common in the Anansa and Okon regions. Most people landed at Esuk Anansa (56.28%), next at Esuk Okon (26.1%), and finally at Esuk Anantigha (17.1%).

Exploitation rates and sizes of fish

During the study period, more than 80% of the captured fish were in the growth stages. According to data on fish length distributions, the average size of *P. elongatus* was 14.30±2.45 cm, the average size of *E. fimbriata* was 10.47±1.58 cm, and the average size of *C. nigrodigitatus* was 17.7±3.23 cm. Length distributions of the three most-caught fish species revealed that the captures were dominated by smaller fish (Appendix V). The average length of the 1,009 fish in the sample was between 10.5 and 19.5 cm. Fewer than 10% of the fishes surveyed were

in the 20-25 cm total length range, and this size range was the most common. However, few huge adult fish were captured; most were mature females carrying eggs. With a total length of 53.2 cm, *C. nigrodigitatus* was the longest fish caught and landed. Although there is a statistically significant variation in CPUE between sites, the monthly average showed no statistical significance in the simple ANOVA test (Appendix VII and VIII).

The results of the growth indices of the target species for this study were $L\infty$ = 26.78cm, K = 0.32yr^{-1}, M =1.80, Z = 2.72, F = 1.83, E = 0.67 for *P. elongatus.* $L\infty$ =17.33cm, K = 0.63yr^{-1}, M = 1.57, Z = 2.75, F = 1.18, E = 0.43 for *E. fimbriata* and $L\infty$ = 25.70cm, K = 0.46yr^{-1}, M = 1.15, Z = 3.78, F = 2.60, E = 0.69 for *C. nigrodigitatus*, at mean temperature 29.48°C (Table 3).

Socioeconomic information

To better understand the health of local fisheries, 142 surveys were sent to local fishermen, fish processors, and mangrove fellers. As a result, a total of 109 people (or 76.8% of the sample population) were discovered to be fishermen; 9 people (or 6.3% of the sample population) were engaged in fish processing; and 24 people (or 16.9% of the sample population) were involved in mangrove felling. In addition, 82% of those surveyed were also engaged in farming or commerce for their own subsistence.

The male population numbered 107 (75.35% of the total), while the female population numbered 35 (24.65%). Moreover, 44 people (31.0% of the total) said they were 31-35 years old, and another 33 (23.2%) said they were 26-30 years old. Twenty-one (21.8%) of the respondents fell in the 36-40 age range, and twenty-two (15.5%) were in the 41-45 age range.

Ten (7.0%) respondents were between 46 and 50 years old, whereas only two (1.4%) were between 51 and 55 years old. There were 108 married respondents (76.9%), twenty-five single respondents (17.6%), and nine divorcees (6.3%). Among the respondents, 93 (68.4%) were based in estuaries, followed by 29 (21.3%) in freshwater, eight (5.6%) in the ocean, and six (4.4%) in lagoons. Respondents' usage of gillnets as their primary fishing gear indicates that this is the method of choice. Among the respondents, 55.2% (79) relied on gillnet fishermen, 14.0% (20) on hook-and-line fishermen, and 7.0% (10) on fishing traps.

Sixty-three respondents (44.4%) highly disagreed with the availability of records of catch and fishing excursions, forty-eight (33.8%) disagreed, twenty-four (16.9%) agreed, and seven (4.9%) strongly agreed. Town/village councils received the most votes (52.9%), followed by chiefs (37.2%), and then chief fishermen (2.1%). 75 (52.8%) people strongly disagreed that enforcement was efficient, 43 (33.1%) people disagreed, 15 (10.6%) people were neutral, and 3 (5%) people were in agreement about the efficiency of the enforcement of the rules and regulations in the area. It was said that Chief Fishermen, Traders Associations, and Municipal Governments all played roles in the administration of fisheries. Of those polled, 46% strongly disagreed that fisheries management was effective, 41% disagreed, 13% somewhat disagreed, 3% barely disagreed, and 3% only agreed. Eighty-six (74.8%) of those surveyed agreed that certain fish species were deficient in their most recent landings. In comparison, twenty-nine (25.2%) found themselves unable to draw any firm conclusions either way. Refuse disposal was ranked as the top environmental issue in the study area by 33 respondents (23.2%), followed by poor sanitation with 29 (20.4%), erosion at 21 (14.8%), deforestation at 19 (13.4%), inadequate environmental management at 17 (12.0%), inadequate drainage at 15 (10.6%), and flood at only 8 (5.6%).

While 88 respondents (62%) had access to social infrastructure like roads, hotels, schools, drinkable water, power, and hospitals, 54 respondents (38%) did not. About 41.5% of respondents reported using mangrove wood for food preparation, whereas 19.7% made palm oil, 18.3% made bread, 16.1% constructed homes, and 6.3% prepared fish. Eighty-five people (60.7%) identified as Ibibios, thirty-five as Efiks, and twenty as belonging to another ethnic group. There were 140 respondents (99.3% response rate); 89 of them (62.7%) said they believed conflicts existed in the area, and 53 (37.3%) said they did not.

According to everyone who chimed in, the town council, in conjunction with the local government council, runs things. Most respondents agreed that a community-based approach to coastal management was important better to oversee the region's fisheries and other coastal resources. Eighty-three percent of those polled were in favor of implementing CBCRM, while just sixteen percent were neutral.

Discussion

Physicochemical characteristics of the study area

Water quality examination results from all three sites in the research region showed consistent physicochemical characteristics, except turbidity, across the board. Nonetheless, measurements showed that the average surface temperature of the water was 29.48±0.20, with a range of 28°C to 30°C. The situation here is similar to that of other African bodies of water (Akpan 1999). Mustapha (2008) reports a little temperature discrepancy, possibly due to a timing gap between the two readings. There are statistically significant changes in water quality between the study sites, as indicated by a P-value less than the 0.05 confidence limit.

Table 3. Growth parameters and exploitation rates of target species

Species	$L\infty$ (cm)	K (yr^{-1})	Z	Z/K	M	F	E
P. elongatus	26.78	0.32	2.72	2.34	0.89	1.83	0.67
E. fimbriata	17.33	0.63	2.75	2.14	1.57	1.18	0.43
C. nigrodigitatus	25.70	0.46	3.78	1.35	1.15	2.60	0.69

According to Boyd (1979), the pH range of 6.25 to 6.47 is suitable for the survival of fish and shellfish in estuaries. According to Akpan et al. (2002), unpolluted tropical rivers often have a pH between 5 and 6.75. Geological and biochemical factors (shales and sandstones) and humus materials from swamps and streams within the river basin may account for the mildly acidic condition of the water during the study, as described by Akpan et al. (1999). pH dropped in March and April. It could be because of the entry and exit of salt water in the estuary during the rainy season. Karikari et al. (2006) found a similar pattern in Ghana's Korle lagoon. Consistent with our findings and those of Akintola et al. (2011) in Badagry Creek, Nigeria, Michael (1992) found that the pH of surface water varies during the day. According to Nyam, insufficient environmental nutrition levels could explain the study's low pH (1998). According to Akpan (2004), varying pH levels are caused by a combination of water's evaporation and transpiration and biological activity.

The minor temperature rise in April may be caused by the action of prevailing air masses (Akpan, 2004) as the rain gets closer. The study found that as temperature and precipitation rose, so did the pH of the water. The findings of Adebisi's (1981) investigation along the upper Ogun River in Nigeria are consistent with this.

Dissolved oxygen values varied from 5.15 to 5.90 mg/L, with a mean value of 5.62±0.75 mg/L. Although this can support fish grow in a reservoir, Boyd suggests it may slow their development (1979). The higher the salinity, the lower the dissolved oxygen (DO) content. Contrarily, Michael (1992) reported that warm-water organisms could live for extended periods with only 2–3 mg/L of dissolved oxygen. During the dry part of the research, DO levels were greater (December and January). Consonant with the findings of Akpan et al. (1999). March and April had the lowest oxygen readings across the board (Ezenwa 1981). Respiration and photosynthesis are dynamic processes that may explain the variations in oxygen content. Moses's (1979) reported range of DO levels for the Cross River is within the range seen in this study. Flowing water allows atmospheric oxygen to diffuse and combine with the water, which could explain why the DO level is somewhat higher at Esuk Okon. For the Qua Iboe River, this finding agrees with the results of Akpan (1993). When oxygen is used up in the decomposition of organic matter (leaf litter), this causes a decrease in the available oxygen (King and Ekeh 1990).

On the other hand, Kemdirim and Ejike (1992) contended that increased photosynthetic activity of phytoplankton causes dissolved oxygen concentrations to rise during dry seasons. The wetter months of March and April saw a more comprehensive range of turbidity, from 21.80 to 52.20 NTU, with a mean value of 34.78±21.87. It could result from erosional deposits caused by runoff from the increasing rainfall.

Esuk Anansa (with a turbidity of 52.20 NTU) was the most turbid location in the research region, while Esuk Anantigha was the least turbid. Possible causes include the dispersal of agricultural and human wastes to the area and the suspension of detritus and silt from mangrove exploitation due to the concentration of mangrove logging activities in the swamp. Evaporation crystallization due to sea salt intrusion may also contribute to the local turbidity. Although Akpan (1991) claimed the same, his studies on Uyo's water bodies in 2004 revealed an increase in turbidity alongside an equivalent rise in precipitation, so the two findings contradict one another. After observing the increase in turbidity in the Umtata River (South Africa), Fatoki et al. (2001) concluded that runoff from settlements during the summer rains was a significant contributor. Fish are rarely directly affected by solid particles in suspension. But they could harm fish populations (Boyd 1979). Kausch (1990) claims that most estuaries have photic depths of less than 1 m and are characterized by significant turbidity.

Moses (1979) and Lowenberg and Kunzel (1992) all reported salinities that were lower than the range found (1999). Possible explanations include shifts in the tidal and seasonal conditions during the research. The salinity peaked in the winter months, from December to February, when rainfall was at its lowest. Saltier than usual water is present during high tide because ocean water has made its way inland. Since Akpan et al. (1999) limited their sample to low tides, they could avoid the confounding effects of seawater intrusion, resulting in usually lower salinity levels in their study compared to reports from the Cross River. The salinity of estuaries is regulated primarily by inflows and outflows of fresh water (Cronin et al. 1962). With a salinity between 7.0 and 8.0 ppt, Esuk Okon exhibits substantial salt and fresh water mixing and may be categorized as a mid-estuary according to Fairbridge's (1980) classification scheme. Throughout the research, the alkalinity levels at the three stations were remarkably consistent. According to the United States Department of Agriculture's Soil Conservation Service (1975), the phosphate levels were below the threshold of 0.01 to 0.03 mg/L for phosphorous typically observed in uncontaminated streams. The presence of phosphorus and nitrate facilitates plant blooms and the eutrophication of lakes and streams. Phosphate enters the estuary through various sources, including industrial waste, surface runoff, the decomposition of organic matter at the river's bottom, and the accumulation of detergent. The deposition of nutrients by agricultural runoff in the area has been linked to eutrophication, nutrient enrichment, productivity, degradation, and sedimentation in the research areas. From October to January, the phosphate concentration in Tapi estuary, India's surface water, was observed by George et al. (2012) as being between 0.001 mg/L and 0.822 mg/L. They mentioned that the phosphate in the Tapi estuary could be mainly due to home and industrial effluents emitted from Surat city. It backs up the conclusion drawn from the current investigation into the estuary of the Cross River. Michael (1992) reported that over ten mg/L nitrate is safe, but water may have harmful chemicals and contamination from industrial and agricultural sources; the range and mean of nitrate recorded in the present study were below this level. Location1, Anansa (0.048 mg/L), and Location3, Anantigha (0.046 mg/L) may have greater nitrate concentrations since they are urban centers with concomitant local industrial and agricultural activity.

Generally speaking, Jaji et al. (2007) found that nitrate levels in untreated natural water were relatively low.

It indicates that no significant water pollution occurred throughout the time of the study. According to Mustapha and Omotosho (2005), the nitrate content in Nigeria's Moro Lake is the highest at 22.4 mg/L, whereas Kolo (1996) found that Shiroro Lake's value was only 0.5 mg/L. Nitrate concentrations in this investigation were within the safe range established by the Federal Ministry of Environment and the World Health Organization. There is likely a high quantity of nitrate because fertilizers wash off surrounding farms. The most excellent oxidized form of nitrogen, nitrate, is one of the most prominent water pollution indicators. While studying nitrogen levels in the Tapi estuary, India, George et al. (2012) found a fluctuation from 16 mg/L to 1.43 mg/L between June and December.

Catch composition, exploitation rates, and sizes of fish

Holzlohner et al. (2007), two previous researchers of the Cross River estuary, reported fish species identical to those found in the current study. This study confirms the importance of the marine near-shore area as a nursery location for a diverse assemblage of fishes, as noted by Bassey (1988) and Holzlohner et al. (2007), and finds that *P. elongatus, Ethmalosa fimbriata,* and *C. nigrodigitatus* were the most important species in the catch (Nunoo et al. 2007). Bassey (1988) found that these species accounted for 80.1% of the catch by weight, Holzlohner et al. (2007) found that they accounted for 92.1%, and the current study found that they accounted for 94.5%. Throughout the recent study, from December 2014 to May 2015, *P. elongatus* was consistently observed in the captures. From January through April, with peak abundance in March, *E. fimbriata* was widely distributed throughout the region.

Monthly catch averages of 21.2 kg/boat/trip and mean CPUE of 7.1 kg/boat/trip in the current study are comparable to 36.2 kg/boat/trip and 6.2 kg/boat/trip, respectively, as reported by Holzlohner et al. (2007). Although the prior study spanned an entire year and sampled more areas than this study, which investigated only three locations in six months, the results also indicate declining fisheries. Bassey (1988) states the average CPUE was 4.9 kg/boat/trip. The adult population of E. fimbriata, according to research by Ama-Abasi et al. (2004) on the species' migration pattern and life cycle, remains in coastal waters all year round for feeding and spawning activities, making them susceptible to near-shore purse seine fishing.

However, *C. nigrodigitatus* dominated the freshwater area of Anantigha, while *P. elongatus* and *E. fimbriata* dominated the captures in the Anansa and Okon areas, which are closer to the marine water of the ocean. *C. nigrodigitatus*, according to Moses (1979), lives in brackish water, small and large freshwater bodies in Africa, while *P. elongatus* and *E. fimbriata* were reported by Holzlohner et al. (2007) as marine species. Esuk Anansa boasts the largest catches. As a result of the deposition of detritus from mangrove exploitation and other nutrients from runoff of adjacent agricultural activities, the water may be extremely murky. Throughout the research period, a sparse population of *C. nigrodigitatus* persisted. Rates of capture were lowest in December and April. The *P. elongatus* and *E. fimbriata*, along with various other marine species, leave the estuary at the start of the wet season, which begins in April (Ama-Abasi et al. 2004). Most of the fish collected in the current study were relatively small, highlighting the importance of implementing sustainable fishing practices such as standardizing fishing net mesh sizes and developing a community-based coastal resource management system. Holzlohner et al. (2007) and Ama-Abasi and Uduakobong (2014) in the Cross River estuary, and Ngodigha et al. (2015) in the River Nun estuary in Bayelsa state, Niger Delta, Nigeria, all reported findings similar to these.

Overfishing of *P. elongatus* in the Cross River estuary was reported by Nwosu et al. (2010), who found an exploitation ratio of 0.79. The current study found that *P. elongatus* and *C. nigrodigitatus* had exploitation rates of 0.67 and 0.69, respectively, whereas *E. fimbriata's* rate was 0.43. Possible causes include the time frame, time of year, and geographical location of the samples used. However, the study recommends implementing management restrictions, including seasonal closures during peak spawning, to better the estuary's fishery. In addition, the mangrove ecosystem, which is essential to the system's productivity, should also be carefully managed and conserved.

Overfishing has put a strain on the Cross River's fishery, with the exploitation rate calculated by Ajang et al. (2011) coming in at 0.81 per year. It necessitates controls on fishing hours, gear types, mesh sizes, and restrictions on the amount of work put into fishing. However, Holzlohner et al. found that a lack of comprehensive effort data hinders the management of estuarine fisheries resources (2004). The amount of time and energy expended while fishing also matters greatly. In turn, it allows for determining an abundance index (Holden and Ritts 1974). Tracking fish populations' biomass spectra requires constant observation or at least a systematic study of the fishery's catch structure. Actions to preserve fish stocks can be implemented in response to sudden structural shifts, such as the disappearance or proliferation of species due to fishing, habitat disturbance, pollution load, or natural disasters (Holzlohner et al. 2007).

Socioeconomics

Fishing was found to be the most common occupation among the study's settlers, followed by mangrove logging, subsistence cultivation, and commerce. The primary focus of this research is on the importance of implementing a sustainable management plan to increase the efficiency of fisheries and restore near-shore fish-producing habitats with the involvement of community groups. The requirement to promote technology that fishers might apply with minimal support services should direct the work of the community organization. Sea ranching, aquaculture, and limiting damaging fishing techniques are all examples of such initiatives. Researchers have found that unsustainable fishing practices and the loss of coastal ecosystems, notably mangrove forests, are strongly linked to declining fishery production in the estuary. The widespread public

has become more aware of the vital service activities of this ecosystem in sustaining fishing harvests due to direct observations of highland deforestation and the elimination of mangrove forests.

According to Alcala (1998), a crucial part of current CBCRM programs worldwide is creating marine reserves, parts of the marine environment that are protected from various forms of exploitation. Nearly all CBCRM projects have a provision for creating marine reserves to facilitate environmental and resource recovery (such as mangroves and coral reefs) (e.g., fishery). Marine reserves could be used in the management of coral fisheries to preserve critical stock biomass, for instance, to guarantee a recruitment supply via larval dispersal to fished regions and maintain enhanced fish yields to areas adjacent to reserves via the movement of adult fish. Stakeholder communities would likely see the creation of reserves as part of CBCRM in the research region favorably, if not rationally. Sustainable management of the fisheries in the area under investigation is necessary because they have the potential to underpin efforts to increase economic activity, reduce poverty, and increase the availability of animal protein for Nigeria's massive population. However, as Pinkerton and Weinstein (1995) outlined, the absence of community organization and competence for carrying out fundamental management responsibilities is a crucial obstacle to the formation of CBCRM in the Cross River estuary.

Approaches for community-based coastal resource management

Weak management structures are to blame for the pervasive disorganization of the study areas' communities and their inability to perform even the most fundamental management tasks. Traditional community institutions are so weak as to be non-functional, even in remote, rural villages like Esuk Okon and Ine Abasi, where the lure of modern commercialism is absent. As a result, the villagers, predominantly fishermen, do not understand the connection between declining fisheries and mangrove destruction and have forgotten how to work together. Therefore, organizations that serve several purposes in these communities, including fisheries management, must be established.

Elements common to community-based coastal resource management include social preparation and community organizing; environmental education and capacity building; resource management plans, including protective management; support activities for livelihood and financial resources mobilization; research and monitoring; and networking activities. Social preparation, community organizing, and environmental education are generally given priority and great importance in the early stages of project implementation. The effort and duration dedicated by project implementers to these efforts vary from project to project. It is because, via these activities, a community can recognize its own needs and the challenges it must address to improve the socioeconomic well-being of the people with the participation of all its members.

Successful community organizing leads to establishing citizen groups capable of conceiving and carrying out local improvement initiatives. In the beginning stages of CBCRM, environmental education is also crucial. They must persuade the locals that safeguarding and controlling their own resources is in their best interest. Community members must be shown the need to maintain ecological balance for continued maritime productivity. The economic benefits of tropical ecosystems like coral reefs and mangroves for coral reef fish production and mangrove values should also be communicated to the resource's beneficiaries (Alcala 1998).

At least one other organization, typically a university or non-governmental organization (NGO), must be involved in implementing the CBCRM strategy. Development is catalyzed by partner organizations' initiative, direction, technical expertise, and finance. Partner agencies act as co-managers of projects during the partnership period. Still, because CBCRM's ultimate goal is to give local communities the tools to safeguard and manage their resources, those agencies must leave the sites of completed projects after a set period has passed. Timelines for various CBCRM activities typically range from 2-3 years but can go as high as 4-5 years (Alcala 1998). It is, however, not uncommon for partner groups to keep ties to organized communities even after the original partners have withdrawn.

About 20 programs and projects dealing with fisheries or coastal resources have been implemented throughout the last 20 years (the 1970s-1990s). These programs and projects range from highly participatory to community-based (Alcala 1998). There are projects on a small scale that affect one town, and projects on a much larger scale affect the entire country.

Government and non-profit organizations contribute financially. Even though most of the smaller CBCRM projects have been started by universities or NGOs, they have always been carried out in conjunction with municipal agencies. For example, among the several community-based initiatives at Carbin Reef Marine Reserve in Sagay, Negros Occidental, only one was managed by a town mayor.

Thus, a successful community-based project may be characterized by the following features: the formation of one or more functional community organizations; the creation of a community-protected marine reserve; the development of sustainable economic activities based on coastal (fishery) resources; the establishment of connections with relevant government and international agencies and non-governmental organizations; and the implementation of a capacity-building program. Even though not all community-based projects have been successful, the most successful ones have been community-based Alcala (1998). However, due to its dependence on a wide range of uncontrollable social elements, the CBCRM strategy carries an inherent risk of failure.

Further, a legislative framework and the development of community-based organizational and technical capacities are necessary for effective CBCRM. Governments and multilateral agencies alike have realized the importance of community and partner groups in managing and protecting coastal ecosystems and fisheries. As a result, CBCRM has gained popularity as a solution to

the problem of exhaustion of open-access resources like fisheries. However, it is impossible to establish legal ownership of these resources using appropriate tenurial instruments, as with most land resources. In an open-access system, only possession or actual usage confers legal title.

It is held accountable for the unrestricted use of fishing resources. One benefit of the CBCRM is that it gives those with a stake in helping the feeling of ownership and rightful access that these individuals may otherwise lack. For example, suppose coastal fisheries and other coastal resources are to be effectively protected and managed. In that case, local coastal people must be acknowledged and given authority over their management on a day-to-day basis (Alcala 1998).

Sustainability of CBCRM projects

The question of sustainability is one of many in CBCRM, but it is one of the most pressing. Because of their restricted area of jurisdiction, limited research ability, budget limits, and the dominance of parochial interests in local politics, it is believed that local governments and communities typically cannot appropriately manage coastal ecosystems. These restrictions make it difficult, if not impossible, for management initiatives to get off the ground and remain viable over time. One of the main reasons specific initiatives have failed is local officials' narrow or even self-serving motives (Alcala 1998). Although there are constraints on research capacity and local jurisdiction, these problems are not intractable. The good news is that these obstacles have been addressed through training, capacity building, and networking with NGOs and academic institutions, leading to relatively successful projects. The constraint of the budget is of primary importance.

While, it often takes communities four to five years to establish sustainable organizations capable of creating and implementing development plans, partner organizations that launch CBCRM programs are typically only prepared to financially support these projects for two to three years. Providing communities with sustainable livelihood options likewise takes around the same time.

Interestingly, it takes only four years for plankton-feeding fish to migrate from coral reef reserves to fishing regions (whereas it takes eight to ten years for carnivores to do the same). Partner organizations concerned with showing the impact of protected areas on local fish food supplies should look to these timelines as essential references. Convincing individuals of the importance of community resource management is best done by "tangible gains in a project," as stated by Newkirk and Rivera (1996).

Before cutting off communities' access to external financial aid, they must make adequate preparations to guarantee that their residents will continue to engage in sustainable livelihood activities. The Apo Island Marine Conservation Project in Central Visayas is a prime example of a successful CBCRM initiative in the Philippines. The initiative kicked out in 1981, and by 1982, a marine reserve (10% of the coral reef area) had been formed, and by 1985 and 1986, community organizing had ramped up. Since 1987, the local community of 500 has been well organized, and with little assistance from the partner agency (Silliman University), they have administered and preserved the reserve. The fishermen say that since the reserve was established, their fish catches outside of the area have increased dramatically. They are pleased with the reserve since it has enhanced their income from fish and tourism.

The research concluded that *P. elongatus, Ethmalosa fimbriata,* and *C. nigrodigitatus* were the most common species caught in the estuary's multispecies gillnet fishing. Using the collected data, we found that the water quality metrics varied considerably. However, fish could survive in the water since it was not too polluted. On the other hand, about 70% of the gear utilized in the research region was a gill net, which also impacted the average size of the fish caught. The study found that most of the fish caught were undersized, and the rate of exploitation constituted a significant threat to the fisheries. Habitat loss occurred due to the indiscriminate harvesting of mangroves for fuel in industries such as oil palm processing, fish processing, cooking, baking, agriculture, and construction. Therefore, there must be pressure for sustainably managed fisheries in the region because they can contribute to efforts to increase economic activity, reduce poverty, and increase the availability of animal feed. The following are some of the suggestions for regional fishery management that emerged from the study.

REFERENCES

Adebisi AA. 1981. The physicochemical hydrology of a tropical seasonal River-Upper Ogun River. Hydobiology 79: 157-165. DOI: 10.1007/BF00006123.

Aiman WM, Yusoff FM, Arshad A, Kamal AHM, Ismail J, Idris MH, Karim NU, Asif AA. 2020. Distribution of zooplankton community in Toli shad (*Tenualosa toli*) habitats, Sarawak, Malaysia. Biodiversitas 21: 4022-4033. DOI: 10.13057/biodiv/d210913.

Ajang RO, Ndome CB, Ekwu A, Uttah E, Iboh CI. 2011. Population dynamics and gillnets selectivity of *Chrysichthys nigrodigitatus* (Lalepede 1803) in lower reaches of the Cross River Estuary, Nigeria. Ethiop J Environ Stud Manag 6: 31- 40. DOI: 10.4314/ejesm.v6i1.4.

Akintola SL, Anetekhai MA, Lawson EO. 2011. Some physicochemical characteristics of Badagry Creek, Nigeria. West Afr J Appl Ecol 18: 95-107. DOI: 10.4314/wajae.v18i1.70313.

Akpan AW. 1993. The effect of hydrological regime on the temperature and salinity profiles of a tropical coastal river (Nigeria). Acta Hydrobiol 35 (4): 275-284.

Akpan AW. 2004. The water quality of some tropical freshwater bodies in Uyo (Nigeria) receiving municipal effluents, slaughter house washings and agricultural land drainage. Environmentalist 24: 49-50. DOI: 10.1023/B:ENVR.0000046346.93401.5c.

Akpan ER, Offem JJ, Nya AE. 2002. Baseline ecological studies of the Great Kwa River, Nigeria 1: Physicochemical studies. Afr J Environ Pollut Health 1: 83-90.

Akpan ER. 1991. Seasonal Variation in Phytoplankton Biomass and Pigments in Relation to Water Quality in the Cross River System. [Dissertation]. University of Calabar, Calabar. [Nigeria]

Akpan ER. 1993. Seasonal cycles of phytoplankton and grazing activity in the Cross River system of southeastern Nigeria. Trop Ecol 34 (2): 143-149.

Akpan ER. 1999. Spatio-seasonal trends of physicochemical characteristics of Cross River Estuary, Nigeria. Prog. Biometeorol 13: 127-131.

Akpan I, Bankole MO, Adesemowo AM. 1999. A rapid plate culture method for screening of amylase-producing micro-organisms. Biotechnol Tech 13 (6): 411-413. DOI: 10.1023/A:1008965808641.

Alcala AC. 1998. Community-based coastal resource management in Philippines: A case study. Ocean Coast Manag 38: 179-186. DOI: 10.1016/S0964-5691(97)00072-0.

Ama-Abasi D, Holzlohner S, Enin UI. 2004. The dynamics of the exploited population of *Ethmalosa fimbriata* (Bowdich, 1825. Clupeidae) in the Cross River Estuary and adjacent Gulf of Guinea. Fisher Res 68: 225-235. DOI: 10.1016/j.fishres.2003.12.002.

Ama-Abasi D, Uduakobong S. 2014. Fecundity, gonadosomatic index and spawning period of *Chrysichthys nigrodigitatus* of the Lower Cross River, Nigeria. J Fisher Aquat Sci 9: 277-280. DOI: 10.3923/jfas.2014.277.280.

Ama-Abasi D. 2002. Aspects of Population Biology of the Bonga, *Ethmalosa* (Bowdich, 125) in the Cross River Estuary, Nigeria. [Dissertation]. University of Calabar, Calabar. [Nigeria]

American Public Health Association (APHA). 2005. Standard Methods for the Examination of Water and Wastewater. 21st Ed., American Water Works Assoc., Water Pollution Control Federation, Virginia.

Bassey BU. 1988. The Catch Structure of the Artisanal Gillnet Fishery of the Lower Cross River. [M.Sc. Thesis]. University of Calabar, Calabar. [Nigeria]

Blaber SJM, Cyrus DP, Albert CVC, Day JW, Elliot M, Fonseca MS, Hoss DE, Orensanz J, Potter IC, Silvert W. 2000. Effects of fishing on the structure and functioning of estuarine and near-shore ecosystems. ICES J Mar Sci 57: 590-602. DOI: 10.1006/jmsc.2000.0723.

Boyd CE. 1979. Water Quality in War Water Fish Ponds. Auburn University Publications, Alabama.

Cochran WG. 1977. Sampling Techniques. (3rd ed.). John Wiley and Sons. Inc., New York.

Cronin LE, Daiber JC, Hulbert EM. 1962. Quantitative seasonal aspects of zooplankton in the Delaware River Estuary. Chesapeake Sci 3: 63-93. DOI: 10.2307/1351221.

Elliot M, O'Reily MG, Taylor CJL. 1990. The Forth estuary: A nursery and overwintering area for North Sea fishes. Hydrobiologia 195: 89-103. DOI: 10.1007/BF00026816.

Eugenia BB, Armah AK, Dankwa HR. 2019. Fish as bioindicators of habitat degradation in coastal lagoons of Ghana. Bonorowo Wetlands 9: 9-26. DOI: 10.13057/bonorowo/w090102.

Ezenwa BIO. 1981. A Study of the Reproductive Biology of the Catfish, *C. nigrodigitatus* (Lacepede), in Nigeria. [Dissertation]. University of Lagos, Lagos. [Nigeria]

Fairbridge RW. 1980. The estuary: Its definition and geodynamic cycle. In: Olausson E, Cato I (eds). Chemistry and Biogeochemistry of Estuaries. Wiley, New York.

Fatoki OS, Muyima NYO, Lujiza N. 2001. Situation analysis of water quality in the Umtata River catchment. Water SA 27: 467-473. DOI: 10.4314/wsa.v27i4.4959.

Franco A, Elliott M, Franzoil P, Torricellil P. 2008. Life strategies of fishes in European estuaries: The functional guild approach. Mar Ecol Progr Ser 354: 219-228. DOI: 10.3354/meps07203.

George B, Nirmal KJI, Kumar RN. 2012. Study on the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India. Egypt J Aquat Res 38 (3): 157-170. DOI: 10.1016/j.ejar.2012.12.010.

Gill TD, Dotinga H, Rosenne H, Molenaar EJ, Elferink AG. 2003. Rosenne's the World Court; What it is and how it works. United Nations Publications.

Hobbie JE. 2000. Estuarine Science: A Synthetic Approach to Research and Practice. Island Press, Washington, DC.

Holden MJ, Ritts DFS. 1974. Manual of fisheries science. Part 2. Resource investigation and their application. FAO Fish Tech Pap 115 (1): 214.

Holt AE, Miller WS. 2011. Bioindicators: Using organisms to measure environmental impacts. Nat Educ Knowl 2 (2): 8.

Holzlohner S, Enin UI, Ama-Abasi D, Nwosu FM. 2007. Species composition and catch rates of the gillnet fishery in the central cross river estuary, SE Nigeria. J Afr Trop Zool 2007: 107-112.

Holzlohner S, Nwosu FM, Enin UI. 2004. Fishing effort statistics of the artisanal fisheries of the Cross River Estuary, Nigeria. Glob J Pure Appl Sci 10 (2): 249-256. DOI: 10.4314/gjpas.v10i2.16390.

Hossain MS, Gopal DN, Sarker S, Rahaman MZ. 2012. Fish diversity and habitat relationship with environmental variables at Meghna River Estuary, Bangladesh. Egypt J Aqua Res 38 (3): 213-226. DOI: 10.1016/j.ejar.2012.12.006.

Jaji MO, Bamgbose O, Odukoya OO, Arowlo TA. 2007. Water quality assessment of Ogun River, South West Nigeria. Environ. Monit Assess 133 (1-3): 447-482. DOI: 10.1007/s10661-006-9602-1.

Jennerjahn TC, Mitchell SB. 2013. Pressures, stresses, shocks and trends in estuarine ecosystems – An introduction and synthesis. Estuar Coast Shelf Sci 130: 1-8. DOI: 10.1016/j.ecss.2013.07.008.

Karikari AY, Asante KA, Biney CA. 2006. Water quality characteristics at the estuary of Korle Lagoon in Ghana. West Afr J Appl Ecol 10: 73-85. DOI: 10.4314/wajae.v10i1.45700.

Kausch H. 1990. Biological processes in estuarine environment. In: Michaelis W (eds). Coastal and Estuarine Studies. Vol. 36. Springer Verlag, Berlin. DOI: 10.1029/CE036p0353.

Kemdirim EC, Ejike C. 1992. The phytoplankton response to artificial enrichment with Nitrates and Phosphates in an upland and lowland reservoir in Plateau State. J Aquat Sci 7: 45-57.

Kennedy VS. 1984. The Estuary as a Filter. Academic Press, Orlando. FL.

King RP, Ekeh IB. 1990. Status and seasonality in the physicochemical hydrology of a Nigerian headwater stream. Acta Hydrobiol 32 (314): 313-378.

Kolo R. 1996. The assessment of physicochemical parameters of Shiroro Lake and its major tributaries. In: Eyo AA (eds). Proc Ann Conf Fisher Nigeria.

Lowenberg U, Kunzel T. 1992. Investigations on the hydrology of the lower Cross River, Nigeria. Mar Res 42 (1): 63-75.

Mc. Lusky DS, Elliott M. 2004. The estuarine Ecosystem: Ecology, Threats and Management. (3rd Ed). Oxford University Press, Oxford.

Micheal KS. 1992. Fish Medicine. W.B Saunders Company, Philadelphia.

Mosepele K. 2000. Preliminary Length Based Stock Assessment of the Main Exploited Stocks of the Okavango Delta fishery. [Mphil. Thesis]. Department of Fisheries & Marine Biology, University of Bergen, Norway. [Norway]

Moses BS. 1979. The Cross River, its ecology and fisheries. In the Proceedings of the International Conference on Kainji Lake and River Basins developments in Africa. Kainji Lake Research Institute, New Bussa, Nigeria.

Moses BS. 1990. The status of artisanal fisheries and fish resources conservation in southeastern Nigeria. Trans Nig Soc Biol Conserv 1: 43-60.

Mustapha M, Omotosho JS. 2005. An assessment of the physicochemical properties of Moro Lake. Afr J Appl Zool Environ Biol 7 (1): 73-77. DOI: 10.4314/ajazeb.v7i1.41151.

Mustapha MK. 2008. Limnology and Fish Assemblages of Oyun Reservoir, Offa, Nigeria. [Dissertation]. University of Ilorin, Ilorin. [Nigeria]

Newkirk GF, Rivera RA. 1996. Synthesis. In: Ferrer EM, dela Cruz LP, Domingo MA (eds). Seeds of Hope. College of Social Work and Community Development, University of the Philippines, Diliman, Quezon City.

Ngodigha SA, Alaoga KJ, Alfred JF. 2015. Aspects of the population dynamics of *Nematopalaemon hastatus* (Aurivillius 1898) in River Nun Estuary, Bayelsa State, Niger Delta, Nigeria. Intl J Curr Res Biosci Plant Biol 2 (4): 161-167.

Nunoo FKE, Hiablie SA, Patu DO. 2007. Trends in fish species diversity found in near-shore marine waters along the coast of Ghana, West Africa. J Ghana Sci Assoc 9: 10-19.

Nwosu FM, Enin UI, Holzlohner S. 2010. Assessment of artisanal fishery impacts on West African croaker, *Pseudotolithus elongatus* in the Cross River Estuary, Nigeria, using length-based models. North Ame J Fisher Manag 30 (4): 860-865. DOI: 10.1577/M10-011.1.

Nwosu FM. 2005. An Overview of Nigeria's mangrove Ecosystem: Problems and Prospects. National Workshop on Coastal and Marine Biodiversity Management. ABGREMO/SU/TCDC/UNDP /UNOPS. Calabar.

Nyam L. 1998. Eco- Environmental Aspects of Integrating Small Scale Aquaculture with Rural Development Programs in Southern Africa. Fisheries Development Series (Sweden). 0280-5375, No .24. National Swedish Board of Fisheries, Goeteborg, Sweden.

Officer CB. 1976. Physical Oceanography of Estuaries and Associated Coastal Waters). Wiley-Interscience, New York.

Oribhabor BJ, Udoidiong OM, Udoh DF, Akpan BE. 2013. Evaluation of the ecological impact of human settlement on the water quality of Lower Cross River, Nigeria. J Ecosyst 2013: 12. DOI: 10.1155/2013/840295.

Paturej E, Gutkowska A, Koszałka J, Bowszys M. 2017. Effect of physicochemical parameters on zooplankton in the Brackish, Coastal

Vistula Lagoon. Oceanol 59 (1): 49-56. DOI: 10.1016/j.oceano.2016.08.001.

Pinkerton E, Weinstein M. 1995. Fisheries that Work. Sustainability Through Community Based Management.

Pomfret JR, Elliott M, O'Reilly MG, Phillips S. 1991. Spatial and temporal patterns in fish communities in two UK North Sea estuaries. In: Elliott M, Ducrotoy JP (eds). Estuaries and Coasts: Spatial and Temporal Inter comparisons. Olson & Olson, Fredensborg, Denmark.

Potter IC, Beckley LE, Whitfield AK, Lenanton RC. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. Environ Biol Fish 28: 143-178. DOI: 10.1007/978-94-009-2065-1_9.

Rahim KAA, Tumiran MHL Shabdin M, Esa Y, Husaini ASA. 2014. The Status of Tenualosa toli(Valenciennes, 1847) in the Southwest Coast of Sarawak, Malaysia. Kuroshio Sci 8: 37-42.

Rezai H, Yusoff FM, Othman BHR. 2011. Vertical distribution of zooplankton and copepod community structure in the Straits of Malacca. J Persian Gulf (Mar Sci) 2(3): 17-23.

Saifullah ASM, Abu Hena MK, Idris MH, Halima AR, Johan I. 2014. Seasonal variation of water characteristics in Sibuti River Estuary in Sarawak, Malaysia. Malays J Sci 33 (1): 9-22. DOI: 10.22452/mjs.vol33no1.3.

Sokal RR, Rolf FJ. 1981. Biometry. The Principles and Practice of Statistics in Biological Research. (2nd ed.). Freeman and Company, San Francisco, California.

Tumiran MHB, Rahim KAA, Shabdin ML, Esa Y, Husaini AASA. 2011. Environmental Parameters of "Core Terubok Areas" and the Relationship with Terubok Sarawak Population. International Fisheries Symposium. Universiti Malaysia Terengganu, Kuala Nerus, October 2011.

Twilley RR, Snedaker SC, Yanez-Aranciba A, Medina E. 1996. Biodiversity and ecosystem processes in tropical estuaries: Perspectives from mangrove ecosystems. In: Money H, Cushman H, Medina E (eds). Biodiversity and Ecosystem Function: A Global Perspective. Department of Biology, University of Southwestern Louisiana, Lafayette.

United States Department of Agricultural Soil Conservation Service (USDASCS). 1975. Agricultural waste management. Field Manual, U.S. Printing Office

USEPA. 1998. Estuaries and Your Coastal Watershed. Coastal Watershed Factsheets. E.P.A. 842-F-98-009.

Valiela I. 2006. Global Coastal Change. Blackwell, Malden, MA.

Zaleha K, Abang Jefri AM, Hasimah MS. 2013. Fauna of Porcellidiidae (Copepoda: Harpacticoida) from Sungai Pulai, Malaysia. Malay Nat J 64 (4): 159-167.