# Bonorowo Wetlands

| Bonorowo Wetlands | vol. 9 | no. 1 | June 2019 | ISSN 2088-110X | E-ISSN 2088-2475|

***Striped mullet (Mugil cephalus)* photo by Mary Keim**

# Bonorowo Wetlands

| Bonorowo Wetlands | vol. 9 | no. 1 | June 2019 | ISSN 2088-110X | E-ISSN 2088-2475 |



**Published semiannually**

**PRINTED IN INDONESIA**

ISSN 2088-110X
E-ISSN 2088-2475

9 772088 247172

# Bonorowo Wetlands

**| Bonorowo Wetlands | vol. 9 | no. 1 | June 2019 |**

**ONLINE**
http://smujo.id/bw

**p-ISSN:** 2088-110X, **e-ISSN:** 2088-2475

**PUBLISHER**
Society for Indonesian Biodiversity

**CO-PUBLISHER**
Institut Pertanian Bogor, Bogor, Indonesia
Nusantara Institut of Biodiversity, Universitas Sebelas Maret, Surakarta, Indonesia

**OFFICE ADDRESS**
1. Forest and Land Fire Laboratory, Department of Silviculture, Faculty of Forestry, Institut Pertanian Bogor. Jl. Lingkar Akademik Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia. Tel.: +62 251 8626806, Fax.: +62 251 8626886;
2. Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia. Tel./Fax.: +62-271-663375, email: bw@smujo.id, jbonorowo@gmail.com

**PERIOD OF ISSUANCE**
June, December



Society for Indonesian Biodiversity

Universitas Sebelas Maret Surakarta, Indonesia

Institut Pertanian Bogor, Bogor, Indonesia

Published by Smujo International for The Society for Indonesian Biodiversity and Universitas Sebelas Maret & Institut Pertanian Bogor, Indonesia

# GUIDANCE FOR AUTHORS

**Aims and Scope** *Bonorowo Wetlands* encourages submission of manuscripts dealing with all topics relevant to freshwater, brackish and marine coastal ecosystems, include zoology, botany, ecology, geology, sedimentology, hydrology, biogeochemistry; waste water disposal; as well as management, laws and regulations, policy and economics.

**Article types** The journal seeks original full-length research papers, reviews, and short communication. Manuscript of original research should be written in no more than 8,000 words (including tables and picture), or proportional with articles in this publication number. Review articles will be accommodated, while, short communication should be written at least 2,000 words, except for pre-study.

**Submission** The journal only accepts online submission through system or email to the editors at **jbonorowo@gmail.com** (until the end of 2017). Submitted manuscripts should be the original works of the author(s). The manuscript must be accompanied by a cover letter containing the article title, the first name and last name of all the authors, a paragraph describing the claimed novelty of the findings versus current knowledge. Submission of a manuscript implies that the submitted work has not been published before (except as part of a thesis or report, or abstract); and is not being considered for publication elsewhere. When a manuscript written by a group, all authors should read and approve the final version of the submitted manuscript and its revision; and agree 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 of the manuscript and correcting of the revision. All authors must be responsible for the quality, accuracy, and ethics of the work.

**Acceptance** The only articles written in English (U.S. 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. The manuscript is rejected if the content does not in line with the journal scope, does not meet the standard quality, inappropriate format, 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 biodiversity significance. **Uncorrected proofs** will be sent to the corresponding author as *.doc* or *.rtf* files for checking and correcting of typographical errors. To avoid delay in publication, corrected proofs should be returned in 7 days. The accepted papers will be published online in a chronological order at any time, but printed in June and December.

**Ethics** Author(s) must 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 and when the manuscript is accepted for publication, the author(s) still hold the copyright and retain publishing rights without restrictions. Authors or others are allowed to multiply article as long as not for commercial purposes. For the new invention, authors are suggested to manage its patent before published.

**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.

**A charge** The journal is committed to free of charge for submission and publication of non-institutional funded research (waiver).

**Reprints** The sample journal reprint is only available by special request. Additional copies may be purchased when ordering by sending back the uncorrected proofs by email.

**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 size can be applied in presenting table and figure (9 pt). Word processing program or additional software can be used, however, it must be PC compatible and Microsoft Word based (*.doc* or *.rtf*; **not *.docx***). **Scientific names** of species (incl. subspecies, variety, etc.) should be written in italic, except for italic sentence. Scientific name (genera, species, author), and cultivar or strain should be mentioned completely for the first time mentioning it in the body text, especially for taxonomic manuscripts. Name of genera can be shortened after first mentioning, except generating confusion. Name of the author can be eliminated after first mentioning. For example, *Rhizopus oryzae* L. UICC 524, hereinafter can be written as *R. oryzae* UICC 524. Using trivial name should be avoided, otherwise generating confusion. **Biochemical and chemical nomenclature** should follow the order of the IUPAC - IUB. For DNA sequence, it is better used Courier New font. Symbols of standard chemical and abbreviation of chemistry name can be applied for common and clear used, for example, completely written butilic hydroxyl toluene (BHT) to be BHT herein after. **Metric measurement** use IS denomination, usage other system should follow the value of equivalent with the denomination of IS first mentioning. Abbreviations set of, like g, mg, mL, etc. do not follow by dot. Minus index ($m^{-2}$, $L^{-1}$, $h^{-1}$) suggested to be used, except in things like "per-plant" or "per-plot". **Equation of mathematics** does not always can be written down in one column with text, in that case can be written separately. **Number** one to ten are expressed with words, except if it relates to measurement, while values above them written in number, except in early sentence. The fraction should be expressed in decimal. In the text, it should be used "%" rather than "percent". Avoid expressing ideas with complicated sentence and verbiage, and used efficient and effective sentence.

**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. **Name and institution** address should also be completely written with street name and number (location), postal code, telephone number (O), facsimile number (O), and personal email address. For Indonesian universities, use local name. Manuscript written by a group, author for correspondence along with address is required. First page of the manuscript is used for writing above information.

**Abstract** should not be more than 200 words. **Keywords** is about five words, covering scientific and local name (if any), research theme, and special methods which used; and sorted from A to Z. All important **abbreviations** must be defined at their first mention. **Running title** is about five words. **Introduction** is about 400-600 words, covering the background and aims of the research. **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 manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains for 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. **Acknowledgments** 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 maximum of three pages should be clearly presented. Title of a picture is written down below the picture, while 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; chart is preferred to use black and white images. 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 source. **There is no appendix**, all data or data analysis are incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

**References** Author-year citations are required. In the text give the authors name 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 as shown with word "*cit*" should be avoided. 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 an alphabetical order (better, if only 20 for research papers). 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). 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.

**Book:**

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

**Chapter in 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 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. www.molecularsystemsbiology.com. DOI:10.1038/msb.2008.24

THIS PAGE INTENTIONALLY LEFT BLANK

**BONOROWO WETLANDS**
Volume 9, Number 1, June 2019
Pages: 1-8

P-ISSN: 2088-110X
E-ISSN: 2088-2475
DOI: 10.13057/bonorowo/w090101

# Impact assessment of Komadugu-Yobe Basin Wetlands Development Initiative Project on farmers livelihood in Jigawa State, Nigeria

**BASHIR UMAR, J.G. AKPOKO♥, M.W. MUSA**
Department of Agricultural Economic and Rural Sociology, Faculty of Agriculture, Ahmadu Bello University. Zaria, Kaduna State, Nigeria.
♥email: josephgamboakpoko@gmail.com

Manuscript received: 7 November 2018. Revision accepted: 14 April 2019.

**Abstract.** *Umar B, Akpoko JG, Musa MW. 2019. Impact assessment of Komadugu-Yobe Basin Wetlands Development Initiative Project on farmers livelihood in Jigawa State, Nigeria. Bonorowo Wetlands 9: 1-8.* This study assessed the impact of the Komadugu-Yobe Wetlands Development Initiative project on income, agricultural production, and the standard of living of the people. Primary data were obtained by the use of a structured questionnaire that was administered to 456 respondents comprising the project participants and non-participants. Descriptive statistics, logistic regression, and the Chow test analyzed the data collected. The findings on the socio-economic variables revealed that the mean age of the participants was 36 years and participants were younger in terms of age distribution; the participants were relatively more educated than the nonparticipants, the participants were also organized into viable associations under the project, and the average years of farming experience of participants was 15 years while the nonparticipants had about 14 years. It was also found that the majority (85.5) of the participants have not benefitted from credit facilities. The logistic regression analysis shows that the socio-economic characteristics such as age (0.022**), level of education (0.000*), farm size (0.018*), Household size (0.224*), membership of cooperatives (0.022*), and access to credit (0.023**) were the essential variables that predicted farmer participation in the project. The results of the Chow test show that the F-calculated values on income, crop output, and living standards were higher than the F-tabulated values. It has been concluded that the Komadugu-Yobe Basin Wetlands Development Initiative project positively impacted the project participants. It is recommended that the project should register more participants as the activities of the project had impacted positively on the lives of the participants, to provide more employment opportunities for the youth in the area. Access to loans happened to be a factor that militates against enhancing crop production in the study area. It is recommended that farmers in the study area be linked with financial institutions or government agencies by the project to access loans to boost crop production in the area. The Government should revive extension activities which play a significant role in extending information to farmers as the ratio of an extension agent is very low; when extension problems are solved, crop production in the area would be enhanced.

**Keywords**: Basin wetland, farmers livelihood, Komadugu-Yobe

## INTRODUCTION

There has been a growing realization of wetlands' ecological, socio-economic, climatological, and even strategic importance during the past two decades (Maltby 1996). Consequently, the imperative to conserve and utilize wetlands sustainably has also increased, particularly in developing countries whose economies depend heavily on the wise use of resources such as those provided by wetlands (Aminu-Kano et al. 1993; Organization for Economic Cooperation and Development,1995). Despite the dramatic increase in the appreciation of their values in Nigeria, wetlands remain one of the most threatened and critical ecosystems (Moses 1990).

Wetlands are areas where the soil is covered by water, or water is present either on or near the soil surface all year or for a different period during the year, including during the growing season. Wetlands are also economic drivers because of their crucial role in fishing, agriculture, hunting, and recreation. The areas include swamps, marshes, and bogs. Characteristics of wetlands can vary widely because of differences in soils, topography, water chemistry, climate hydrology, vegetation, and other factors.

Komadugu-Yobe Basin Wetlands Development initiative project is a donor-funded project introduced in 2007 for empowering the inhabitant of the wetlands to harness their well-being. The project activities range from clearance of typha grass using a mechanical and manual approach, skill acquisition on pomade, dye, beads for women, Farmer-Pastoralists Conflict resolution, and dyking the river banks to improve the lives of the inhabitants (KYB-WDI 2007). The wetland creates a strategic ecosystem in the Sudan-Sahelian zone due to the annual inundation of the flood plains of the rivers and those of their several non-contributing channels (Roggeri 2001).

The Hadejia-Ngruru wetlands are an area of flood plain that extends in the north-eastern Sudan-Sahelian zone of Nigeria. The wetlands thereby support the livelihood systems of approximately 1.5 million people in this otherwise sparsely populated region. This support is performed through various functions of the wetlands and the exploitable natural resources that the ecosystem provides (Oguntala 1996). The wetlands constitute a natural barrier to the southward advancement of the process of desertification, which is a significant threat in the region, and flooding of the wetland contribute to recharging of the groundwater that supplies the wells and boreholes in and around the wetlands without which the supported communities would have to disperse (Dugau 1995). The groundwater also supports the unique ecosystem of the area. The wetlands facilitate nutrient recovery in Fadama farms, which support higher agricultural productivity in the region and improve micro-climatic conditions in and around the area. Floodwaters of the wetlands provide natural irrigation for rice and ground moisture for recession agriculture, which are significant elements of the region's economy.

Fodder is provided for over 250,000 herds of cattle during critical periods. These cattle support a trade that has an annual turnover of N416 million in the livestock market dotted in and around the wetlands and keep a yearly catch of over 6,000 metric tons of fish with a market value of N45.4 million and which are exported to national markets like Onitsha and Lagos (Thomas et al. 1993). The wetlands provide plant resources harvested as fuel, timber, fiber, and medicines (Thomas et al. 1993).

Over 3 millionaires have generated annually from doum palm fronds which find their way to national markets as well as support a large variety and several birds and other animals that are illegally and in an unregulated manner for sale and subsistence and facilitate the production of large quantities of honey, which are collected from both improved and natural beehives. The aesthetic atmosphere of the wetlands encourages eco-tourism, which has placed the area on the map of the tourism world (Aminu-Kano et al. 1993).

The specific objectives are to describe the socio-economic characteristics of the participants in the project, assess the impact of the Komadugu-Yobe Basin wetlands development initiative on farmers in the study area, examine the socio-economic factors influencing farmer's participation in the Komadugu-Yobe Basin wetlands development initiative project, and identify the constraints to farmer's involvement in the project in the Study area.

## MATERIALS AND METHODS

### Study Area

Jigawa State lies between latitude 11.00$^{oE}$ to 13.00$^{o}$ North of the equator and longitude 8.00$^{oE}$ to 10.15$^{/}$ East the Green, which is meridian and covers a land area of 22,410 square kilometers, as shown in figure 1. It was created from Kano State on 27$^{th}$ August 1991. The land surface is generally undulating, giving way to Jigawa|, a Hausa word referring to vast loamy and non-marshy soil favorable for cultivating crops like groundnut, guinea corn, millet cassava, rice, wheat (Central Information Authority 2006).

The State is bordered in the south by Bauchi State, in the west by Kano State, in the east by Yobe State, and in the north by Yobe and Republic of Niger. Most of the State (Jigawa) lies within the Sudan vegetation zone. Jigawa has an arduous climate with considerable fluctuation in temperature and humidity. Humidity at times rises to 100%, with the average daily maximum and minimum temperatures being 33.10ºC and 15.0ºC, respectively (CIA 2006).

The harmattan is at its highest during December and January, blowing thin dust over the State from the Sahara Dessert (CIA 2006). The temperature can fall to as low as 10oC at this period, with average rainfall ranging from 653.00-889.00 millimeters. The year is divided into a well-marked rainy season between June and September and a dry season from October to May.

In 2006, the Population of Jigawa State was 2,829,929, and the projected population of the State in 2015 will be 4,348,649 going by the population growth rate of 3.25 %. The predominant occupation in the state is farming. It is one of the priorities of the government of Jigawa to boost this sector by increasing the production of food and cash crops to cope with the rapid population growth. The government intervenes to use the Hadejia Jama'are River Valley that runs through the state to provide irrigation facilities for optimum food production and the establishment of agro-allied industries (CIA 2006).

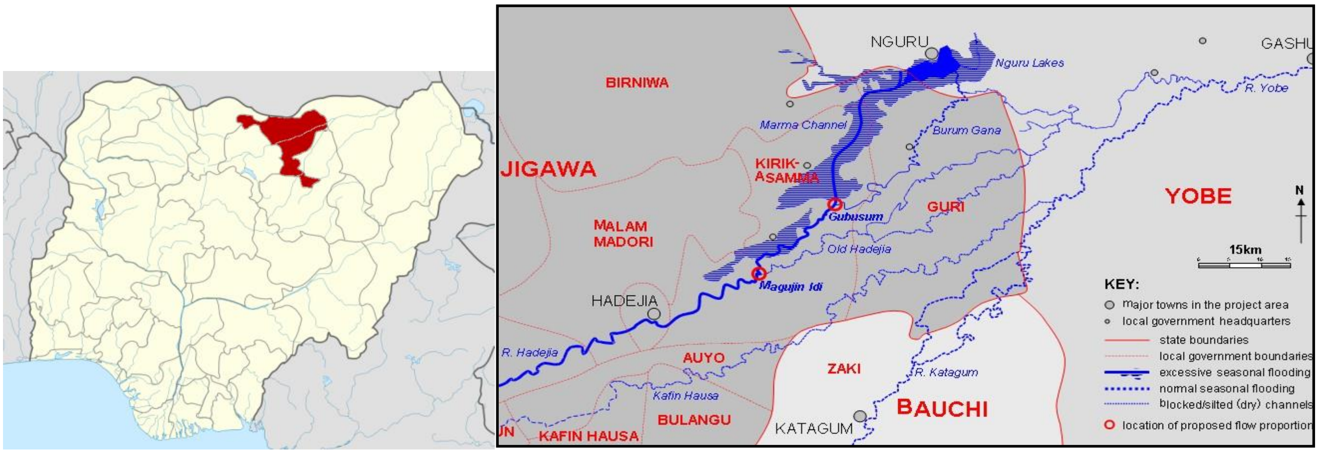



**Figure 1.** Map of the HN Wetlands showing LGAs covered by the project, Nigeria

**Table 1**. Showing sampling procedure and sample size and of the respondents

| Village | Population | Participants | Non-participants | Sampling rate% |
|---|---|---|---|---|
| Marma | 850 | 43 | 43 | 10 |
| Likori | 600 | 30 | 30 | 10 |
| Guri | 750 | 37.5 | 37 | 10 |
| Dawa | 700 | 35 | 35 | 10 |
| Matara Uku | 800 | 40 | 40 | 10 |
| Dagilfanni | 890 | 44.5 | 44 | 10 |
| Total | | 230 | 229 | |

## Sampling technique and sample size

The study employed a multi-stage sampling procedure. In the first stage, three out of eight Local Governments Areas (LGAs) in the Hadejia Zone were selected. These were Kirikasamma with a population of 191,523, Birniwa with 193,334 (wetland areas), and Guri with 115,018. The criteria for the selection were based on the fact that the three LGAs were the wetland areas of the Komadugu-Yobe wetlands Development Project (KYB-WDI) in Jigawa State. In the second stage, two villages known for intensive activities were selected from each of the three LGAs.

Hence, six villages were chosen for the study: Marma, Likori from Kirikasamma LGA; Matara uku, Guri, Dawa from Guri LGA, and Dagilfanni from Birniwa LGA. A pilot survey of the area identified 459 participants and non-participants. Marma and Likori had a population of 850 and 600, Matara Uku and Dagilfanni 800 and 890, and Guri and Dawa 750 and 700 (Federal Office of Statistics 2014). From these figures, 10% of the population was used as the matched samples of participants and nonparticipants, as shown in Table 1.

## Data collection

The study used primary and secondary data obtained through a structured questionnaire administered to the Komadugu-Yobe Basin wetlands Development Project participants and nonparticipants. During the survey, the questionnaire was given by interviews with the respondents by using enumerators in the local language (Hausa).

## Data analysis

Descriptive statistics, including averages, percentages, standard deviation, and frequency counts, were used to summarize, classify, and tabulate data on farmers' characteristics and other variables in the study. Descriptive statistics were used to achieve objectives i, and iv, and the Chow test was employed to achieve specific objectives ii. Logistic regression was employed to achieve objective iii.

### *Chow test*

Statistical and econometric analysis of whether the coefficients in two linear regressions on different data sets are equal? It is also often used to determine whether the independent variables have other impacts on various population subgroups.

$$\text{F-Chow} = \frac{(Sc - S_1 + S_2 / k)}{(S_1 + S_2) / (N_1 + N_2 - 2k)}$$

Where:

Sc: Sum of squared residuals from the combined data

$S_1$: Sum of squared residuals from the first group (participants)

$S_2$: Sum of squared residuals from the second group (nonparticipants)

$N_1$: Number of observations for participants

$N_2$: Number of observations for nonparticipants

K: Total number of parameters

### *Measurement of variables for the chow test for objective II*

In this study, the impact was measured by the participants' income and living level changes.

**Income**. This is the amount of money in naira generated by the farmers from the sales of their produce. (i)

**Level of living.** For this study, livelihood means the standard of living of the participating farmers and that of the nonparticipants. This was measured by the number of goods owned by a household such as motor cars, motorcycles, bicycles, houses, radio, TV, cushion chairs, refrigerator, handset, the amount spent on health care per year, the amount spent on administration of children per year, total expenditure on food and clothing per year. (ii)

### *The logistic regression models for objective III*

The logistic regression model was employed to achieve objective iii. The logistic regression model is one of the binary choice regression models. A dichotomous regression variable is considered the dependent variable, and this dichotomous variable is related to a set of independent variables that are hypothesized to influence the outcome. Hence the model allows one to predict a result from a set of paired variables. In this study, the outcome variable, i.e., participation is binary (i.e., participants and non-participants), were assigned 1 for participants of the project and 0 for nonparticipants. The model included all predictor variables useful in predicting the response variable to accomplish the goal. Several different options were available during the model creation. However, Menard (1995) recommended that backward stepwise regression appeared to be the preferred method for survey and exploratory analyses and was used to analyze the data generated for objective III. The analyses began with a full or saturated model, and variables were eliminated from the model in an interactive process. After eliminating each variable, the model's fit was tested to ensure that the model still adequately fit the data. One of the primary uses of logistic regression in the study provided knowledge of the relationship and strengths of influence among the variables, i.e., the impact of the socio-economic characteristics and institutional factors on farmer participation.

The logit model, characterizing the influence of the socio-economic and institutional factors is specified as follows:

$(Y_i = 1/X_j, j = 1\ldots.10) = F(Z_i) = \frac{1}{I + e^{-zi}} = \frac{ez_i}{ez_i + 1}$; i=1-180) ... (1)

Where:

$Z_i = \alpha + \beta_1 x_{j1} + \beta_2 x_{j2} + \text{---------------} + \beta_9 x_{j9}$ ...................... (2)

L F : (.) = cumulative logistic distribution

To obtain the value of Z, the likelihood of observing the sample needs to be formed by introducing a dichotomous response variable such that:

$$Y_i = \begin{cases} 1 \text{ if ith is a participant} \\ 0 \text{ if } i^{th} \text{ is a non-participant} \end{cases}$$

$X_j$: 1-9 were the socio-economic and institutional factors of the ith farmers defined as:

- $X_1$ : Age (years)
- $X_2$ : Educational level (years)
- $X_3$ : Farm size (ha)
- $X_4$ : Family sizes
- $X_5$ : Sex (male=1, female=2)
- $X_6$ : Years of farming experience (years)
- $X_7$ : Extension contacts (Number of visits)
- $X_8$ : Membership of cooperatives/associations (years)
- $X_9$ : Access to credit facilities (Amount)
- $X_1$-$X_9$ : the coefficient to be explained

*Independent variables*

**Age.** This is the number of years an individual has spent from birth to study time.

**Educational level.** This refers to the capacity of an individual to acquire western education knowledge and be able to read and write. Education level was measured by determining the actual number of years spent in school and was scored as follows: Adult education 1, Primary education 2, Secondary education 3, and Tertiary education 4.

**Farm size.** This refers to the total land area under cultivation measured by the farmer's total number of hectares cultivated.

**Household size.** This is the total number of people in one household. It is expected to affect the livelihood of participants.

**Sex.** The biological characteristics for identifying an individual as either a male or female, measured by scoring male 1, female 2.

**Farming experience.** This refers to the actual number of years put in farming activities. It is expected that farmers would gain more experience as they spend more years in farming activities.

**Extension contacts.** This is a meeting the respondent has had with extension officials. The role of extension is to create awareness among farmers, enlightenment, and demonstration of innovations and to compare the benefits of the innovations. It was measured by the number of visits or contacts with extension workers of the Komadugu-Yobe Basin Wetlands Development project and scored as follows if visited by an extension agent 1 and 0 if otherwise.

**Membership of cooperatives/associations.** This represents the membership of farmers in any association. Membership in social organizations facilitates awareness, economic empowerment, and participation in the KYB-WDI activities. It was measured by the number of years the farmer belongs to the associations organized by the KYB-WDI project at the time of the study, 1 was scored if a farmer belongs to any association and 0 if otherwise.

**Access to credit facilities.** This represents a farmers' access to a loan received either in cash or in kind. Access to credit has excellent potential to influence farmers' interest in innovations. It is, therefore, expected that the more farmers have access to credit, the higher the probability of their participation in the project's activities. It was measured by the total money borrowed from financial institutions, credit availability 1, and non-availability 0.

*Dependent variable*

**Participation is the number of project activities a particular farmer involves**. The project's activities were a mechanical and manual clearance of typha grass, Dyking of the river banks, farmer-pastoralist conflict resolution, Skill acquisition on pomade making, beads making.

## RESULTS AND DISCUSSION

### Socioeconomic characteristics of the respondents

The socio-economic characteristics of the respondents examined by the study were age, level of education, farm size, farming experience, sex, household size, extension contact, membership of cooperatives societies, and access to credit.

*Age distribution*

The age distribution of the respondents was between 20-51 years. The result in Table 2 shows that 1.7% of the participants fall within the range of 20-30 years, 10% fall within the range of 31-40 years, 77.4% fall within the range of 41-50 years, and 10.9% fall within the range of 51-. The age distribution implies that age played a significant role in crop production and is expected to positively influence their participation in the project program in the study area.

*Level of education*

As many as 21.3% of the participants acquired adult education, 31.7% acquired primary education, 41.7% acquired secondary education, and 5.2% acquired tertiary education. On the other hand, for statistics, the non-participants, 52.4% acquired adult education, 27.1% acquired primary education, 20.5% acquired secondary education, and no one among the non-participants received tertiary education. The result indicated that the level of education of both participants and nonparticipants was low. This could be attributed to adult education being emphasized in the study area. It indicates that the respondents lacked the formal education required to comprehend complex new technologies.

The study by Centro Internationale de majoramanto de maize Y Trigo (CIMMYT),i.e., international maize and wheat improvement center (1995), had confirmed that education was important for easy understanding of improved methods of agricultural production and make farmers more receptive to advice from extension agency or be able to deal with technical recommendations that require a certain level of numeracy and literacy.

*Farm Size*

Because farmland is an important resource for improving the living conditions of farmers and fighting against poverty, farm sizes were examined in the study area. Most of the participants (73.9%) possessed farms of less than 2 hectares (Ha), 20.9% possessed 2-4 hectares (Ha) land, and 5.2% of the participants had above 4 hectares (Ha) of land (Table 2). In contrast, 83.0% of the nonparticipants possessed less than 2 hectares (Ha), 10.5% of the nonparticipants had 2-4 hectares (Ha) of land, while 6.6% of the nonparticipants had above 4 hectares of land. The result showed that both participants and nonparticipants owned smallholdings, in line with the Federal Office of Statistics (1999) findings that farm size affects adoption cost, risk perception, labor requirement, human capital, and tenure arrangement.

*Household size*

Table 2 shows that the area was dominated by small households, whereby 37.8% of the participants had 1-3 persons, 59.1% had 4-6 persons, and 3.0% of the participants also had 7-9 persons. Hence, there would be more people to cater for, which means more pressure on their income hence their participation in the KYB-WDI project. This result is tallied with the International Fund for Agricultural Development (IFAD 2001) findings.

*Sex*

All the project participants were male, which signifies that culture played a significant role in the area as women were not allowed to farm by themselves. Moreover, women were not allowed to be interviewed by enumerators. It is believed that when women were allowed to cultivate, there would be no successor bumper harvest in crop production.

*Farming experience*

Table 2 demonstrated that the participants (66.67% ) and nonparticipants (20.83%) have been in farming for less than ten years; 20.6% of the participants had farming experience between 11-25, while 12.50% had the experience of between 11-25 years. Also, those who had farming experience of more than 25 years comprised 12.73% of the participants and 66.67% of the nonparticipants. The years of experience are expected to translate into a better understanding of the program, invariably resulting in better income. It is expected that respondents would make sound decisions regarding resource allocation and management of their farms.

**Table 2.** Socioeconomic distribution of participants and Nonparticipants

| Variables | Participants frequency | Percent-age | Non participants frequency | Percent-age |
|---|---|---|---|---|
| **Age** | | | | |
| 20-30 | 4 | 1.7 | Nil | Nil |
| 31-40 | 23 | 10.0 | 104 | 45.4 |
| 41-50 | 178 | 77.4 | 101 | 44.1 |
| 51-60 | 25 | 10.9 | 24 | 10.5 |
| **Education** | | | | |
| Adult | 49 | 21.3 | 120 | 52.4 |
| Primary | 73 | 31.7 | 62 | 27.1 |
| Secondary | 96 | 41.7 | 47 | 20.5 |
| Tertiary | 12 | 5.2 | Nil | Nil |
| **Farm size (ha)** | | | | |
| Less than 2 | 170 | 73.9 | 190 | 83.0 |
| 2-4 | 48 | 20.9 | 24 | 10.5 |
| Above 4 | 12 | 5.2 | 15 | 6.6 |
| **Household size** | | | | |
| 1-3 | 87 | 37.8 | 46 | 20.1 |
| 4-6 | 136 | 59.1 | 142 | 62.0 |
| 7-9 | 7 | 3.1 | 23 | 10.0 |
| 10-12 | Nil | Nil | 15 | 6.6 |
| 13-15 | Nil | Nil | 3 | 1.3 |
| **Sex** | | | | |
| Male | 230 | 100 | 229 | 100 |
| Female | Nil | Nil | Nil | Nil |
| **Farming experience (years)** | | | | |
| Less than 10 | 80 | 66.67 | 25 | 20.83 |
| 11-25 | 115 | 20.6 | 40 | 12.50 |
| Greater than 25 | 35 | 12.73 | 164 | 66.67 |
| **Extension contacts** | | | | |
| No | 97 | 42.2 | 197 | 86.0 |
| Yes | 133 | 57.8 | 32 | 14.0 |
| **Membership of cooperatives** | | | | |
| No | 8 | 3.5 | 47 | 20.5 |
| Yes | 222 | 96.5 | 182 | 79.5 |
| **Access to credit** | | | | |
| No | 214 | 85.5 | 16 | 14.17 |
| Yes | 16 | 14.5 | 213 | 85.83 |
| **Total** | 230 | 100 | 229 | 100 |

*Extension contacts*

Respondents who had extension contact fell in the range of 57% from the participants, while 42.2% of the participants had no extension contact (Table 2). The result indicates that more than half of the project participants had extension contact. This shows a need for more visits by the extension workers to the project participants to enhance crop production in the area.

*Membership of cooperatives*

Cooperative groups are organized to promote special interests or meet certain needs that individual efforts cannot achieve. They contribute to disseminating new ideas, practices, and products and sourcing for loan and farm inputs. Table 2 revealed that 3.5% of the participants did not belong to any organization, while 96.5% belonged to a cooperative society. This indicates that the more farmers participated in cooperative societies, the better the idea, knowledge, and benefit derived from, among others.

*Access to credit*

Table 2 showed that 85.5% of the participants did not have credit facilities, while only 14.5% enjoyed credit facilities. This phenomenon indicates that the project's impact on participants would have been more when the participants were able to access loans from a lending institution as a loan plays an important role in enhancing crop production.

The participants had more farming experience with a mean value of about 15 years, while nonparticipants had about 14 years (Table 4). Therefore, with more experience in farming, they are less likely to oppose the adoption of new technologies. Farmers' knowledge could also generate more confidence. Thus, the farming experience could positively affect farmers' decisions.

The mean extension visit to the participants by an extension agent was 2.42. This indicated that the necessary agricultural information flowed through the extension agents to the contact participants, while the nonparticipants derived agricultural information from fellow farmers.

The result of membership of cooperatives societies showed that participants belonged to social organizations registered under the project. Thus, the farmers under the project were adequately organized for easy access to credit facilities, indicating that the more farmers participated in cooperative societies, the better the idea, knowledge, and benefits among members. The results on access to credit facilities indicate that project participants have not benefitted from credit facilities (Table 4).

**Impact of KYB-WDI Project**

The second objective of the study was to assess the impact of the KYB-WDI project on crop output, income, and the farmers' standard of living.

*Analysis of the impact of KYB-WDI project on crop output, income, and standard of living*

The Chow test model was used to compare outcomes of the response variables between participants and nonparticipants to determine the projects' impact on crop output, income, and people's standard of living. The entries table 4 shows that the F-calculated on output (2418.23) was greater than the F-critical value (4.12); F-calculated on income was 5608.46 and was greater than the critical F-value (4.12); and the F-calculated on the standard of living (62965.91) was also greater than the critical F-value (4.12), all at 5% level of probability. This indicates that the value of the F-calculated for income, crop output, and standard of living was greater than the F-tabulated. This implied that the KYB-WDI had a positive impact on crop output, income, etc., and the beneficiaries' standard of living.

The findings supported the development and social impact assessment perspective, which stated that whenever project beneficiaries are adequately motivated through the provision of functional extension delivery services, the tendency for increased crop productivity, income, and standard of living of the people is assured (Sanginga 1999).

**Table 3**. Distribution of respondents by socioeconomic factors

| Variable | Respondent type | Number | Mean | SD |
|---|---|---|---|---|
| Age (years) | Participants | 230 | 46.44 | 6.087 |
| | Nonparticipants | 229 | 52.21 | 5.462 |
| Education level | Participants | 230 | 38.52 | 9.220 |
| | Nonparticipants | 229 | 18.16 | 9.220 |
| Farm size | Participants | 230 | 3.49 | 1.710 |
| | Nonparticipants | 229 | 2.11 | 0.990 |
| Farming experience | Participants | 230 | 15.0 | 6.330 |
| | Nonparticipants | 229 | 14.0 | 7.940 |
| Household size | Participants | 230 | 5.86 | 2.284 |
| | Nonparticipants | 229 | 8.02 | 4.487 |

**Table 4.** distribution of respondents by institutional factors

| Variable | Respondent type | Number | Mean | SD |
|---|---|---|---|---|
| Extension contacts | Participants | 230 | 2.42 | 1.533 |
| | Nonparticipants | 229 | 0.41 | 0.831 |
| Membership of coop | Participants | 230 | 1.34 | 0.476 |
| | Nonparticipants | 229 | 1.08 | 0.276 |
| Access to credit | Participants | 230 | 0.19 | 0.391 |
| | Nonparticipants | 229 | 0.14 | 0.351 |

**Table 5.** Results of the chow test on crop output, income, and standard of living

| Group | Variable | Residual | $N_1+N_2$ | K | F-cal | F-table |
|---|---|---|---|---|---|---|
| Pool | Standard of Living | 2017.52 | 55 | 16 | 62965.91 | 4.12 |
| Participants | Standard of Living | 556.96 | | | | |
| Non-participants | Standard of living | 1126.49 | | | | |
| Pooled | Income | 178.29 | 559 | 16 | 5608.46 | 4.12 |
| Participants | Income | 4.46 | | | | |
| Non-participants | Income | 123.71 | | | | |
| Pooled | Crop output | 77.41 | 559 | 16 | 2418.23 | 4.12 |
| Participants | Crop output | 9.14 | | | | |
| Nonparticipants | Crop output | 54.77 | | | | |

*Test of hypothesis using Chow test*

The result of the Chow test indicates that there was a significant impact on crop output, income, and standard of living of the participants as the values of the F-calculated were greater than the F-tabulated values. Therefore, the null hypothesis was rejected.

*Socio-economic factors influencing farmers' participation*

The third objective of the study was to determine the socio-economic factors influencing participation in the project. Table 4.6 shows the result of the logistic regression analysis of factors influencing participation. The results of the analysis indicated that the variables, age (0.050), level of education (1.666), membership of Cooperatives (1.916), and access to credit (1.519) were found to be significant at 1% \] level. Farm size (0.315), Household size (-0.053) were found effective at a 5% level. However, farming experience (-0.012) and extension contact (0.346) were insignificant. This study is in line with those reported by Okwole (1998), Maskey and Weber (1996), and Edi et al. (2007), who noted that age, social participation, access to credit, farm size, and level of education influence participation. This is contrary to the findings of Oni (1991) and Nicholas (2002) on household size, formal education, and farming experience.

This is evident from the study that the participants had acquired more than the nonparticipants, implying that farmers with more education become less opposed to adopting innovations. Similarly, participants were organized into social groups by the project. They indicate that the more farmers participate in cooperative societies, the better the idea, knowledge, and benefits among members. On the other hand, farming experience, household size, and extension contact were inversely related to participation since the values of the coefficients were negative.

Based on these findings in table 4, age, level of education, farm size, membership of cooperatives, years of membership, and access to credit were the most important variables that predicted farmers' participation; they also had a strong influence on participation in the KYB-WDI project. Therefore, greater participation in the project activities may be assured when farmers are properly organized. Similarly, if they are motivated through access to credit facilities, education, membership of the association by KYB-WDI, it would likely increase crop output and higher participation in the project.

Overall, the study has justified diffusion and adoption theory which provides valuable insights on the factors studied and how these factors influence the participation of farmers in the project activities and innovations introduced by the KYB-WDI project. The theory's proponents stated that program interventions are bound to be influenced by certain socio-economic and institutional factors that must be identified.

*Constraints encountered by farmers in the KYB-WDI Project Area.*

The fourth objective of the study was to identify the constraints encountered in the KYB-WDI project area. Despite the contributions of the project to improve rural livelihoods, income, and crop output, it was found that the project participants‘ faced some challenges; the major constraints faced by respondents were ranked in the following order by the respondents: low capital outlay; low prices of farm produce; disease and weed infestation; water shortage; and lack of transportation (Table 7) these are discussed in details as follows:

*Low capital outlay*

A shortage of capital-constrained farmers. About 21.3% of the participants complained of a lack of capital to invest in large-scale farming or adopt farm technologies requiring huge capital investments. Lim and Douglas (1998) emphasized that; poverty in rural areas is still a significant barrier for small-scale farmers. Therefore, if poverty alleviation measures were not adequately implemented in the area, farmer participation could be affected. If participants in the KYB-WDI project could access loans from financial institutions, then the tendency for improved production may be assured.

*Low prices of farm produce*

Since farmers had no stand market to sell their produce, which gave rise to an influx of market middlemen in the project area, 31.7% of the respondents complained of low market prices for their farm produce. The implication was that farmers are at the expense of these middlemen who take advantage of the situation to get a higher income than the farmers.

**Table 6.** Logit regression estimate of socio-economic characteristics of the farmers and institutional factors influencing participation

| Variables | Coef-ficient | SE | Z | Level of Sign |
|---|---|---|---|---|
| Constant | -4.490 | 3.1941 | -1.41 | 0.160 |
| Age | 0.050 | 0.0220 | 2.28 | 0.022** |
| Level of education | 1.666 | 0.3364 | 4.95 | 0.000* |
| Farm size | 0.315 | 0.1336 | 2.36 | 0.018* |
| Farm experience | -0.012 | 0.0412 | -0.30 | 0.767 |
| Household size | -0.053 | 0.0437 | -1.22 | 0.224* |
| Extension contacts | -0.347 | 0.2293 | -1.52 | 0.130 |
| Membership of Association | -1.325 | 0.5803 | -2.28 | 0.022* |
| Years of membership | 0.872 | 0.2307 | 3.78 | 0.000** |
| Access to credit | 1.519 | 0.6680 | 2.27 | 0.023** |
| | | | | |
| Access to credit | | | | |
| Sample size | 459 | | | |
| Log likely hood function | -67.656164 | | | |
| Ch-squared value | -146.6 | | | |
| Degrees of freedom | -15 | | | |
| Prob > chi | 20.0000 | | | |
| Pseudo $R^2$ | 0.520 | | | |

Note: P <0.01, ** P<0.05

**Table 7**. Constraints of farmers in the KYB-WDI project

| Constraints | Frequency | Percentage |
|---|---|---|
| Low Capital outlay | 49 | 21.3 |
| Low prices of farm produce | 73 | 31.7 |
| Disease and weed infestation | 96 | 41.7 |
| Water shortage | 12 | 5.2 |

## Summary

This study was conducted to assess the impact of the Komadugu-Yobe Basin Wetlands Development Initiative (KYB-WDI) project on farmers in Jigawa state. Primary data were obtained using a structured questionnaire administered to participants and nonparticipants of the project. The results are summarized below:

The study showed that the respondents were between the minimum age of 20 years and a maximum of 51 years, with an average of 35. Still, the participants were younger than the nonparticipants, and participants might have a stronger interest in the project activities than the older ones.

It was found that the respondents had a low level of formal education, but the participants were relatively more educated than the nonparticipants. The farm holdings of the respondents were small, with an average of fewer than 2 hectares per farmer. It was found that the average years of farming experience of participants was 15 years while the non-participants had about 14 years. It was also found that the mean household of the respondents was nine persons per household head. The participants had extension contacts. The participants were also organized into a platform of viable associations under the project. At the same time, the nonparticipants were left to manage their social groups, and also revealed that both the participants and nonparticipants had rarely benefitted from the credit facilities; this means that the participants could have more opportunities to enjoy credit facilities from the Government and commercial banks if there was a concerted effort by the state Government and agricultural extension service delivery system.

The result of the logistic regression estimates indicated that Household size (-0.053), farming experience (-0.012), and extension contact (-0.347) negatively influenced participation. Age (0.050), education (1.666), membership of cooperatives (1.916), access to credit (1.519), farm size (0.315) positively influence participation. A unit increase in these variables could lead to increased participation in the project by their corresponding exponentials (probabilities).

The result of Chow test showed that crop output (2,418.23), income (5,608.46), the standard of living (62,965.91) was at a 5% level of probability since the calculated values are higher than the table values, the hypothesis tested in the study was rejected.

Despite the significant impact of the KYB-WDI project, faced with certain constraints that could limit their performance, these constraints were ranked according to the participants' responses. The majority, 41.7 of the respondents, reported disease and weed infestation, 31.7 of them indicated low prices of farm produce, 21.3 low capitals outlay, and 5.2 water shortages.

It could be concluded that the KYB-WDI project had a positive impact on participants as the calculated F-values for income, crop output, and standard of living of the participants were greater than the F-tabulated values. Hence the null hypothesis that the KYB-WDI project has no positive impact on participants was rejected.

## REFFERENCE


Aminu-Kano GE, Adams M, Hollis WM. 1993. Environment, Economy and Sustainable Development of a Sahelian Flood Plain Wetlands, IUCN, UK.

Ani AO. 2007. Agricultural Extension: A Pathway for Sustainable Agricultural Development. Apani Publications, Kaduna.

Center for Information and Administration. 2006. Information Management and Dissemination Report. Center for Information and Administration, Nigeria.

Dimitiri D, Nicholas G. 2002. Farmers participation in agric-environmental schemes in Greece. Brit Food J 3 (4): 261-275. DOI: 10.1108/00070700210425705.

Dugau PJ. 1995. Wetland Conservation: A Review of Current Issues and Required Action. Monteux, IUCN, UK.

Edi D, Paola G, Ford R, Samuel T. 2007. Factors affecting farmers participation in agri-environmental measures: a northern Italian perspectives. J Agric Econ 59 (1): 114-131. DOI: 10.1111/j.1477-9552.2007.00134.x.

Federal Office of Statistics. 1999. Annual Report Chapter. Federal Office of Statistics, Nigeria.

IFAD. 1999. Roots and Tubers Expansion Programme. Report and Recommendations of the President to the Executive Board on a proposed loan to the Federal Republic of Nigeria Executive Board 68th session. International Fund for Agricultural Development, Rome, Italy.

KYB-WDI. 2007. Komadugu-Yobe Basin Wetlands Development Initiative Report.

Maltby E. 1996. Water Logged Wealth: Why Waste the World‘s Wet Places? Earth Scan, London.

Maskey RK, Weber KE. 1996. Evaluating factors influencing farmers satisfaction with their irrigation system. A case from the hill of Nepal. Irrig Drainage Syst 10 (4): 331-341. DOI: 10.1007/BF01104897.

Moses BS. 1990. Distribution, Ecology and Fisheries Potentials of Nigerian Wetlands, In: Akpata TVI, Duu O (eds) Nigerian Wetlands. MAB National Committee Publication, Nigeria.

Oguntala MI. 1996. National Biodiversity Strategy and Action plan. In: FEPA Nigerian Biodiversity. Strategy and Action Plan. A Draft Working Document for the Development of the National Biodiversity Strategy and Action Plan. Abijan, Nigeria.

Okwace VA. 1998. Adoption of Agricultural Innovation among Members and Non-members of Women Cooperative Societies in Oju L.G.A. of Benue State. [Unpublished MSc Thesis] Ahmadu Bello University, Zaria.

Oni O. 1991. A review of adverse health effect associated with irrigated agricultural development in Africa. Water Resource National Seminar. Kaduna, 12th March.

Organization for Economic Co-operation and Development. 1995. National Biodiversity Strategy and Action Plan. In: FEPA Nigerian Biodiversity. Strategy and Action plan. A Draft Working Document for the Development of the National Biodiversity Strategy and Action Plan. Abijan, Nigeria.

Roggeri H. 2001. Tropical Fresh Water Wetlands. A Guide to Current Knowledge and Sustainable Management. Kluwer Academic Publishers, London.

Sanginga PC. 1999. Social impact of soya bean in Nigeria’s southern Guinea savannah. IITA, Ibadan, Nigeria.

Thomas DHI, Jimo, Mathis H. 1993. Fishing, Environment, Economy, and Sustainable Development of a Sahelian Flood Plain Wetland. IUCN, UK.

**BONOROWO WETLANDS**
Volume 9, Number 1, June 2019
Pages: 9-26

P-ISSN: 2088-110X
E-ISSN: 2088-2475
DOI: 10.13057/bonorowo/w090102

# Fish as bioindicators of habitat degradation in coastal lagoons of Ghana

**BADU BORTELEY EUGENIA, A.K. ARMAH, H.R. DANKWA**
Institute for Environment and Sanitation Studies, University of Ghana. Legon, Accra, Ghana.
♥email: akarmah@ug.edu.gh

Manuscript received: 23 August 2019. Revision accepted: 4 May 2019.

**Abstract.** *Eugenia BB, Armah AK, Dankwa HR. 2019. Fish as bioindicators of habitat degradation in coastal lagoons of Ghana. Bonorowo Wetlands 9: 9-26.* Lagoons' habitat forms an integral part of the marine fishing industry and provides essential spawning and nursery grounds for many fishes. Fish act as biological indicators of water quality and changes by summarizing information regarding their environment. Two lagoons, Laloi and Oyibi, in the Greater Accra and Central Regions of Ghana were studied to determine the ecological status using the Estuarine Fish Community Index (EFCI). Metrics assigned were the species diversity, nursery function, trophic integrity, and species abundance and composition. Water samples were obtained at the riverine, middle, and seaward portions during both high and low tides at each site. Fisherfolks were hired to fish at each of the sites. There are no significant differences between sites as measured by diversity indices. Multivariate analysis showed a considerable similarity between sites regarding species composition. This study identified eighteen species, including both finfish and shellfish. During the study, the two most abundant species were the flathead grey mullet (*Mugil cephalus*) and the black-chinned tilapia (*Sarotherodon melanotheron*). *Mugil cephalus* dominated catches in the Laloi lagoon, whereas *Sarotherodon melanotheron* was dominant in the Oyibi Lagoon. The most predominant species collected for the Laloi lagoon were *S. melanotheron, Lutjanus fulgens,* and *Eucinostomus melanopterus*. *Caranx hippos, L. fulgens*, and *M. cephalus* constituted a significant part of fishes caught in the Oyibi lagoon. The carangid, *Caranx hippos* contributed primarily to the biomass of fishes collected for both lagoons. In the rainy season, total fish abundance was higher than in the dry season. Chlorophyll-a concentrations and condition factors of *S. melanotheron* were highest at both lagoons. Total organic carbon was high in the Oyibi lagoon; hence, the high numbers of *S. melanotheron* recorded. Tides were an essential factor affecting physicochemical parameters. Oyibi displayed a moderate site rating, suggesting that it was under mild stress with some stress factors identified were garbage dumping, defecation, land-use changes, and increased human pressure. Meanwhile, Laloi Lagoon had a poor site rating, suggesting severe stress. The principal strains identified were overfishing, garbage dumping, mangrove degradation, and increased human settlements along the sides of the lagoon. The multi-metric index described served as an effective method that reflects the status of lagoon fish communities and the overall ecosystem conditions.

**Keywords**: Bioindicator, coastal lagoon, fish

## INTRODUCTION

Lagoons are relatively shallow water that has been partly or wholly sealed off from the sea by forming barriers. The barriers are built up above high tide level by wave action and lie parallel to the shoreline (Kjerfve 1994; Hill 2001). It is a highly productive coastal feature that provides a range of natural services society values. There are over 90 coastal lagoons in Ghana, which cover less than 5 km$^2$ in the surface area along the 550 km, which forms 7% of the total land area of Ghana (Armah 2005). Lagoons present unique environments and habitats supporting valuable products and services, including fisheries, flood assimilation, regulation and supply of water, and biodiversity protection.

Most tropical lagoons are associated with mangrove swamps. These mangroves serve as a habitat for finishes, migratory birds, and hellfish. They also absorb pollutants from upland sources and coastal, protect the coast against erosion, trap sediments from rivers and accumulate washed silt to increase the ground level, stabilize shorelines and improve water quality (Entsua-Mensah 2002). In Ghana, the majority of mangrove species are Rhizophora spp and Avicennia spp. These mangrove species are threatened by salt winning and indiscriminate harvesting as fuelwood for cooking and smoking of fish. Observation has shown that the mangroves, which filter inland water as it flows to the sea and serves as a nursery and habitat for many shells and finfish, are being rapidly destroyed (Entsua-Mensah 1996). Lagoons in Ghana are used in artisanal fisheries and play a significant role in the economy of some coastal inhabitants, particularly during the off-season for marine fishing (Entsua-Mensah et al., 2004).

Environmental conditions underlie the productivity of fisheries (Finney et al. 2002; Wynne & Cote 2007) and fishing on the ecosystem. Fishing activities affect the benthic fauna and habitat, fish community structure, and trophic interaction. Overfishing and reducing fish catches of some fish species have affected the rural fishing economies (Entsua-Mensah 2006). One of the types of over-fishing that occurs in most coastal lagoons is growth overfishing. Growth overfishing is when fish are caught at an average size that is smaller than the per recruit, and recruitment overfishing is when the mature adult population is reduced to a level where it is no longer has the reproductive capacity to replenish itself, thus not enough adults to produce offspring. Overfishing impacts fisheries' livelihoods through income and profit reduction directly, increasing competition and conflicts over fishing grounds, resources of the fishery, and markets (Entsua-Mensah 2006). Because of increased pressure in fish stock and dwindling stocks, small-scale fishers have started using fine mesh nets, explosives, poisons, putting further pressure on the resource (Bailey 1994; Entsua-Mensah 2006).

Some of the additional pressures in this urbanized coastal area include loss of natural habitat through physical change to the system and discharge of potentially toxic materials into the wetland that can change both aquatic species diversity and the ecosystem due to their toxicity and accumulative behavior (Heath 1987). Degradation of wetlands ultimately caused narrowing of the habitat dimensions, thus, reducing the survival ability of species which cannot adapt (Jude and Pappas 1992). The complexity of fishing gears, excessive fishing pressure, and overexploitation are factors that have an adverse impact on the lagoon ecosystem (Koranteng 1995). Laé (1997) observed that fishing activities could change species composition, size class, structure, and annual fish yields. When fishing activity is high, fish diversity declines and alters the trophic system.

Fish and other species act as biological indicators of water quality and alterations. Fish responds to the cumulative effects of both physical and chemical disturbances to the water in which they live. Bioindicators refer to organisms and their attributes, which could be utilized to assess the environment's health (Peakall,1992). They can be used to detect changes in the natural environment, monitor for the presence of pollution and its impact on the ecosystem in which the organism living, test substances like drinking water for the existence of contaminants, monitor the progress of environmental cleanup (O‟ Connor and Ehler 1991; Davis 1993). The most significant reasons for using bioindicators are the direct determination of synergistic and antagonistic effects of multiple pollutants on an organism, the early recognition of pollutants damage to organisms, and toxic dangers to humans. A bioindicator is also relatively low cost compared to technical measuring methods (Zimmermann and Umlauff-Zimmermann 1994). Bioindicators provide the following information for ecosystem management according to Lorenz (2003): a description of ecosystem processes and structures, cause-effect relationships with an ecosystem, and ecosystem condition by comparing the ecosystem with a reference level of proper ecological functioning.

Fish has widely used in the biomonitoring of water pollution because of its unique biological characteristics such as relatively big body size, ease to raise, and long-life cycle (Qunfang et al. 2008). Moreover, fish species are at the top position in the aquatic food chain and might directly affect the health of humans, which makes biomonitoring using fish much more significant. Fish health also reflects the state of pollution very well because of their limited ability to eliminate contaminants (Sucman et al., 2006). Fish serve as an excellent indicator of watershed health because all their life is spent in the water and differ in their tolerance to amount and types of pollution. Fish are easy to collect with the right equipment, easy to identify in the field, and live for several years. They provide an accurate assessment of environmental health because they have long life spans and therefore can reflect long and short-term water resource quality; they offer a broad spectrum of community tolerances from very sensitive to highly tolerant species. Because they spend their entire life span in water, they integrate the waters' physical, chemical, and biological histories, and they are less affected by natural microhabitat discrepancies than smaller organisms (Holt and Miller 2011).

The objectives of this research are to compare the species diversity, composition, and abundance of the Oyibi and Laloi lagoons of Ghana, determine the similarities and dissimilarities in species composition, ascertain any effects of physicochemical parameters on the distribution of species, to determine the ecological status of the Oyibi and Laloi lagoons.

## MATERIALS AND METHODS

### Study sites

The study sites are taken within the central coast with two rainy seasons, reaching its maximum in May-June, and the minor seasons start in mid-August and end in October. The average rainfall is 735 mm. The typical economic activities in the catchment of the lagoons are salt winning and fishing. The study was conducted in the Laloi (Greater Accra) and Oyibi (Central regions of Ghana) lagoons (Figure 1-2). The sites are situated at Kpone and Nsuekyiri (near Winneba) and were chosen due to their easy accessibility and economic significance.

*Laloi Lagoon*

The Laloi lagoon is located within latitude 5.42.30 N and longitude 0.04.35 E, with a total area of 0.695 $km^2$ (Gordon et al. 1998). It is situated at Prampram and enters the sea at Kpone, which lies in the Tema Export Processing Zone. The lagoon serves an essential economic role in the community by providing fish for domestic purposes and income. The typical economic activity in this area is salt mining and fishing. The lagoon is open all year round, but it is not fished on Tuesdays. Fish landed from the lagoon can only be boiled or smoked. The main fishing gears employed are the dragnets, cast nets, and traps mainly for crabs. Boys mostly use the traps for the blue-swimming legged crab, Callinectes sp. The trap is baited and allowed to float in the area. The Gao lagoon feeds the lagoon.

*Oyibi Lagoon*

The Oyibi lagoon falls within latitude 5°21’N and longitude 1°36‟ E with a size of 0.300 $km^2$ and a mean depth of 0.5 m (Gordon et al. 1998). It is located at the mouth of the Ayensu River and close to Winneba. The lagoon joins the sea at Warabeba, a fishing village with Essuekyir at the northern side of the lagoon and the women mostly fishmongers. There is extensive mangrove cover around the lagoon with mangrove species, including Rhizophora racemosa and Avicennia germinans. The primary economic activity at the site is fishing and salt production. The lagoon water is not used to produce salt, but seawater is pumped into pans. The lagoon is open throughout the year but is not fished on Wednesdays. The main fishing gears used in the lagoon are the cast and drag nets.

**Field methods**

Each of the sites was visited once a month during the six months. Tide predictions were made by the Ghana Ports and Harbour Authority (GHAPOHA). To ascertain any tidal influence on physicochemical parameters, water samples were collected from the seaward, riverine, and middle reaches during low and high tides.

*Sampling*

Sampling was performed from January to May 2012.

*Fish sampling methods*

Fisherfolks were hired to fish at each location, and the fish samples were also bought from fisherfolks to represent the fish species at each location. The main fishing gear used at the sites was the cast net of mesh size 2.5 cm. Fishing was done during high and low tides. Fish harvested were sorted out according to species and stored in an ice chest before further identification was transported to the laboratory. Fish samples were done from January to May.

*Water sampling methods*

Water samples were acquired from February to May. The physicochemical parameters measured were BOD, DO, the nutrients (nitrates and phosphates), chlorophyll-a, pH, salinity, temperature, TSS, and TDS. Sub-surface water samples were obtained at three points (lower, middle, and upper reaches) from each site and kept in a 250 mL tight plastic bottle for nutrient analysis. DO was calculated using the Winkler method. Water samples collected were fixed as soon as possible with 2 mL of Winkler 1 (Manganese sulfate) and Winkler 2 (Alkaline iodide-azide reagent) solutions and firmly corked, ensuring no air bubbles were trapped in the bottle. Temperature and pH were calculated in-situ using the YOKOGAWA pH meter model PH 82. Salinity was measured using the ATAGO 2SE refractometer, then analyzed with HACH Spectrophotometer.

*Sediment sampling method*

A digger was used for sediment sampling. A cylindrical PVC pipe with open sides was placed vertically in the lagoon and pressed about 2 cm deep. The sediment was then stored in transparent polyethylene bags and transported to the laboratory for analysis. Sediment samples were taken at three locations; middle portions, upper reaches, and the seaward end of both lagoons. Sediment was taken once during the study period at low tide.

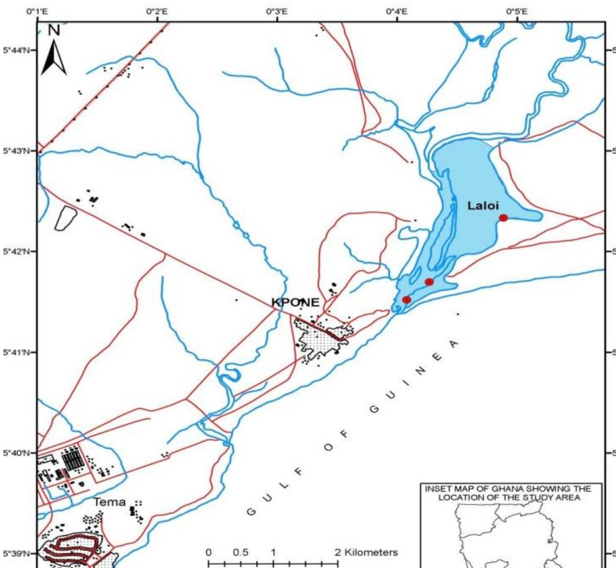



**Figure 1.** Map of Laloi lagoon displaying the sampling points, Ghana

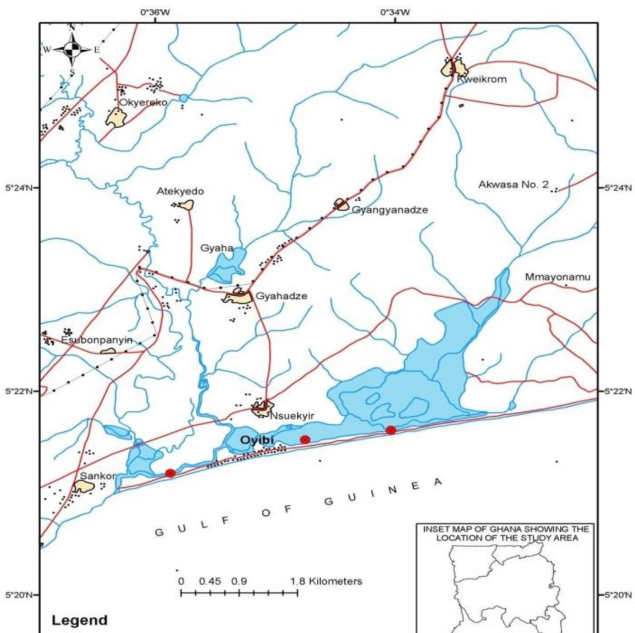



**Figure 2.** Map of Oyibi lagoon showing sampling points, Ghana

## Laboratory methods

*Length-weight analysis*

The total length (TL) of the dominant fish was calculated from the snout to the extended tip of the caudal fin using a meter rule calibrated in centimeters. The relationship between TL and weight (W) of fish was expressed by formula (Pauly 1983).

$W= aL^b$ ……………………………………….. (1)

Where,

W = Weight of fish in (g)

L = Total Length of fish in (cm) a= Constant (intercept)

B =The Length exponent (slope)

The values of constants "a" and "b" were predicted from a linear regression of the length and weight of fish after a logarithmic transformation of equation 1. The correlation ($r^2$), the degree of correlation between the size and weight, was calculated from the linear regression analysis.

The condition factor (CF) of the fish was analyzed by the formula Condition Factor (CF) = W/ $L^3$ * 100% (Pauly 1983)

Fish was identified using the identification keys of Schneider (1990), Dankwa et al. (1998), and an online fish identification site FishBase (www.fishbase.com).

## Water analysis

The water samples were allowed to reach room temperature before laboratory analysis. Nitrates and phosphates content was measured using a direct reading spectrophotometer based on protocols provided in the manual of HATCH 2800 and 2007 and the standard methods for examining water and wastewater (AWWA 1998). The sample blanks utilized deionized water to which reagents were added.

*Total suspended solids & total dissolved solids*

A photometric method determined the TSS level. 500 mL of the sample was blended for precisely 2 minutes at high speed, then poured into a 600 mL beaker and stirred. A 10 mL was poured into a sample cell swirled to remove any gas bubbles and suspended residue. TDS was analyzed using the gravimetric method. The sample was filtered, then the filtrate evaporated on a water bath—the waste left after evaporation was dried to a constant weight in an oven at $105^0$C. The increase in weight over that of the empty dish is the weight of the TD. The weight includes liquids, solids, and materials passed through the filter media that were not volatilized during the drying process (APHA 1998).

*Nitrates and phosphates*

Analysis of nitrates was done using the cadmium reduction method. Cadmium metal reduces nitrates to nitrite. The nitrite reacts in an acidic medium with sulphuric acid, creating an intermediate diazonium salt that couples with the acid to form an amber-colored product, the intensity of which depends on the concentration of nitrates in the sample. Ten mL of each sample was poured into a sample cell, and the contents of one NitraVer 5 nitrate reagent pillow powder were added and stopped. The sample was shaken vigorously to aid in the dissolution of the reagents and inserted into the cell reader.

Phosphates were analyzed using ascorbic acid methods. Phosphates in the sample react with molybdate in an acidic medium to produce a phosphomolybdate complex. Ascorbic acid reduces the complexion giving the molybdenum blue color, proportional in intensity to the concentration of phosphates in the sample. Ten mL of each sample was measured into an example, and then PhosVer 3 reagent pillow powder was added, corked, shaken vigorously for 30 seconds, and inserted into the cell holder.

*DO and BOD determination.*

Water samples were added with 2 mL of concentrated sulphuric acid ($H_2SO_4$) and shaken until dissolution was complete. A 50 mL solution was titrated with a standard concentration of 0.0125M sodium thiosulphate ($Na_2S_2O_3.5H_2O$) solution until a pale-yellow color was obtained. Then, 2mL of the starch indicator was added to the solution, which gave the solution blue color, and titration was continued until the solution became colorless (APHA 1998). The initial DO was measured for BOD calculation and then incubated in the dark at $20^O$C for five days. After the five days, the DO was measured again. BOD is the difference between the DO consumed by microorganisms during the incubation period and the initial DO.

*Chlorophyll a*

Water samples were filtered using filter papers. The filtrate was extracted carefully using 90% acetone. The filtrate and acetone solution was read using the spectrophotometer at wavelengths 630 nm, 647 nm, 664 nm, and 750 nm.

*Total organic carbon (TOC)*

TOC was calculated using the wet oxidation method. A 10 mL dichromate solution was mixed to 0.5g of the sediment. 20 mL of concentrated $H_2SO_4$ was mixed to the sediment, swirled, then allowed to stand for 30 minutes. 200 mL of distilled water, 10mL of orthophosphoric acid, and 2 mL of barium diphenylamine sulphonate indicator were added to the sample. The solution was then titrated with ferrous ammonium sulfate. The percentage of carbon was calculated as follows:

% Carbon = (10.0-(vN)*0.3/ W

V: volume of ferrous ammonium for titration

N: Normality of Ferrous ammonium

W: Weight of sediment in grams

*Health and safety assurance*

The following quality assurance procedures were used: (i) Sampling bottles were washed thoroughly and then rinsed with deionized water to remove all traces of soap. (ii) Blank samples were prepared using deionized water.

(iii) Water samples were equilibrated to room temperature before analysis. (iv) Personal protective equipment was used to prevent damage from chemicals.

**Data analysis**

The environmental parameters and fish communities were described using univariate and multivariate techniques. A multi-metric fish index describes the water bodies' condition, including species diversity and composition, trophic integrity, species abundance, and nursery function following Harrison and Whitfiel (2004).

*Metric selection*

A metric represents some aspect of biological assemblage structure, function, or another community component that can be measured (USEPA 2000). Community structure and function refers to biological measures such as species dominance, species diversity, faunal abundance and biomass, presence of indicator species, and trophic function or structure (Krebbs 1985; Elliot et al. 2002). The metrics were selected based on work done by Harrison and Whitfield (2004). A total of 10 parameters were chosen from the 14 metrics because of the lack of information on the feeding habits and fisheries of the study sites.

*Species diversity and composition*

Species diversity is an attribute of faunal communities used in most biological, environmental health assessments. It tends to be reduced in stressed biotic communities (Odum,1983). The total number of taxa (metric 1) showed the most straightforward measure of species diversity. The presence of rare or threatened species was selected because their existence imparts additional conservation value to the ecosystem. Because rare species are fragile, they may become endangered or even locally extinct with higher anthropogenic stress (Costello et al., 2002). The presence of exotic or introduced species (metric 3) provides a potential threat to naturally occurring taxa through competitive exclusion and predation. They also serve as a direct measure of human interference.

*Species abundance*

The relative abundance of species (metrics 5) in water about a reference from fish community results in a quantitative assessment. Environmental stress generally changes the relative abundance from „diverse‟ communities, which consist of many species in relatively low proportions, to "simple" assemblages dominated by a few species (Odum 1983; Fausch et al. 1990). The concept of dominance is linked to this idea; the number of taxa required to make up 90% of the total abundance (metric 6) represents a simple measure of dominance.

*Nursery functions*

Lagoons are important nursery sites for marine species and serve as essential habitats for resident taxa (Wallace et al. 1984; Whitefield 1998). The number of estuarine or resident taxa (metrics 7) identified two groups of fishes that are most likely susceptible to lagoon degradation by characteristics of their strong dependency or association with these environments. The number of estuarine-dependent marine taxa (metric 8) showed how well an estuary fulfills its role as a nursery habitat. Undisturbed water is expected to maintain a relatively balanced fish community consisting of representatives of both groups. An extremely low numerical abundance or unexpected high dominance by one particular group often implies an imbalance or disturbance within a system (Begg 1984a). The relatively high number of both estuarine-dependent marine species (metric 10) and estuarine resident species (metric 9) are complementary measures to quantitatively assess estuarine habitat quality and nursery function for these two major groups.

*Trophic integrity*

Lagoons are among the most productive ecosystems on the earth (Odum 1983; McHugh 1985). They provide abundant food resources for filter and deposit-feeding invertebrate prey and various fish species, including detritivorous, zooplankivorous, herbivorous, benthic invertebrate feeders, and piscivorous taxa, by acting as detritus traps (Whitfield 1998). The condition factor and chlorophyll-a concentration were used to measure trophic integrity for this study.

*Univariate analysis*

The community structure was analyzed using abundance and diversity indices, e.g., Shannon-Wiener diversity index (H'), Margalef's species richness (d), and Pielou's evenness index. (J) were counted. The Shannon-Wiener diversity index is a combination of richness and evenness species measurement. A minimum value of 0 for this index shows a community with single species. It increases as species' evenness and richness increase (Hamillton 2005).

The Shannon-Wiener diversity index (H') was calculated as

$$H' = -\sum P_i (\log p_i)$$

Where p = the proportion of the total count coming from the $_i$th species, the index was calculated using the natural logarithmic base ($\log_e$). The Shannon Diversity Index usually falls between 1.5-3.5 and rarely surpasses 4.5 (Margalef 1972).

Pielou's evenness calculates the relative abundance of species in the community, the number of individuals, biomass, and how it is distributed among the other species (Ludwig and Reynolds 1988).

Species Evenness as Pielou‟s index (J) was calculated as

$$J = H' \text{ (observed)}/H'_{max}$$

Where H' is the Shannon-Wiener diversity and $H'_{max}$ is the maximum possible diversity achievable if all species were equally abundant.

Margalef"s richness is an expression of the number of species that constitute the community. Species Richness as Margalef"s index (d) was calculated as

D = (S-1)/log N Where
S = total number of species
N = total number of individuals

These diversity indices were calculated using the PRIMER v.6.0 software package (Plymouth Routine in Marine Ecological Research) (Carr 1996).

Diversity indices compare the statistical associations of organisms and allow populations; they are generally a more reliable indicator of environmental health or stress than are individual indicator species (Cain and Dean 1976). Abundance and distribution graphs were generated using Microsoft Office Excel (v.2010).

*Multivariate Analysis*

*Bray-Curtis similarity index*

Multivariate analysis was done using the PRIMER v.6.0 software package (Plymouth Routine at Marine Ecological Research) (Carr 1996). The similarity matrix for the classification among the Laloi and Oyobi was analyzed as Bray-Curtis's similarity indices (Bray and Curtis 1957). The results were then described in the form of a dendrogram. The Similarity Coefficients are based on the presence or absence of data. They may vary from 0 when the pair of sampling units are entirely different to 1 when sampling units are identical. The Bray-Curtis similarity indices allow all species to contribute to the definition of similarity while retaining some information on the prevalence of a species, ensuring that the widespread species are usually given higher weight than the rare ones.

A $4^{th}$ root transformation was applied to fish data to keep information regarding relative abundance and minimize differences in scale among variables in the standardization of the data on species diversity (Clarke 1993; Anderson and Underwood 1997). The similarity indices of species composition among stations do not consider the double absences usually found in the data. Its calculation is also unaffected by the difference in sample size (Clarke and Green 1988).

*Metric calculation.*

The metrics score assigned 1, 3, or 5. High scores indicate an unpolluted site not suffering from stress, while low scores reflect a polluted site under pressure. The scores are summed to point out sites ratings which are interpreted as follows: 0-15: Critical and no fish, 16-20: the site is very poor, 22-38: the site is rated poor, 40-44: the site is rated moderately stressed, 46-62: the site is rated excellent and 64-68: the site is rated very good.

## RESULTS AND DISCUSSION

**Fish composition and abundance**

This study identified 19 species consisting of 17 finishes and two shellfishes. The finfishes are classified into 14 families and 17 genera, while the shellfish belong to 2 families and two genera. *Mugil cephalus* was the dominant fish species for the Laloi Lagoon, and *Sarotherodon melanotheron* was majorly found at Laloi. *Callinectes latimanus* and *Penaeus* sp. were the only shellfishes found during the study period from Laloi and Oyibi, respectively. The total number of individuals recorded was 532 (Oyibi), and Laloi was 437. The number of species recorded at Oyibi were 15 fin fishes and two shellfishes. A lower number of species was identified at Laloi, comprising 12 fin-fishes and a shellfish (Table 1). Species encountered at Oyibi was consisted of *S. melanotheron* making up 56% of the total species, followed by *Tilapia guineensis* (4%), *Lutjanus fulgens* (6%), *Mugil cephalus* (7%), and *Caranx hippos* (17%). Species found at Laloi was made up of *M. cephalus* (41%) followed by *S. melanotheron* (20%), *Caranx hippos* (3%), *L. fulgens* (16%), *C. latimanus* (5%), *Eucinostomus melanopterus* (5%), and *T. guineensis* (3%) (Figure 4).

**Metric selection**

*Nursey functions*

The number of adventitious marine species found in the Oyibi lagoon was seven species, and six were found in Laloi. The highest number of estuarine resident species recorded was 5 in Oyobi and 3 in Laloi. The number of freshwater species found at both locations was 2 (Figure 3).

*Trophic Integrity*

Chlorophyll-a concentrations were higher at Oyibi than Laloi. For the Oyibi lagoon, the highest chlorophyll-a level was 0.20 mg/L recorded in the riverine end in April at high tide, and the least value recorded was 0.00028 mg/L in May at the middle portion. For the Laloi lagoon, the highest chlorophyll-a level was 0.015 mg/L recorded in the riverine end in March at low tide, and the least value recorded was 0.0010 mg/L in April at the seaward end at low tide (Figure 5).

*Metric calculation*

From the metrics assigned, Laloi scored 34, indicating a poor site rating, suggesting that it was under severe stress, and Oyibi scored 40, stating a moderate site rating, implying that it was under mild stress (Table 2).

**Species diversity**

The Shannon Wiener Index (H") calculated for Oyibi shows the highest value of 1.64 and the least value of 0.42 recorded at Oyibi were in April and February, respectively. Laloi recorded the highest amount of 1.51 (May) and the least amount of 1.24 (February). The average for Laloi was 1.81±0.53 (Figure 6).

Pielou"s species evenness index (J) at Oyibi had the least value of 0.36 in May and the highest amount of 0. 71 in April. The average value recorded at Oyibi was 0.57±0.13. For Laloi, the highest value was recorded in April and the least amount recorded in February. The average recorded for Laloi was 0.67±0.10 (Figure 7).

The Margalef"s species richness index (d) recorded for Oyibi had the highest recorded value in March and the least in February. The mean value recorded for Oyibi during the study was 2.39±0.63. The highest amount of the species richness for Laloi was recorded in February, and the least amount was recorded in April. The mean value recorded for Laloi during the entire study was 2.30±0.28 (Figure 8). The species diversity indices for the analysis are represented in Figure 8.

**Physico-chemical parameters**

BOD recorded in the Oyibi lagoon fell between 0. 20-2.8mg/L. DO values recorded in the Oyibi lagoon ranged between 3.3-6.5 mg/L with an average of 4.7±0.97 mg/L for the Oyibi lagoon. DO values were highest at high tide than low tide. BOD observed in the Laloi lagoon ranged between 0.1-4.5 mg/L with an average of 1.80±1.04 mg/L for the entire study. DO values recorded in the Laloi lagoon ranged between 3.0-7.5 mg/L (Figure 10-11).

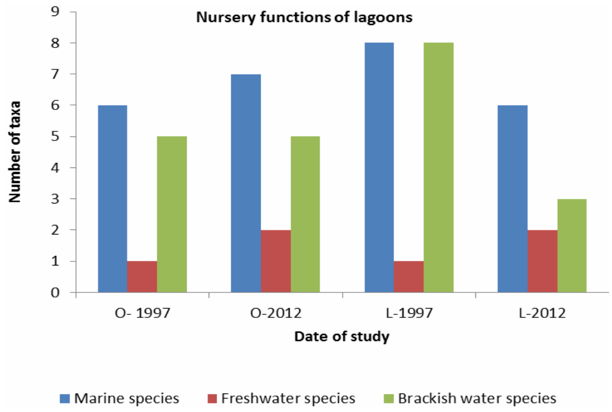
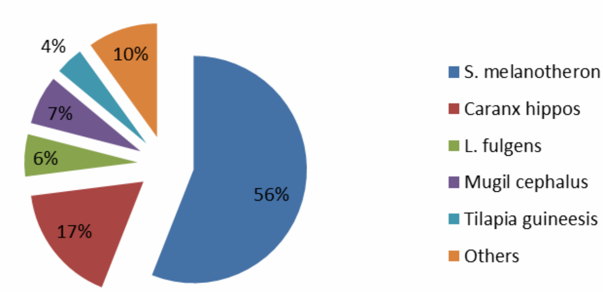
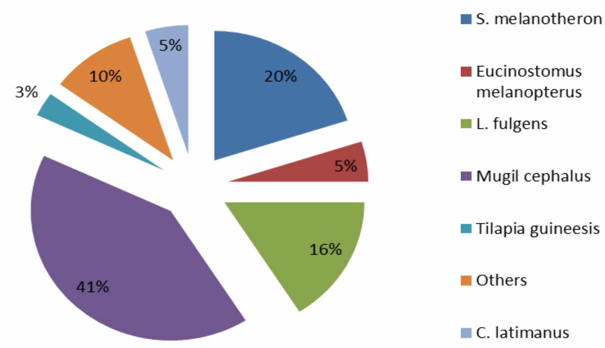



**Figure 3.** Comparison of the number of taxa of the study locations in 1997 and 2012. Note: O: Oyibi, L: Laloi




A




B

**Figure 4. a and b** Relative abundance of species found in the (A) Oyibi and (B) Laloi lagoons, Ghana

**Table 1.** Fish species identified in the Oyibi and Laloi lagoons, Ghana

| Family | Species | Common name | Laloi lagoon | Oyibi lagoon | % Composition | Category |
|---|---|---|---|---|---|---|
| Bothiade | *Syacium microrum* | Rock sole | + | + | 0.9 | MA |
| Carangidae | *Caranx hippos* | Horse mackerel | + | + | 10 | MA |
| Cichlidae | *Sarotherodon melanotheron* | Black-chinned tilapia | + | + | 39 | ER |
| | *Tilapia guineensis* | Guinean tilapia | + | + | 4 | FW |
| | *Hemichromis fasciatus* | Banded jewelfish | + | | 0.1 | FW |
| | *Oreochromis niloticus* | Nile tilapia | | + | 0.1 | FW |
| Clupeidae | *Ethamalosa fimbriata* | Bonga shad | | + | 0.8 | MA |
| Cyprinodontidae | *Epiplatys sexfasciatus* | Six bar panchax | | + | 0.3 | FW |
| Eleotridae | *Eleotris vittata* | Eleotrid | + | + | 0.6 | ER |
| Elopeidae | *Elops lacerta* | Ten pounders | | + | 0.2 | ER |
| Gerreidae | *Eucinostomus melanopterus* | Flagfin mojarra | + | + | 3 | MA |
| Gobidae | *Chonophorus lateristriga* | West african freshwater goby | | + | 0.2 | FW |
| Lutjanidae | *Lutjanus goreensis* | Goreen snapper | | + | 1 | MS |
| | *Lutjanus fulgens* | Golden african snapper | + | | 11 | MS |
| Muglidae | *Mugil cephalus* | Flathead grey mullet | + | | 22 | ER |
| | *Mugil curema* | White mullet | + | + | 0.7 | ER |
| Penaidae | *Peneaus sp* | Shrimp | | + | 1 | FW |
| Portunidae | *Callinectes latimanus* | Blue-legged swimming crab | + | + | 3 | ER |
| Serranidae | *Epinephelus aeneus* | Common white grouper | + | | 0.8 | MA |
| Lethrinidae | *Lethrinus atlanticus* | Atlantic emperor | + | | 0.1 | MA |
| Scaridae | *Callyodon hoefleri* | Parrot wrasse | + | | 0.5 | MA |

Note: MA: Marine species, FW: Freshwater species, ER: Estuarine species, X: present

**Table 2**. Estuarine fish community index calculation for the lagoons

| Estuarine Fish Community Index Metric | Score | |
|---|---|---|
| | Oyibi | Laloi |
| **Species diversity and composition** | | |
| 1. Total number of taxa | 3 | 3 |
| 2. Species composition | 3 | 3 |
| 3. Exotic or introduced species | 3 | 3 |
| 4. Rare or threatened species | 3 | 3 |
| **Species abundance** | | |
| 5. Species relative abundance | 3 | 3 |
| 6. Number of species that make up 90% of the abundance | 3 | 3 |
| **Nursery function** | | |
| 7. Number of estuarine resident taxa | 5 | 3 |
| 8. Number of estuarine-dependent marine taxa | 1 | 1 |
| 9. The relative abundance of estuarine resident taxa | 5 | 5 |
| 10. The relative abundance of estuarine-dependent marine taxa | 5 | 5 |
| **Trophic Integrity** | | |
| 11. Condition factor | 3 | 1 |
| 12. Chlorophyll a | 3 | 1 |
| **Total** | **40** | **34** |

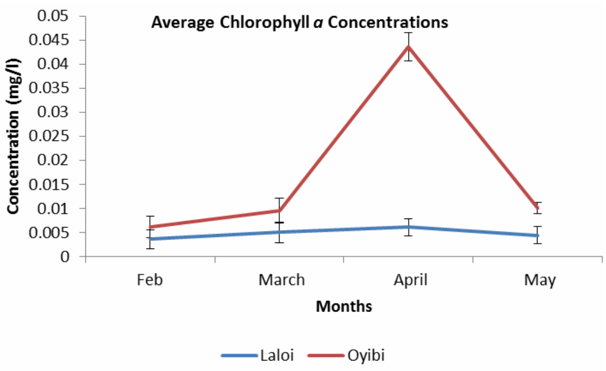



**Figure 5.** Average Chlorophyll an in the Oyibi and Laloi lagoons. (vertical bars =±SD)

TSS recorded for the Oyibi lagoon fell between 10-105 mg/L with an average value of 31.1±21.90 mg/L for the entire study period. The average TSS values recorded for Oyibi lagoon during high tides was 31.1±19.70 mg/L and during low tides was 31.1±24.79 mg/L. TSS recorded for the Laloi lagoon ranged between 5.0-80mg/L with an average value of 19.7±14.81 mg/L for the entire study. The mean for the Laloi lagoon during high and low tide during the study as a whole was 23.3±19.94 mg/L and 16±5.64 mg/L, respectively. The physicochemical parameters measurement is represented in Figures 12.

TDS recorded for the Oyibi lagoon fell between 0.15-37.0 mg/L with an average of 11.9±11.74 mg/L for the entire study. The lagoon's mean TDS values were 10.7±10.67 mg/L during high tides, and low tides were 13.1±13.08 mg/L. TDS observed for the Laloi lagoon ranged between 15.0-152.0 mg/L. The average TDS values observed for the Laloi lagoon during high and low tides were 54.7±41.59 mg/L and 38.7±20.72 mg/L, respectively. TDS was highest at Laloi than Oyibi (Figure 13).

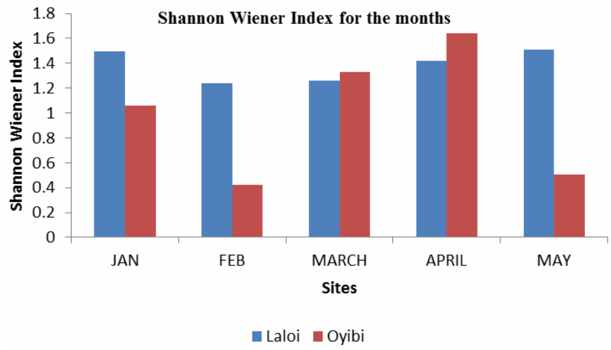



**Figure 6.** Shannon Wiener Index for the Laloi and Oyibi lagoons

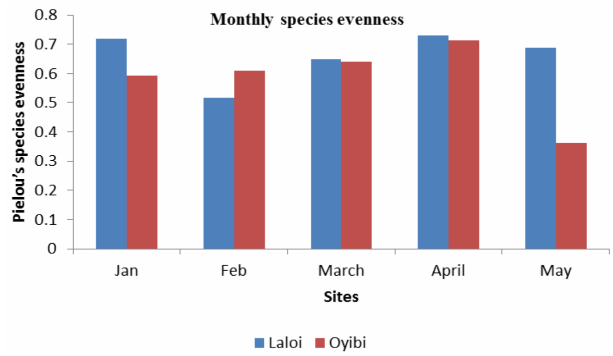



**Figure 7**. Pielou"s species evenness for the Laloi and Oyibi lagoons

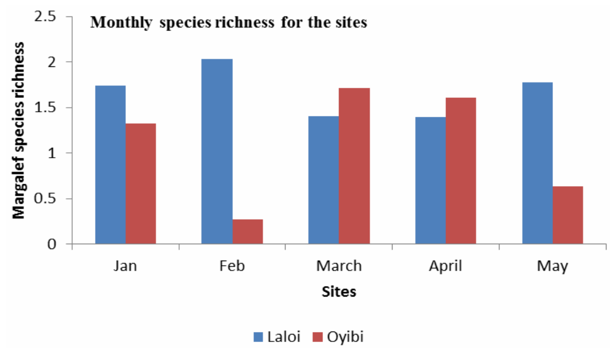



**Figure 8**. Margalef species richness for the Laloi and Oyibi lagoons

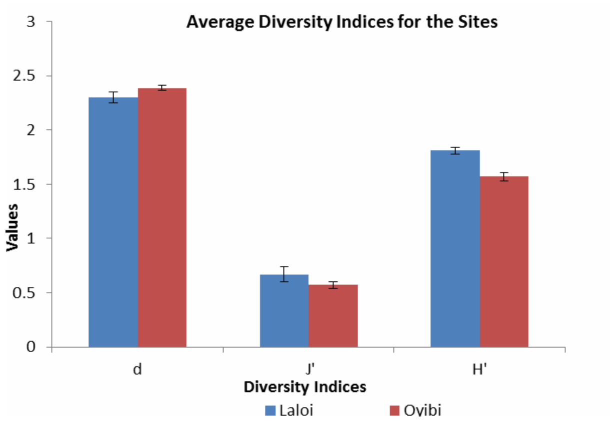



**Figure 9**. Average Diversity indices for the Oyibi and Laloi lagoons. (vertical bars =±SD). Note: d: Magarlef's species richness index, J': Pielou's species evenness, H': Shannon Wiener Index

The temperature recorded in the Oyibi lagoon ranged between 22.2°C and 32.4°C with an average of 27.7±0.60°C for the entire study. Temperatures were high at the riverine end than the middle and seaward end at Oyibi. The temperature recorded in the Laloi lagoon ranged between 21.3-33.6°C, with an average of 26.7±3.17°C for the study period. The average temperature at the Laloi lagoon during both high tide and low tides were 27.4±3.36 °C and 26.1±3.03°C, respectively. Average temperatures measured for these lagoon sections were 27.1±3.77°C, 26.8±3.53 °C, and 26.2±2.49 °C, respectively (Figure 14).

Salinity observed in the Oyibi lagoon ranged between $5^{0}/_{00}$ and $40^{0}/_{00}$ with an average of 22. $0±7.46^{0}/_{00}$. The seaward end at Oyibi recorded the least value of $7^{0}/_{00}$ in March during low tide. The mean salinity values for Oyibi during the high tides was 20. 6±6.08 $^{0}/_{00}$ and low tides were $23.5±6.08^{0}/_{00}$. Salinity recorded in the Laloi lagoon ranged from 20.0 $^{0}/_{00}$ to $40^{0}/_{00}$ with an average of 37. $0±3.40^{0}/_{00}$ during the entire study period. The mean salinity values for Laloi during the high and low tides were $37.8±1.47^{0}/_{00}$ and $36.2±4.54^{0}/_{00}$, respectively (Figure 15).

The pH recorded in this study ranged between 7.0-9.0 for the Oyibi lagoon, with an average of 7.97±0.40. The average pH values during high and low tides were 8.07±0.39 and 8.02±0.43, respectively. The pH recorded in the Laloi lagoon ranged between 8.0-8.6, with an average of 8.60±0.25. The average pH values for the Laloi lagoon during high tide and low tide were 8.50±0.25 and 8.60±0.26, respectively. Mean pH values recorded for these lagoon sections were 8.60±0.22, 8.6±0.17, and 8.4±0.31, respectively (Figure 16).

Nitrates levels observed at the Laloi lagoon ranged between 0.30-5.2 mg/L with an average value of 1.77±1.24 mg/L. Nitrate levels observed for the Oyibi lagoon ranged between 0.20-9.9 mg/L with an average value of 3.25±4.59 mg/L. Phosphate levels observed for the Laloi lagoon ranged between 0.07-1.98 mg/L with an average value of 0.61±0.35 mg/L. Phosphate levels observed for the Oyibi lagoon ranged between 0.15-1.12 mg/L with an average value of 0.61±0.24 mg/L. The results for the nutrients are shown in Figures 17-24.

## Length-weight relationship

From the length-weight relationship, the condition factor of *Sarotherodon melanotheron* at Oyibi lagoon fell in the range between 1.50 and 2.40, with an average value of 2.07±0.20 for the entire study period. The condition factor observed at Laloi lagoon was measured between 1.40-2.0, with an average value of 1.72±0.12 (Figure 25).

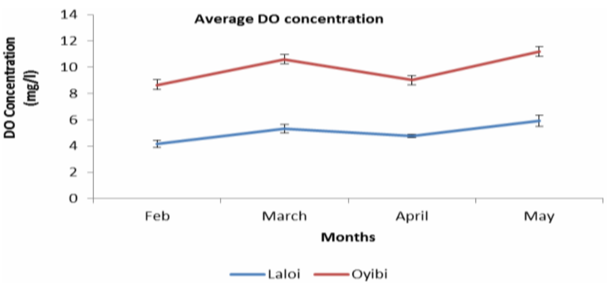



**Figure 10.** Average DO concentrations in the Oyibi and Laloi lagoons. (vertical bars =±SD)

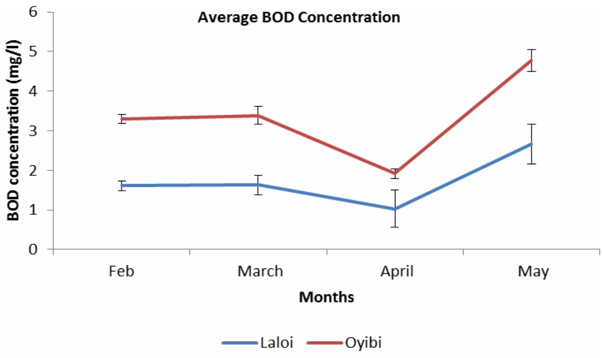



**Figure 11.** Average BOD concentrations in the Oyibi and Laloi lagoons. (vertical bars =±SD)

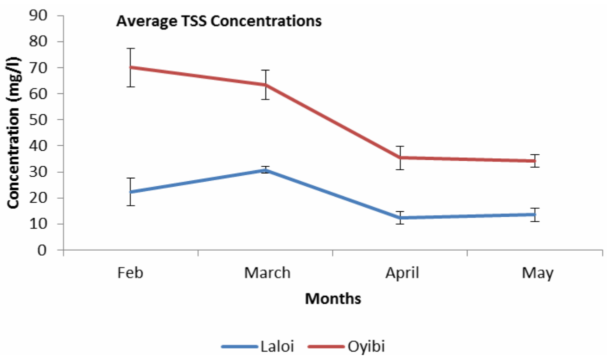



**Figure 12.** Average TSS concentrations in the Oyibi and Laloi lagoons. (vertical bars =±SD)

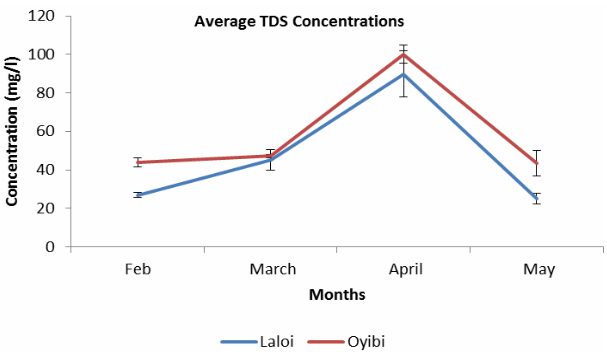



**Figure 13.** Average TDS concentrations in the Oyibi and Laloi lagoons. (vertical bars =±SD)

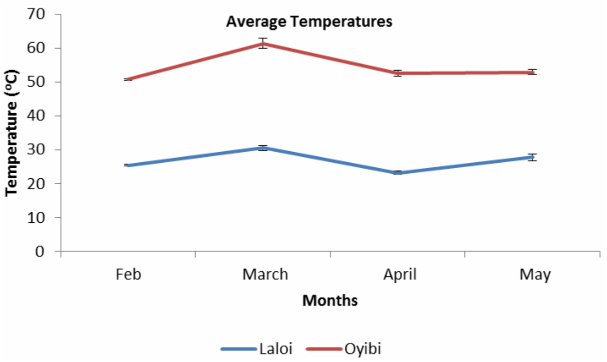



**Figure 14.** Average temperatures in the Oyibi and Laloi lagoons. (Vertical bars =±SD)

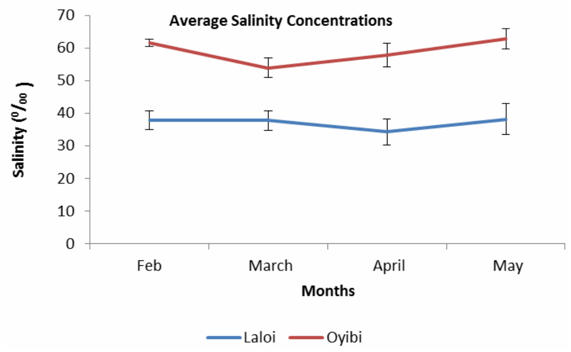



**Figure 15.** Average salinity concentrations in the Oyibi and Laloi lagoons. (Vertical bars =±SD)

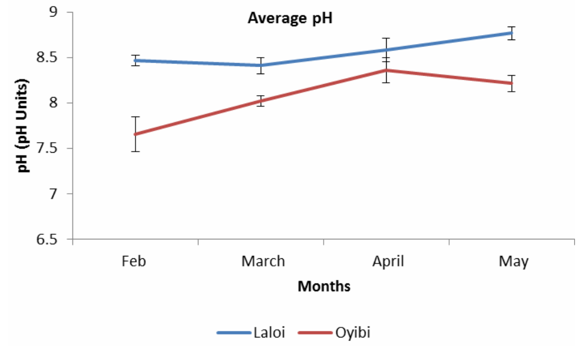
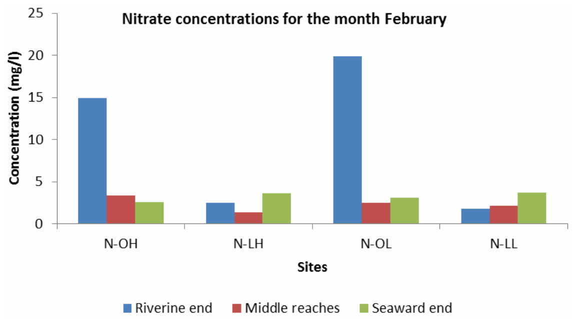
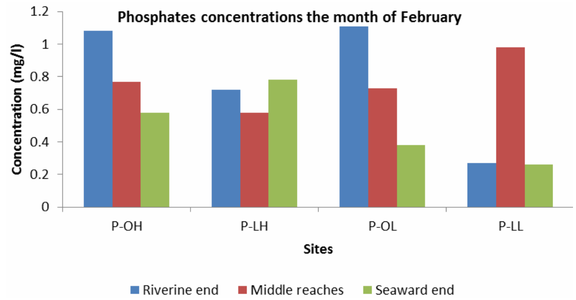



**Figure 16.** Average pH in the Oyibi and Laloi lagoons. (vertical bars =±SD)

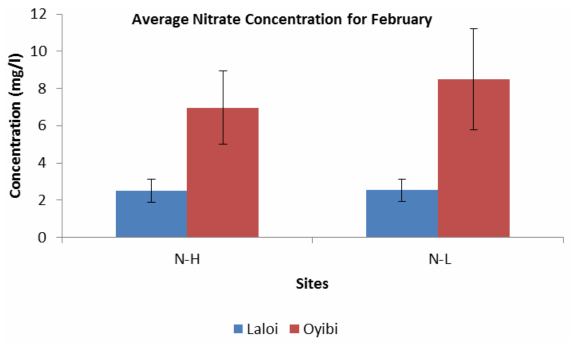



**A**

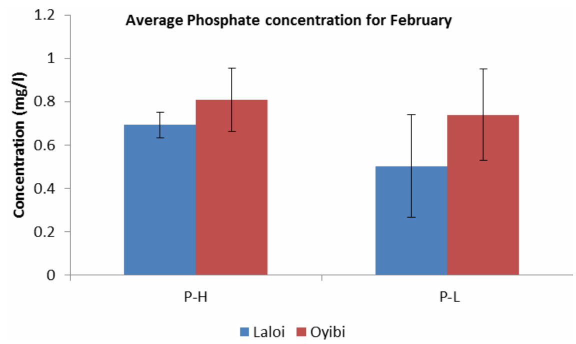



**B**

**Figure 17. A-B.** Nitrates and Phosphates concentrations in the Oyibi and Laloi lagoons for February. Note: N: Nitrates. P: Phosphates L: Laloi. O: Oyibi. H: High tide. L: Low tide.

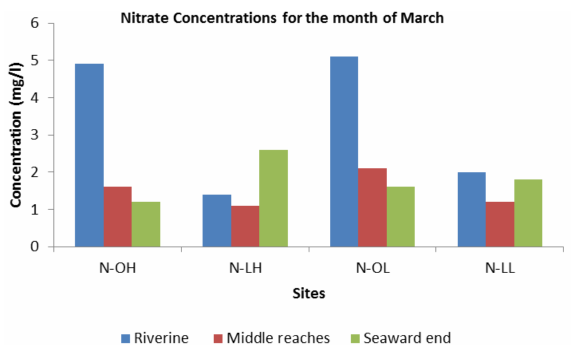



**A**

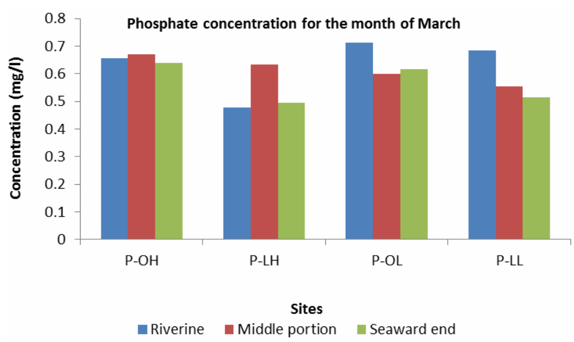



**B**

**Figure 18. A-B.** Average Nitrates and Phosphate concentrations in the Oyibi and Laloi lagoons for February. (vertical bars =±SD). Note: Phosphates. N: Nitrates H: High tide. L: Low tide

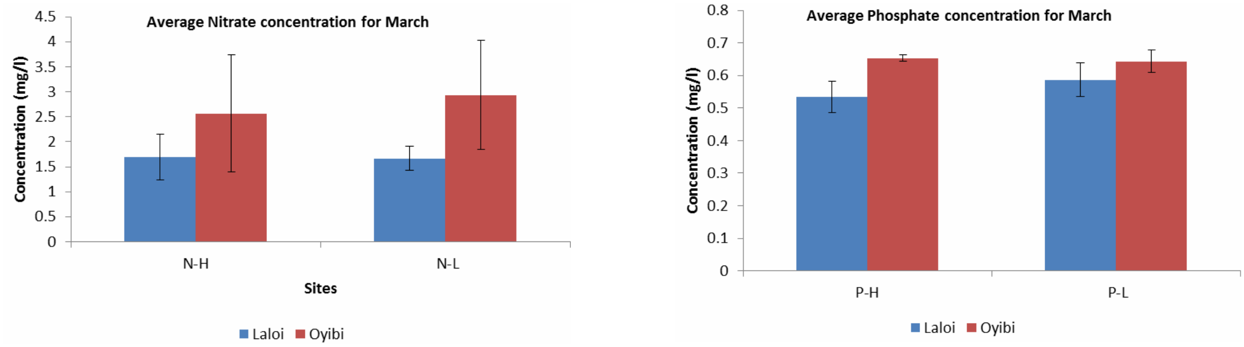



**A**



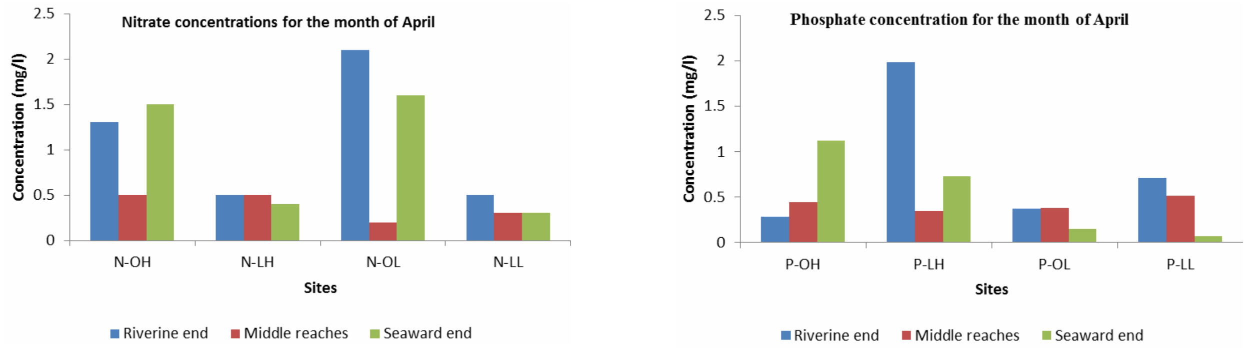

**B**

**Figure 19. A-B.** Nitrates and Phosphates concentrations in the Oyibi and Llaloi lagoons for March. Note: N: Nitrates. P: Phosphates L: Laloi. O: Oyibi. H: High tide. L: Low tide



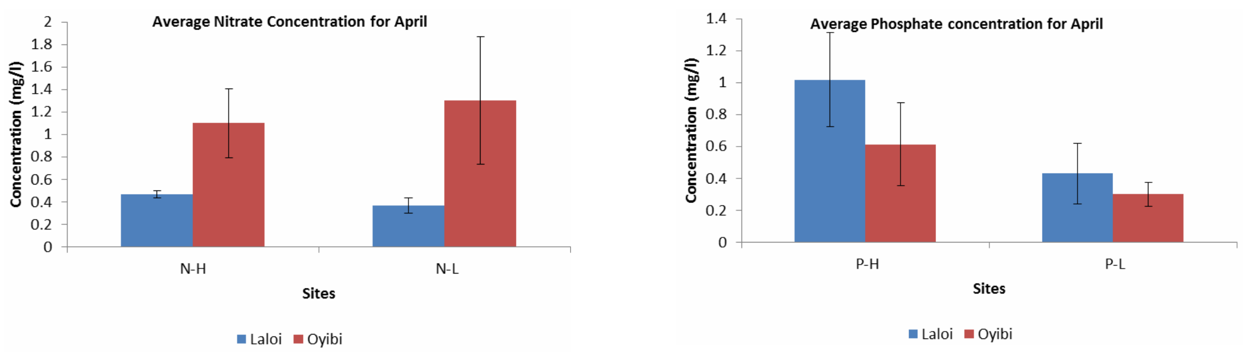

A B

**Figure 20. A-B.** Average Nitrates and Phosphate concentrations in the Oyibi and Laloi lagoons for March. (vertical bars =±SD). Note: P: Phosphates. N: Nitrates H: High tide. L: Low tide




A B

**Figure 21. A-B.** Nitrates and Phosphates concentrations in the Oyibi and Laloi lagoons for April. Note: N: Nitrates. P: Phosphates L: Laloi. O: Oyibi. H: High tide. L: Low tide




A B

**Figure 22. A-B.** The average concentration of nitrates and phosphate in the Oyibi and Laloi lagoons in April (vertical bars =±SD). Note: P: Phosphates. N: Nitrates H: High tide. L: Low tide

**Similarity analysis**

A Bray-Curtis similarity analysis of species abundance data by applying group averaged linking of Bray-Curtis's similarities calculated on standardized fourth root transformed data was employed to show similarities in sites sample (Bray & Curtis,1957; Cormack,1971; Everitt,1980). The sites that exhibit species composition and abundance similarities will cluster close together. Figures 26 demonstrated the dendrogram for hierarchical clustering of the similarities between months for the locations. Most of the clustering existed between the 35-70 % Bray-Curtis's similarity scale for the months, while clustering was observed more than 60 % scale for the entire study. The dendrogram shows the similarity in species composition every month and the overall similarity in species composition between the sites.

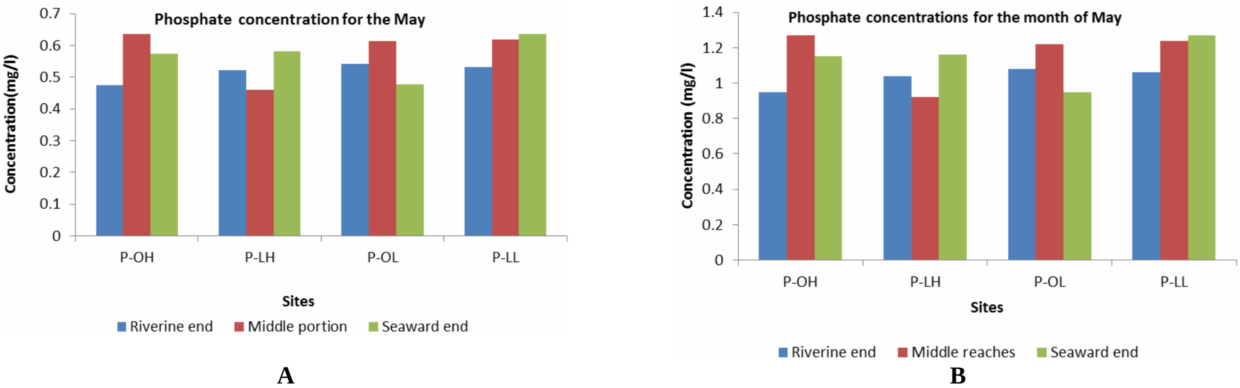



**Figure 23. A-B.** Nitrates and Phosphates concentrations in the Oyibi and Laloi lagoons in May. Note: N: Nitrates. P: Phosphates L: Laloi. O: Oyibi. H: High tide. L: Low tide

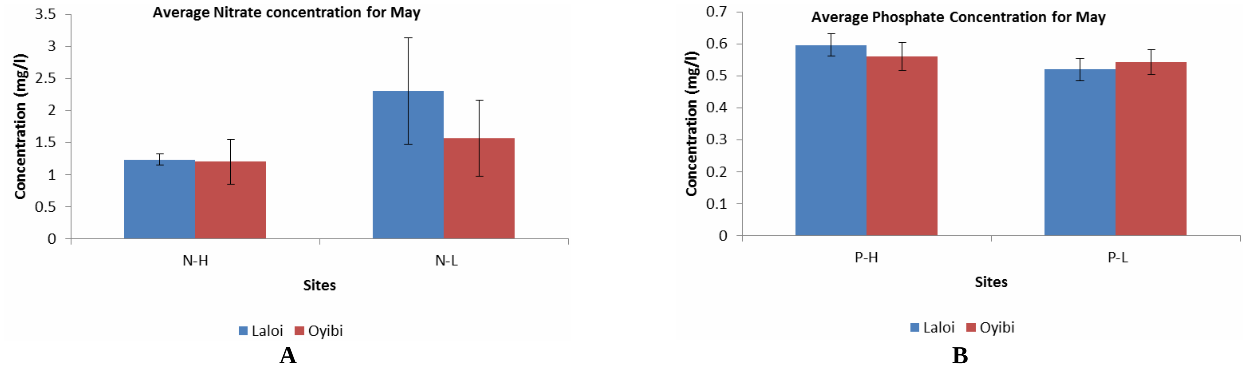



**Figure 24. A-B.** Average Nitrates and Phosphate concentrations in the Oyibi and Laloi lagoons in May (vertical bars =±SD). Note: P: Phosphates. N: Nitrates H: High tide. L: Low tide

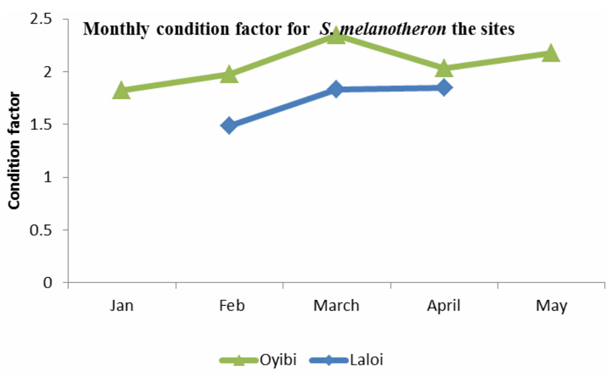



**Figure 25.** Condition Factor for *S. melanotheron* in the Oyibi and Laloi lagoons for the entire study period

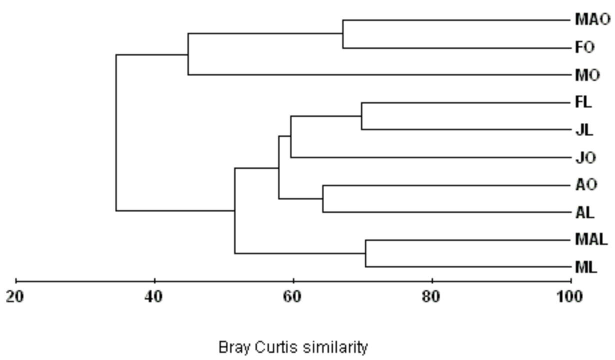



**Figure 26.** Bray-Curtis's similarity between sampling months**.** Note: J: January; F: February; M: March; A: April; MA: May, O: Oyibi, and L: Laloi

**Total organic carbon**

Total organic carbon recorded for the Oyibi lagoon ranged between 15-20%, with a mean value of 16.92±0.23%. Total organic carbon was higher at Oyibi than at Laloi. The seaward end showed the highest percentage of organic carbon (17.18%), and the least value of 16.74% was recorded in the middle portion for Oyibi. Total organic carbon observed at Laloi lagoon ranged between 10-13%, with an average value of 12.24±1.68%. For the Laloi lagoon, the highest percentage of organic carbon was 13.73% at the seaward end, and the least value of 10.42% was found in the middle portion (Figure 27).

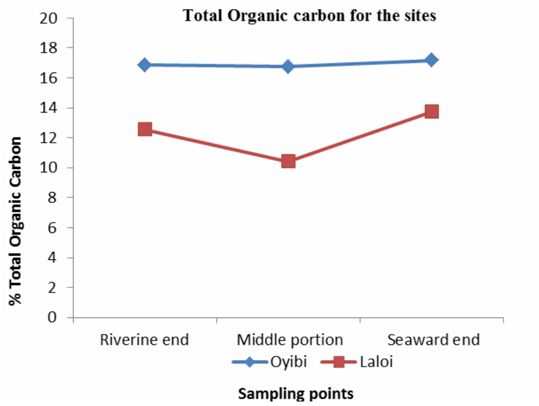



**Figure 27.** Total Organic carbon for the lagoons during the study period

## Discussion

*Species composition and abundance*

The total number of species observed consisted of 16 finishes and two shellfishes. *Sarotherodon melanotheron* represents an essential part of lagoon fisheries in Ghana (Eyeson 1983; Blay and Ameyaw 1993; Koranteng 1995) and make up about 80%-90% of all fishes caught in lagoons (Pauly 1975, 1976; Denyoh 1982). The type of species encountered was close to the species that exist in almost all coastal lagoons in Ghana as described by (Dankwa and Entsua-Mensah 1996; Koranteng et al. 1998; Entsua-Mensah 2003). The *Callinectes latimanus* and *Peneaus* sp were the only shellfish encountered during the study.

The species encountered can be classified into three categories based on their salinity tolerance; marine stenohaline species, freshwater stenohaline species, and euryhaline species (Pauly 1975; Welcomme 1979; Pauly and Yanez-Arancibia, (1994). The freshwater stenohaline species found were *O. niloticus, T. zilli, and H. fasciatus.* The euryhaline species found were *S. melanotheron* and *Elops lacerta.* The typical marine stenohaline species encountered were *Mugil cephalus, Caranx hippos, Lutjanus fulgens, Lutjans goreensis, Syacium microrum, and Epinephelus aeneus.*

An example of the genuinely resident lagoon species found was *S. melanotheron*. *Caranx hippos* and *Ethmalosa fimbriata* were the only marine seasonal migrant species found. The adventitious marine species found were Syacium *microrum, Lethrinus atlanticus,* and *Callyodon hoefleri; some* diadromaous species found were *Eucinostomus melanopterus* and *Elops lacerta.* The freshwater species found were *Hemichromis fasciatus, Oreochromis niloticus,* and *Epiplatys sexfasciatus.*

Oyibi recorded the highest number of species while Laloi had the least amounts of species. Of the 29 shell and finfish species, 15 were recorded at Oyibi and 12 at Laloi. There has been a significant alteration in the number of species as compared to the result of baseline studies (Dankwa et al., 1997). Dankwa *et al.* (1997) reported the number of species at Oyibi to be 12 and that of Laloi to be 15. There has been an increasing number of species in Oyibi (from 12 to 16) and a reduced number of species at Laloi from 17 to 14. He observed that both closed and opened lagoons with extensive mangrove cover had high species diversity. These lagoons were Kpani (28 species), Domini (24 species), Oyibi (12 species), Kpeshie (15), and Brenu and Kako (12 species). This result ascertains that mangroves provide feeding and breeding sites for various fish species. The practical implementation of traditional beliefs in management and conservation might contribute to the high mangrove forest at Oyibi. By comparing the size composition of *S. melanotheron* and *T. fuscatus* in Djange and Sakumo lagoons, a group clearly showed that traditional beliefs and associated taboos could be valuable tools for conservation if they are adhered to (Ntiamoah-Baidu 1991).

The difference in species abundance and composition in both lagoons can be due to the variation of physicochemical parameters such as pH, salinity, temperature, environmental characteristics of the habitats, the size of local human populations, effort, the type of fishing gear, and the associated fishing pressure. *S. melanotheron* was confined more to the upper reaches of the Oyibi lagoon and in Laloi the upper and middle reaches. The marine, primarily stenohaline, lived in the lower ranges when the tides came in.

The tolerance and preference against salinity can influence the abundance and distribution of fish species. In 1978, Yanez-Arancibia, working in Mexican estuarine lagoons, reported significant declines in fish species diversity, densities, and biomass when the salinities rose above $34^0/_{00}$ or declined below $15^0/_{00}$. Wallace (1975) said that species diversity and abundance in the estuarine lake St. Lucia in South Africa declined during hypersaline periods. Thiel *et al.* (1995) also observed that decreased salinity upstream would be followed by decreased species diversity. Salinity recorded between the two lagoons showed no significant difference and had no impact on the fisheries of the range ~ $34.5^0/_{00}$ and $35.5^0/_{00}$ (Anang 1979). The higher salinity towards the eastern coast of Ghana is due to variation in rainfall patterns (Entsua-Mensah 2003). At the seaward end of the Oyibi lagoon, salinity was lowest due to dilution from the Ayensu River.

The pH recorded in this study was optimal for the growth and survival of most aquatic species (Addy et al., 2004). The highest DO at the seaward end is due to mixing and turbulence by the sea. The TDS values fell in the range which could not be harmful to fisheries (below the background values of 50.0-1000 mg/L. The TSS values were above the background levels of 0.5-10.0 mg/L, affecting primary production by attenuating light penetration. The decrease in light penetration through the water column could restrict the rate at which periphyton, emergent, and submerged macrophytes can assimilate the energy through photosynthesis, directly impacting primary consumers (Bilotta and Brazier 2008).

Land use practices around these lagoons may contribute to the increased nutrient concentrations. The primary land-use methods along these lagoons are salt mining, farming, harvesting of mangroves for firewood, and housing construction. The high concentration of nitrates and phosphates in the two lagoons indicates increased human activities in the catchment region and the increased loading from the rivers into the lagoon. High concentration of nitrate at the riverine end of Oyibi lagoon might be caused by agricultural activities as well as other domestic activities and has been described as mildly eutrophic using the Carlson's TSI scale of 56) and the seaward being moderately clear with a TSI score of 42 (Ansa-Asare et al. 2007). It can also be associated with their proximity to population centers and their historical importance as sources of protein and as an area for disposal of human waste (Kennish 2002).

Human population density alone has also been reported to account for a significant variation in riverine transport of nitrogen and phosphorus (Howarth 1988; Caraco 1995) from a wide variety of large watersheds. The high concentration of phosphates can be due to industrial and domestic effluents entering the lagoon from the surrounding area. This may not favor the development of fishes in the lagoons because, at a certain threshold of phosphates, phytoplankton diversity is known to decline; thus, affecting primary productivity (Biney 1990).

Biological oxygen demand (BOD) has been employed to measure the number of organic materials in aquatic solutions with maximum values due to high organic matter. Lagoon with BOD concentration below 4 mg/L is considered unpolluted, and those over 12 mg/L as grossly polluted (Biney 1982). The high BOD concentrations measured at the riverine sections of Oyobi and Laloi lagoons can be attached to the increased human activities at these sections. The smallest value of BOD recorded in April in the Laloi lagoon was due to the decrease in temperatures. Low temperatures tend to retard the reproduction rate of organisms that break down organic matter. For the whole study period, high levels of BOD were recorded at Laloi than Oyibi. The high concentration of BOD in the Laloi lagoon might be caused by the location of the Laloi, which is in an urban area, and hence increase human pressure on its resources. The poor water quality is a strong indication of pollution.

There is a positive relationship between primary productivity and fish production (Boyd 1990). Chlorophyll-*a* concentrations indicate the trophic status, maximum photosynthetic rate, and water quality. Here, the seaward end of both lagoons recorded the least concentrations of chlorophyll-*a*. This result can be attached to the tides or influx of seawater. Tidal mixing reduces the residence time of algae in the photic zone and makes up fine sediment to resuspend, reducing the amount of light available for photosynthesis (Brando et al., 2012). Flushing dilutes nutrients and moves them away from plants, making them less available (Monbet 1992). It can be said that higher chlorophyll-*a* concentration increases species abundance and biomass. Therefore, the increased number of species and biomass from the Oyibi lagoon can be attributed to high chlorophyll-*a* concentrations recorded in the lagoon.

*Metric selection*

The number of resident species in Laloi reduced from eight to three species. This phenomenon supports the assumption that environmental stress caused by pollution decreases the number of species (Harrison and Whitfield 2004). The decline in brackish water species in Laloi might be due to the increased environmental stress. This supports the hypothesis that the relative abundance of species decreases in disturbed systems (Harrison and Whitfield 2004). In the Oyibi lagoon, the number of estuarine-dependent marine taxa identified showed a vast improvement over time, while Laloi decreased. The assumption is that disturbed systems have simple communities dominated by a few taxa. Meanwhile, more natural systems have a more diverse population, with many species dominating was not supported by the study. These phenomena suggest that the Laloi lagoon recorded more taxa, making up 90% of the total abundance than the Oyibi lagoon. The minimum information on the total number of individual species in the reference study on these lagoon fisheries became a significant setback to the metric selection. The total for Oyibi is 40, and Laloi is 34. From the metric evaluation and other biological data such as condition factor and length-weight relationship, Oyibi was observed to be moderately stressed, and Laloi was poorly stressed.

Deposition of organic matter to the sediment by mangroves and high nutrient concentrations contribute to the high chlorophyll-a concentration at Oyibi. The growth of planktonic algae in a water body is related to the presence of nutrients, in particular nitrates and phosphates (Brando et al. 2006). This result was supported by the high nitrates and phosphates concentrations recorded in the Oyibi lagoon. Excessive water column productivity, expressed by high chlorophyll concentrations, can supply large amounts of quickly organic decomposition matter to the sediments, as observed by Duarte (1995). Elevated chlorophyll levels indicate high numbers of phytoplankton and free-floating macroalgae and can translate into changes in animal and plant species diversity (Duarte 1995; Nielson and Jernakoff 1996).

*Species diversity*

Species diversity is an indicator of the well-being of ecological systems (Magurran 1988). The differences in species diversity can be attached to abiotic and biotic factors. The variety of nutrient levels can also be an influencing factor. Increased salts such as phosphates and nitrates are important in supporting phytoplankton growth, which is the basis in the primary food chain and greatly enhances fish production.

The high species richness in Laloi can be attached to the number of fishers that exploit different niches. There were five fishers at Laloi, while for Oyibi, on average, there were three fishers. Fishing contributes to the reduced abundance of species that spend all or part of their life cycle in estuaries (Lotze et al. 2006).

The diversity of fish species within a region is partly a function of the number of available niches and area size (Wootton 1990). Here, Oyibi had the highest species richness, which might be related to the presence of extensive mangrove forest that supports microhabitats for species (Connor et al. 1997). The size of the catchment area has been identified as a significant factor governing both fish species diversity and abundance in South African water (Marais 1988). Biotic factors such as cannibalism, density-dependent predator mortality, intraguild predation, grazer-resistance of algae, and predator-dependent functional responses tend to increase bottom-up effects hence affecting species diversity in aquatic systems (McCauly et al. 1988; Gatto 1991; Ginzburg and Akçakaya 1992; McCann et al. 1998 and Hart 2002).

*Length-weight relationship*

The Length-weight relationship provides information that the fishes were isometric in their growth, meaning that the length increases in equal proportions with body weight and with a regression ci-efficient of „whiles values greater or less than „3" indicate allometric growth (Gayando and Pauly 1997). The condition factor of *S. melanotheron* compares favorably with that from Sakumo, Muni, and Densu of values (2.61-2.77) as seen by Koranteng (1995) and Fosu lagoon of value 2.65 as observed by Blay and Asabere-Ameyaw (1993).

January (Oyibi) and April (Laloi) showed the highest value for the co-efficient growth. The highest value recorded in January can be attached to the upwelling season in the coastal waters (January-February). The mixture of surface and bottom waters raises nutrient salts such as phosphates and nitrates, increasing primary productivity. The highest value observed in April (Laloi) can be attached to the rainfall that occurred on sampling. Rain affects fisheries by making nutrients available and influencing salinity regimes. Koranteng's (1995) research on the Sakumo II lagoon showed that rainfall affects conditions, factors, and species diversity. In his study, he showed that the number of species decreased from 59 in March to 26 in June, resulting in a decrease in species diversity, whiles the condition factor increased from 3.12 in March to 3.72 in June during the onset of the rains.

Condition factor provides information when used to compare two populations living in specific feeding, climate, density. Other condition also serves important information, such as when determining the period of gonad maturation and when following up the degree of feeding activity of a species to verify whether it is making good use of its feed source (Weatherley 1972). The condition factor of *S. melanotheron* improved during the study, which can be attributed to seasonal variability of the environment and food availability or habitat suitability (Mommsen 1998; Henderson 2005; Nieto-Navarro et al. 2010). The high nutrient concentration at Oyibi boosting primary productivity may be one accounting for the high condition factor of the fishes. Biological factors such as nutrition and reprcan cause discrepancies in the condition factor. Higher values may imply the accumulation of fat and gonadal development (Le Cren 1951), whiles the lowest values suggest the transfer of resources to the gonads during the reproductive period (Vazzoler 1996).

*Similarity analysis*

There was no variation in species within the months of sampling, as seen via the Bray-Curtis similarity analysis, though there was a significant similarity between the sites. These results suggest that lagoons experience great environmental variation in temperature, salinity, dissolved oxygen, and turbidity due to the influx of fresh and marine waters. Fish species that live in lagoons must cope with these rapid and extensive environmental changes. If fishes in water consistently respond to the environment, then the communities occupying similar types of estuaries in a particular region would be expected to reflect the similarity (Whitfield 1999).

*Total organic carbon*

The small numbers of *Sarotherodon melanotheron* found in the Laloi lagoon can be attached to the low organic matter content in the sediment of the lagoon. This reason also confers with fisher folks at the site revealed that this species was missing in catches for the past three years compared to previous years. *S. melanotheron* are bottom feeders in the food pyramids, and low organic matter content indicates less food for the species. The stomachs of adult *S. melanotheron* contain a fine fraction of bottom mud, comprising pennate diatoms, inorganic granules of 50-100 μ diameter, and organic detritus (Pauly 1976). Meanwhile, the high organic matter levels in the sediment at Oyibi can be attributed to the extensive mangrove cover. Because organic carbon is an organic pollutant, the high total organic carbon in these lagoons can be attributed to domestic wastes, human excreta, and mangrove forests' litter. The degradation of these wastes in the water column releases organic carbon that accumulates in the sediments. The high total organic matter measured at the seaward end can be attributed to the tidal influx that induces flow and transport of sediments (Blondeaux and Vittori 2005). Sediment transport and deposition may be strongly affected by tide-induced residual currents (Byun and Wang 2003). Ocean water deposits sediments and leaves them behind when the tide goes out during high tide (SlideShare Inc. 2009).

In conclusion, Oyibi, the lagoon with extensive mangrove cover, exhibited the highest species diversity than in the lagoon without mangroves (Laloi). The size of the lagoon was also found to be a possible factor that affects the abundance and distribution of species. During the study, the two most abundant species were the flathead grey mullet (*Mugil cephalus*) and the black-chinned tilapia (*Sarotherodon melanotheron*). In the Laloi lagoon, *Mugil cephalus* dominated catches while *Sarotherodon melanotheron* dominated catches in the Oyibi lagoon. *Lutjanus fulgens, S. melanotheron, and Eucinostomus melanopterus* were the most abundant species collected for the Laloi lagoon Laloi lagoon. *L. fulgens, Caranx hippos,* and *M. cephalus* constituted a major part of fishes caught in the Oyibi lagoon. The *Caranx hippos* contributed much of the biomass of fishes collected from both lagoons. The total fish number was most significant in the rainy season. Oyibi demonstrated a moderate site rating from the metrics assigned, suggesting that it was under mild stress, probably caused by garbage dumping, defecation, land-use changes, and increased human pressure. Laloi lagoon showed a poor site rating, suggesting that it was under severe stress, probably due to overfishing, mangrove degradation, defecation, garbage dumping, mangrove harvesting, and increased human settlements along the banks of the lagoon. The multi-metric index assigned reflects the status of lagoon fish communities and the overall ecosystem conditions. Oyibi lagoon with extensive mangrove cover had high Chlorophyll-*a* level and top condition factor of fish species. Anthropogenic activities and tidal influx are possible factors affecting nutrient value in coastal lagoons. The tidal regime was an important factor that influences physiochemical parameters in coastal lagoons. Total organic carbon in sediments was an essential factor in determining the abundance of *S. melanotheron.*

## REFFERENCES


Addy KGL, Heron E. 2004. pH and Alkalinity. URI Watershed WATCH. Cooperative Extension College of environment and life Science (CELS), Department of Natural Resource Science (NRS), Coastal Institute in Kingston, University of Rhode Island, Kingston, Rhode Island.

Anderson MJ, Underwood AJ. 1997. Effects if gastropods recruitment and succession of an estuarine environment: a multivariate and univariate approach. Oecologia 109 (3): 442-453. DOI: 10.1007/s004420050104.

Annang ER. 1979. The seasonal cycle of the phytoplankton in the coastal waters of Ghana. Hydrobiologia 62 (1): 33-46. DOI: 10.1007/s004420050104.

Ansa-Asare OD, Mensah E, Entsua-Mensah M, Biney CA. 2007. Impact of Human activities on nutrient and trophic status of some selected lagoons in Ghana. West Afr J Appl Ecol 12 (1): 49-60. DOI: 10.1007/BF00012560.

APHA, AWWA, WEF. 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition, American Public Health Association (APHA), Washington.

Armah AK. 1993. Coastal wetlands of Ghana. Coastal Zone 93: 313-322.

Armah AK. 1993. Migratory birds for roosting, feeding, and nesting. Wetlands of Ghana. Coast Zone 93: 313-322.

Armah AK. 2005. The Coastal Zone of Ghana: Vulnerability and Adaptation Assessment to Climate Change. Vulnerability and Adaptation Assessment Training Workshop, 18-22 April 2005. Muputo, Mozambique.

Bagenal TB. 1978. Aspects of Fish Fecundity. In: Gerking SD (ed) Ecology of Freshwater Fish Production, Blackwell Scientific Publications, Oxford, UK.

Bailey C. 1994. Employment, Labour, productivity, and Income in small-scale fisheries of south and southeast Asia. Socio-Economic issues in coastal Fisheries management proceedings of the IFPC Symposium, Bangkok, Thailand, 23-26 November 1993.

Bilotta GS, Brazier RE. 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Res 42 (012: 2849-2861. DOI: 10.1016/j.watres.2008.03.018.

Biney CA. 1982. Preliminary survey of the state of pollution of the coastal environment of Ghana. Oceanol Acta 4 (54): 39-42.

Biney CA. 1990. A review of some characteristics of fresh water and water ecosystems of Ghana. Hydrobiologia 208 (1): 45-53. DOI: 10.1007/BF00008442.

Bird ECF. 1982. Changes on barriers and spits enclosing coastal lagoons. Oceanol. Acta. 1982. Proceedings International Symposium on coastal lagoons, SCOR/IABO/UNESCO 45-53.

Bird EE. 1994. Physical setting and geomorphology of coastal lagoons. In: Kjerfve B (ed) Coastal Lagoon Processes. Elsevier Oceanographic series, Amsterdam. DOI: 10.1016/S0422-9894(08)70007-2.

Blay J Jr, Ameyaw A. 1993. Assessment of the fishery of a situated population of the Cichlid Sarotherodon melanotheron on a closed lagoon in Ghana. J Appl Ichthyol 9 (1): 1-11. DOI: 10.1111/j.1439-0426.1993.tb00382.x.

Blondeauz AS, Vittori JC. 2005. Flow and sediment transport induced by tide propagation: 1. The flat bottom case. J Geophys Res 110 (C7): CO7020. DOI: 10.1029/2004JC002532.

Boughey AS. 1957. Ecological studies of tropical coastlines. The Gold Coast, West Africa. J Ecol 45: 665-687. DOI: 10.2307/2256952.

Boyd W. 1990. Water Quality in Pond for Aquaculture. Alabama Agricultural Experiment Station. Auburn University, Alabama.

Brando V, Dekker A, Marks A, Qin Y, Oubelkheir K. 2006. Chlorophyll and suspended sediment assessment in a macrotidal tropical estuary adjacent to the Great Barrier Reef: spatial and temporal assessment using remote sensing. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management Technical Report 74.

Brando V, Moss A, Radke L, Rissik D, Rose T, Scanes P, Wellman S. 2012. Chlorophyll *a* concentrations. Retrieved on 10th January, 2012 from http: //www.ozcoasts.gov.au/indicators/chlorophyll_a.jsp.

Bray JR, Curtis JT. 1957. An ordination of the upland forest communities of structure South West Wisconsin. Ecol Monogr 27 (4): 325-349. DOI: 10.2307/1942268.

Burger J, Gochfeld M. 1999. On developing bioindicators for human and ecological health. Environ Monit Assess 66 (1): 23-46. DOI: 10.1023/A:1026476030728.

Byun DS, Wang XH. 2003.Tide-induced sediment dynamics. EGS-AGU-EUG Joint Assembly, abstracts from the meeting held in Nice, France, 6-11 April 2003.

Cain RL, Dean JM. 1976. Annual abundance and diversity of fish in a South Carolina Intertidal Creek. Mar Biol 36 (4): 369-379. DOI: 10.1007/BF00389199.

Caraco NF. 1995. Influence of human populations on P transfers to aquatic ecosystems: a regional scale study using large rivers. In: Tiessen H (ed) Phosphorus in the Global Environment. John Wiley, New York.

Carr MR. 1996. PRIMER User Manual: Plymouth Routines in Multivariate Ecological Research. Plymouth Marine Laboratory, Plymouth.

Chaphekar SB. 1991. An overview on bioindicators. J Environ Biol 12: 163-168.

Clarke KR, Green RH. 1988. Statistically, design and analysis for a biological effects study. Mar Ecol Prog Ser 46: 710-23. DOI: 10.3354/meps046213.

Clarke KR. 1993. Non parametric multivariate analyses of changes in the community structure. Aust J Ecol 8 (1): 117-143. DOI: 10.1111/j.1442-9993.1993.tb00438.x.

Connor DW, Brazier DP, Hill TO, Northen KO. 1997(a). Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 1. Littoral biotopes. Version 97.06. Joint Nature Conservation Committee, Peterborough, JNCC Report.

Constanza R, Kemp WN, Boynton WR. 1993. Predictability, Scale and biodiversity in coastal estuarine ecosystems: Implications for management. Ambio 22 (2-3): 88-96.

Costello M, Elliott M, Theil R. 2002. Endangered and rare species. In: Elliott M, Hemmingway KL (eds) Fishes in Estuaries, Blackwell Science, Oxford.

Dankwa H, Entsua-Mensah M, Asmah R. 1997. Fish species composition and richness of lagoons and estuaries in Ghana. IAB Tech. Report 161: 24.

Dankwa H, Entsua-Mensah M. 1996. Fishing gears and methods used in Lagoons and estuaries in Ghana. IAB Tech. Report 155: 24.

Dankwa HR, Abban EK, Teugels GG. 1998. Freshwater fishes of ghana: Identification, ecological and economic importance. Annales Sciences Zoologiques 283.

Davis GE. 1993. Design elements of monitoring programs: the necessary ingredients for success. Environ Monit Assess 26 (2): 99-105. DOI: 10.1007/BF00547489.

Denyoh FMK. 1982. The utilization of coastal areas for aquaculture development in Ghana, p 31-51. In Coche A (ed) Coastal Aquaculture. CIFA Tech. Pap. 9.

Dickson KB, Benneh G. 1980. A New Geography of Ghana. Longman Group Ltd, London.

Duarte CM. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41 (1): 87-112. DOI: 10.1080/00785236.1995.10422039.

Elliot M, Dewailly F. 1995. The structure and components of European estuarine fish assemblages. Netherlands J Aquat Ecol 29 (3-4): 397-417. DOI: 10.1007/BF02084239.

Elliott M, Hemmingway KL, Marshall S, Duhamel S. 2002. Data quality analysis and interpretation. In: Elliott M, Hemmingway KL (eds) Fishes in Estuaries, Blackwell Science, Oxford.

Entsua-Mensah M. 1996. "The importance of Mangroves as transitional ecosystems in Ghana." In: Evans SM, Vanderpuye CJ, Armah AK (eds) The Coastal Zone of West Africa: Problems and Management, Accra, March 1996.

Entsua-Mensah M. 1998. Comparative Studies of The Dynamics and Management of Fish Populations in An Open and Closed Lagoon in Ghana. [Dissertation]. University of Ghana, Accra.

Entsua-Mensah M. 2002. The Contribution of Lagoons to the Continental Shelf of Ghana. In*:* McGlade JM, Cury P, Koranteng KA, Hardman-Mountford NJ (eds) The Gulf of Guinea Large Marine Ecosystems, Environmental Forcing and Sustainable Development of Marine Resources. Elsevier Science, Nederland. DOI: 10.1016/S1570-0461(02)80035-0.

Entsua-Mensah M. 2003. Lagoon Fisheries and Nutrient Data. Report prepared for Nixon Laboratory, Graduate School of Oceanography, University of Rhode Island, USA.

Entsua-Mensah, M. 2006. The Importance of sustainable Fisheries in Rural Economies. Intl J Ecol Environ Sci 32 (1): 119-125.

Eyeson KN. 1983. Eggs and fry swallowing habits of Tilapia. Aquaculture 32: 415-418. DOI: 10.1016/0044-8486(83)90240-5.

Fausch KD, Lyons J, Karr JR, Angermeier PL. 1990. Fish communities as indicators of environmental degradation. Am Fish Soc Symp 8: 123-144.

Finney BP, Gregory-Eaves I, Douglas MSV, Smol JP. 2002. Fisheries productivity in the north-eastern Pacific Ocean over the past 2,200 years. Nature 416 (6822): 729-733. DOI: 10.1038/416729a.

Gatto M. 1991. Some remarks on models of plankton densities in lakes. Am Nat 137 (2): 264-267. DOI: 10.1086/285159.

Gayando FC, Pauly D. 1997. FAO ICLARM stock assessment tools (FISAT): References Manual. FAO Computerized Information Series (Fisheries) (8): 262.

Ginzburg L, Akçakaya H. 1992. Consequences of ratio dependent predation for steady state properties of ecosystems. Ecology 73 (5): 1536-1543. DOI: 10.2307/1940006.

Gordon C, Yankson K, Biney CA, Amlalo DS, Tumbulto JW, Kpelle D. 1998. Report of the Working Group on Wetland Typology: Ghana Coastal Wetlands Management Project Background Documentation for the Ghana National Wetland Strategy. Department of Game and Wildlife, Government of Ghana, Accra.

Hamilton AJ. 2005. Species diversity or biodiversity? J Environ Manag 75 (1): 89-92. DOI: 10.1016/j.jenvman.2004.11.012.

Harrison TD, Whitfield AK. 2004. A multi-metric fish index to assess the environmental condition of estuaries. J Fish Biol 65 (3): 683-710. DOI: 10.1111/j.0022-1112.2004.00477.x.

Hart DR. 2002. Intraguild predation, invertebrate predators, and trophic cascades in lake food webs. J Theor Biol 218 (1): 111-128. DOI: 10.1006/jtbi.2002.3053.

Heath AG. 1987. Water Pollution and Fish physiology. CRC Press, Florida, USA.

Henderson PA. 2005. The Growth of Tropical Fishes. Vol. 21. In: Val AL, Vera MF, Randall DJ (eds) Academic Press, USA.

Hill K. 2001. What is a coastal lagoon? Smithsonian Marine Station. http: //www.sms.si.edu/irlspec/whatsa_lagoon.htm.

Holt AE, Miller WS. 2011. Bioindicators: using organisms to measure environmental impacts. Nat Educ Knowl 2 (2): 8. http: //www.nature.com/scitable/knowledge/libray/ on 09/12/2011.

Howarth RW. 1988. Nutrient limitation of net primary production in marine ecosystems. Ann Rev Ecol Syst 19 (1): 898-910. DOI: 10.1146/annurev.es.19.110188.000513.

Jude DJ, Pappas J. 1992. Fish utilization of Great Lakes Coastal Wetlands. Great Lakes Res 18 (4): 651-672. DOI: 10.1016/S0380-1330(92)71328-8.

Kennish MJ. 1992. Ecology of Estuaries: Anthropogenic Effects. CRC Press, Boca Raton.

Kennish MJ. 2002. Environmental threats and environmental future of estuaries. Environ Conserv 29 (1): 78-107. DOI: 10.1017/S0376892902000061.

Kjerfve B. 1994. Coastal Lagoons. Chapter 1. In: Kjerfve B (ed) Coastal lagoon processes. Elsevier Oceanographic Series, Amsterdam. DOI: 10.1016/S0422-9894(08)70006-0.

Koranteng KA, Ofori-Danson PK, Entsua-Mensah M. 1998. Comparative study of the fish and fisheries of three coastal lagoon in West Africa. Intl J Ecol Environ Sci 24: 371-382 1998.

Koranteng KA. 1995. Fish and Fisheries of three coastal lagoons in Ghana. Global Environmental facility. Ghana Coastal Wetlands Management Programme. GW/A. 285/SF2/3.

Krebbs CJ. 1985. Ecology. The Experimental Analysis of Distribution and Abundance. Harper and Row, New York.

Laé R. 1997. Does overfishing lead to a decrease in catches and yields? An example of two West African coastal lagoons. Fish Manag Ecol 4 (2): 149-164. DOI: 10.1046/j.1365-2400.1997.00098.x.

Lamptey E. 2011. Environmental Effects of Eco-Innovative Coastal Lagoon Dredging for Shoreline Restoration Project in Ghana, West Africa. Nova Science Publishers, Inc, New York.

Lorenz CM. 2003. Bioindicators for ecosystem management with special reference to freshwater systems. In: Markert BA, Breure AM, Zechmeister HG (eds) Bioindicators and Biomonitors: Principles, Concepts, and Application. Elsevier Science Ltd., Oxford, UK. DOI: 10.1016/S0927-5215(03)80134-0.

Lotze HK, Leniham HS, Bourque BJ, Bradbury RG, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312 (5781): 1806-1809. DOI: 10.1126/science.1128035.

Ludwig JA, Reynolds JF. 1988. Statistical Ecology: A Primer on Methods of Computing. Wiley Interscience, New York.

Ly CK. 1980. The role of the Akosombo Dam on the Volta River in Causing Erosion in Central and Eastern Ghana (West African). Mar Geol 37 (3-4): 323-332. DOI: 10.1016/0025-3227(80)90108-5.

Magurran AE. 1988. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, N.J. DOI: 10.1007/978-94-015-7358-0.

Marais JFK. 1988. Some factors that influence fish abundance in South African estuaries. South African J Mar Sci 6 (1): 67-77. DOI: 10.2989/025776188784480609.

McCann KS, Hastings A, Strong DR. 1998. Trophic cascades and trophic trickles in pelagic food webs. Proc R Soc London B 265 (1392): 205-209. DOI: 10.1098/rspb.1998.0283.

McCauly E, Murdoch WM, Watson S. 1988. Simple models and variation in plankton densities among lakes. Am Nat 132 (2): 382-403. DOI: 10.1086/284859.

McHugh JL. 1985. The estuarine ecosystem integrated. Foreword. In: Yanez-Arancibia A (ed) Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration. UNAM Press, Mexico.

Mommsen TP. 1998**.** Growth and Metabolic. In: Evans DH (ed) The Physiology of Fishes. CRC Press, New York.

Monbet Y. 1992. Control of phytoplankton biomass in estuaries: A comparative analysis of microtidal and macrotidal estuaries. Estuaries 15 (4): 563-571. DOI: 10.2307/1352398.

Nichols MM, Boon JD. 1994. Chapter 7. Sediment transport processes in coastal lagoons. In: Kjerfve B. (ed) Coastal lagoon processes. Elsevier Oceanographic series, Amsterdam. DOI: 10.1016/S0422-9894(08)70012-6.

Nielson J, Jernakoff P. 1996. A review of the interaction of sediment and water quality with benthic communities. Port Phillip Bay Environmental Study. Technical Report 25: 1-130.

Nieto-Navarro JT, Zetina-Rejon M, Arreguin-Sanchez F, Arcos-Huitron E, Peria-Messina. 2010. Length-weight relationships of demersal fish from the Eastern Coast of the Mouth of the Gulf of California. J Fish Aquat Sci 5 (6): 494-502. DOI: 10.3923/jfas.2010.494.502.

Nkwoji JA, Igbo JK, Obienu J. 2010. Bioindicators as veritable tools in aquatic pollution management: A case study on the Lagos lagoon, Nigeria. Continental J Fisher Aquat Sci 3: 36-43.

O"Connor TP, Ehler CN. 1991. Results from the NOAA natural status and trends program on distribution and effects of chemical contamination in the coastal and estuarine, United States. Environ Monit Assess 17 (1): 33-49. DOI: 10.1007/BF00402460.

Odum EP. 1983**.** Basic Ecology. Saunders, Philadelphia, PA.

Pauly D, Yanez-Arancibia A. 1994. Fisheries in coastal lagoons. In: Kjerfve B (ed) Coastal lagoon processes. Elsevier Oceanographic series, Amsterdam. DOI: 10.1016/S0422-9894(08)70018-7.

Pauly D. 1975. On the ecology of a small West African lagoon. Sonderdruck aus Bd 24 (1): 46-52.

Pauly D. 1976. The biology, fishery, and potential for aquaculture of Tilapia melanotheron in a small West African lagoon. Aquaculture 7 (1): 33-49.

Pauly D. 1983. Some simple methods for the assessment of tropical fish stock. FAO FISH Tech. Paper 234: 52. DOI: 10.1016/0044-8486(76)90030-2.

Peakall D. 1992. Animal Biomarkers as Pollution Indicators. Chapman and Hall, London. DOI: 10.1007/978-94-011-2346-4.

Qunfang Z, Jianbin Z, Jianjie F, Jianbo S, Guibin J. 2008. Biomonitoring: An appealing tool for assessment of metal pollution in the aquatic ecosystem. State Key Laboratory of Environmental Chemistry and

Ecotoxicology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
Ramakrishnan N. 2003. Bio-Monitoring Approaches For Water Quality Assessment In Two Waterbodies At Tiruvannamalai, Tamil Nadu India. In: Bunch MJ, Suresh VM, Kumaran TV (eds) Proceedings of theThird International Conference on Environment and Health, Chennai, India, 15-17 December, 2003. Department of Geography, University of Madras, Chennai, and Faculty of Environmental Studies, York University, UK.
Roberts CM, Hawkins, JP. 1999. Extinction risk in the sea. Trends Ecol Evol 14 (6): 241-246. DOI: 10.1016/S0169-5347(98)01584-5.
Rodwell LD, Barbier EB, Roberts CM, McClanahan TR. 2003. The importance of habitat quality for marine reserve fishery linkages. Can J Fish Aquat Sci 60 (2): 171-181. DOI: 10.1139/f03-009.
Secor DH, Waldman JR. 1999. Historical abundance of Delaware Bay Atlantic sturgeon and potential rate of recovery. Am Fish Soc Symp 23: 203-216.
SlideShare Inc. 2009. Effects of waves, currents, tides-Presentation transcript. http: //www.slideshare.net/bosch/effects-of-wavescurrents-tides-presentation.
Sucman E, Vávrová M, Gargošová Z.H, Mahrová M. 2006. Fish-Useful bio-indicators for evaluation of contamination in water ecosystems. Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy.
Thiel R, Sepuldeva A, Kafeman R, Nellen W. 1995. Environmental factors as forces structuring the fish continuity of the Elbe Estuary. J Fish Biol 46 (1): 47-49. DOI: 10.1111/j.1095-8649.1995.tb05946.x.
USEPA. 2000. Estuarine and coastal marine waters: Bioassessment and biocriteria technical guidance. U.S. Environmental Protection Agency Report EPA-822-B-00-024. Office of Water, Washington DC.
Vazzoler AEA. 1996. Biologia da reprodução de peixes Teleósteos: teoria e prática. EDUEM, SBI, Maringá.
Wallace JH, Kok HM, Beckley LE, Bennett B, Blaber SJM, Whitfield AK. 1984. South African estuaries and their importance to fishes. South Afr J Sci 80 (5): 203-207.
Weatherley AH. 1972. Growth and Ecology of Fish Populations. Academic Press, London.
Welcome RL. 1979. Fisheries Ecology of Flood Plain Rivers. Longman Press, London.
Whitfield AK. 1990. Life history styles of fishes in South African estuarine. Environ Biol Fish 28 (1): 295-308. DOI: 10.1007/978-94-009-2065-1_19.
Whitfield AK. 1998. Biology and ecology of fishes in southern African estuaries. Ichthyological Monograph of the J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa. DOI: 10.5962/bhl.title.141872.
Willoughby N, Entsua-Mensah M. 1998. Artisanal and Commercial Fisheries Development. Ghana Environmental Resource Management Project Options for Coastal Wetlands. Natural Resources International (NRI), Accra.
Wooton RJ. 1990. Ecology of teleost fishes. Chapman and Hall, London. DOI: 10.1007/978-94-009-0829-1.
Wynne SP, Cote IM. 2007. Effects of habitat quality and fishing on Caribbean spotted spiny lobster populations. J Appl Ecol 44: 488-494. DOI: 10.1111/j.1365-2664.2007.01312.x.
Zimmermann RD, Umlauff-Zimmermann R. 1994. Von der Bioindikation zum Wirkungskataster. UMSF-Z. Ökotox 6 (1): 50-54. DOI: 10.1007/BF02937132.

**BONOROWO WETLANDS**
Volume 9, Number 1, June 2019
Pages: 27-31

P-ISSN: 2088-110X
E-ISSN: 2088-2475
DOI: 10.13057/bonorowo/w090103

# Short Communication: Diversity of dragonflies (Ordo: Odonata) on the natural reserve areas of Mt. Sigogor and Mt. Picis, Ponorogo District, Indonesia

**MALINDA DUTA PERTIWI PRANOTO[1,♥], DHENY MARDIONO[2], TETRI WIDIYANI[1], RIZQI ADANTI PUTRI PERTIWI[1], FATIMAH AZ ZHARA[1], NAILA IZZATI[1]**

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Ir. Sutami 36 A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375. ♥email: malindaduta98@gmail.com

[2]Conservation and Natural Resources Region 1, Madiun. Jl. Dungus Km. 7, Madiun 63181, East Java, Indonesia

Manuscript received: 11 April 2019. Revision accepted: 5 June 2019.

**Abstract.** *Pranoto MDP, Mardiono D, Widiyani T, Pertiwi RAP, Az Zhara F, Izzati N. 2019. Short Communication: Diversity of dragonflies (Ordo: Odonata) on the natural reserve areas of Mts. Sigogor and Picis, Ponorogo District, Indonesia. Bonorowo Wetlands 9: 27-31.* The Mount Sigogor and Picis Natural Reserves are the conservation areas in Ponorogo, East Java. Mount Sigogor and Picis nature reserves have an ecosystem of tropical rain forests that are naturally protected, providing the reserve with a high potential for biodiversity. The preserved ecosystem conditions are a good habitat for the dragonfly since some dragonfly species require a clean habitat and are sensitive to pollutants. The study was conducted from January to February 2019. The research site was carried out at 7 points, covering 5 points in the reserve and 2 points around Mount Sigogor Nature Reserve. Data retrieval was done using the explorative method. Qualitative and quantitative descriptions were used to analyze the results of dragonflies' biodiversity. The results have found 18 species of dragonflies with details of 6 species as damselflies (Zygoptera) and 12 species of common dragonflies (Anisoptera). There are 5 species of endemic dragonflies from Java Island, i.e., *Drepanosticta sundana*, *Euphaea variegata, Heliogomphus drescheri, Heliocypha fenestrat,* and *Vestalis luctuosa*. From the Shannon-Wiener discounting index, the value of index diversity on the entire research site is 1.466. The highest diversity value lies in the river's location leading to Toyo Marto's waterfall with a 2.02 diversity-index value. Obtained results that the *Euphaea variegata* has the most abundant with a 40.23% value.

**Keywords:** Dragonflies, explorative method, Mount Picis Nature Reserve, Mount Sigogor Nature Reserve

## INTRODUCTION

The dragonfly (Order: Odonata) is an easily recognizable flying insect in its distinctive form, having an attractive variety of body colors and wings. The Odonata order itself refers to the mandibular character of a dragonfly with toothlike projections (spina) (Greek, *Odontos* = teeth) (Baskoro et al., 2018). The dragonfly experiences three phases of life cycles: egg, larva (naiad), and adult phase (imago). In both egg and naiad phases, the dragonfly lives in the aquatic ecosystem, while in the adult phase, the dragonfly lives as an aerial insect (Gillot 2015). The dragonfly generally has two large groups: the Anisoptera (the great dragonfly) and the Zygoptera (the needle dragonfly/damselfly). The differences in his body structure are obvious. Anisoptera tends to be larger than Zygoptera, compound eyes coalesced, larger front wings than the rear, and when it alights, an Anisoptera spreads its wings. Whereas the Zygoptera group is small and slender, there are compound eyes of one pair, with the same large front and rear wings, and the way to land is by folding wings over the body (Samways 2008).

Mountain forests with a natural and clean river are the most diverse habitats of the dragonfly, besides vast underwater waters (swamps and lake). Some dragonflies have an exceptional habitat, but some species have adapted to urban areas and utilize manmade aquatic ecosystems (Setiyono et al., 2017). Some dragonfly species cannot live in polluted waters; they can thus become ideal insects to judge the health of the freshwater ecosystem (Cai et al., 2018). The dragonfly also has the role of insect predator. The dragonfly is one of the components of biological diversity that plays a vital role in food nets. The dragonfly larvae occupy the predator position on food nets in the aquatic ecosystem, while the adult dragonfly acts as a predator for plant pests in the breeding area (Siregar and Bakti 2016).

The natural reserve areas are conservations areas because of the natural affinity of plants, animals, and specific systems of animals or ecosystems that need to be protected and progress naturally. Wildlife conservation management is used only to preserve existing plants, animals, and ecosystems. The natural resources conservation hall closely guards it under the Directorate General for Forest Protection and The Conservation of The Ministry of Forestry of The Republic Indonesia. The natural reserve areas are maintained by maintaining natural conditions and minimizing natural damage. However, within reserve areas, it still makes it possible for research, education, science, and other activities that promote the conservation of animals and plants (Undang-Undang No. 5 Tahun 1990).

The Mount Sigogor Natural Reserve is an established reserve in East Java Province, Indonesia, located in Pupus Village, Ngebel Sub-district, Ponorogo. While, The Mount Picis Natural Reserve lies in the village of Gondowido, Ngebel Sub-district, Ponorogo (BBKSDA Jatim, 2012). The reserve area's still heavily protected condition makes it a suitable habitat for the dragonfly. However, no data have been found of species of dragonflies and biodiversity on Mount Sigogor and Mount Picis Natural Reserves. Therefore, the expected use of this study would result in a database of dragonfly diversity in the natural reserve areas of Mount Sigogor and Mount Picis. It is hoped that this research could generate a database on the diversity of dragonflies on the Mount Sigogor and Mount Picis Natural Reserves and could be the first step in safeguarding the natural habitat of dragonflies.

## MATERIALS AND METHODS

Data retrieval in the field occurs from January to February 2019, when the rainy season. An instrument used in the study is the insect net, which is about 150 cm long, cameras, pencil, GPS, and maps application of Avenza Maps. In this study, researchers used the Avenza Maps application to facilitate the logging point of reference to locating dragonflies in Sigogor and Picis Mountain Reserves, Ngebel Sub-district, Ponorogo District, East Java, Indonesia (Figure 1). The object considered in this study is dragonflies found at the research site. The research sites contained mountains of Sigogor and Picis. Data reteaching was done through exploration, which involved tracing the established paths. Mature dragonflies can live in different habitats, such as rivers, forests, lakes, reservoirs, and swamps, with an altitude of 100 meters until 3000 meters. Then, the two natural reserve areas have an altitude of about 1.200-1.600 meters with a type of tropical rain forest ecosystem (BBKSDA Jatim, 2012; Kulkarni & Subramanian 2013; Rugayah and Pratiwi 2014).

The Mount Sigogor and Mount Picis Natural Reserves have very close distances and are situated within the same landscape but have different ecosystem conditions. The Mount Sigogor Natural Reserve was dominated by forests with dense vegetation, valleys, hills, and flowing rivers. On the other hand, the Mount Picis Natural Reserve is a lightly wooded hill with a reed field, and there are also no rivers. Even though the Mount Picis and Sigogor Natural Reserves have a close range, Mount Sigogor and Mount Picis have a distinct landscape form and considerable diversity and quantity of dragonflies. The Mount Sigogor and Mount Picis Natural Reserves have an average air temperature of between 24-36ºC, the lowest temperature being measured at 09.30 am and the highest temperature being measured at 12.00 pm. According to Corbet (1999), dragonflies are found in open places with warm temperatures (about 25-33 ºC).

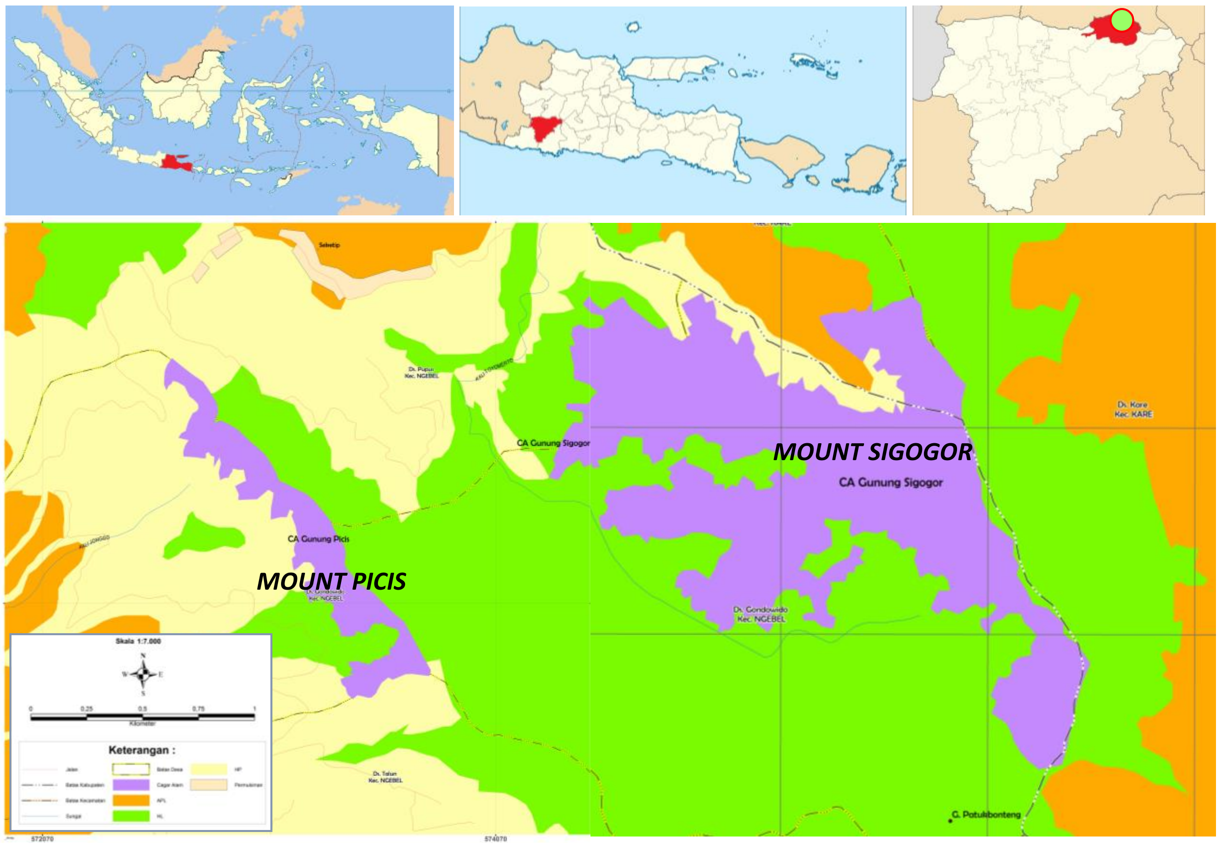



**Figure 1.** Map of research location in the Natural Reverse Area of Mount Picis and Mount Sigogor (○) in Ngebel Sub-district, Ponorogo District, East Java, Indonesia

Since the dragonfly is a mobile animal, it also enhances the diversity of the dragonfly not only in the natural reserve area but also in the areas around the reserve. Hence, areas explored are the river and surrounding areas. The observation was made from 09.30 am-01.00 pm. The dragonfly is found in the name of species and the number of individuals on the tally sheet, and it is then documented. Identification is made by reference to the books *Odonata of Semarang Raya* (2018) and *Dragonflies of Yogyakarta* (2017); data retrieved includes species of dragonflies, altitude of places, time found, and numbers of individuals of dragonflies.

The data analysis used involves qualitative and quantitative analysis. A qualitative analysis of the type and habitat of the host species. A quantitative analysis is done using a comparative index of diversity and abundance index with a formula:

Shannon-Wiener Biodiversity Index:

$$H' = -\sum_{i=1}^{n} pi \ln pi$$

Where:
H: Shannon-Wiener biodiversity index
*pi*: Abundance of proportionality

Relative Abundance Index

$$KR \quad \frac{ni}{N} \; x \; 100\%$$

Where:
KR: Relative abundance
Ni: The number of individual dragonflies
N: The number of individuals all kinds of dragonflies

## RESULTS AND DISCUSSION

In the Mount Sigogor Natural Reserve and nearby areas, data collection is carried out in areas leading to Japan's Cave, Wates (those dominated by the plant of Puspa (*Schima wallichii*), Ngasep (an area surrounded by coffee gardens (*Coffea* sp.), Watu Blandar (there are swift streams with considerable light intensity), and then Perhutani River and river to Toyo Marto waterfalls. On the Mount Picis Natural Reserve, data retrieval occurs at Dawuk, which is the top of the natural reserve area. Data retrieval points were based on the possible discovery of dragonflies and dexterous terrain.

Eighteen dragonflies were discovered in the Mount Sigogor and Picis Natural Reserves, 6 species of dragonflies go into Zygoptera, and 12 other species include suborder Anisoptera. The most common of the Libellulidae, which comprised 9 species and 9 different species belonging to the Calopterygidae (1 species), Chlorocyphidae (2 species), Euphaeidae (1 species), Platycnemididae (1 species), Platystictidae (1 species), Corduliidae (1 species), and Gomphidae (1 species).

Based on calculations of the relative abundance value (Table. 2), it may be known that the *Euphaea variegata* has the highest relative abundance (40.23%). *Euphaea variegata* can be found in practically all research locations except Dawuk. Then, the comparative value of abundance after *Euphaea variegata* was possessed by *Pantala flavescens* (15.28%) and *Vestalis luctuosa* (13.43%). According to Lieftinck (1954), *Euphaea variegata* often fly together with a *Vestalis luctuosa* and *Heliocypha fenestrata*. The abundance of *Vestalis luctuosa* can be a bioindicator that water quality in a body of water is still sufficiently protected since it is a type of dragonfly prone to environmental change. Dragonflies, especially Anisoptera, oviposit their eggs in water, in both streams or slow-moving water, by the naiad's ability to cope with the water speed. This means the presence of dragonflies cannot be separated from water availability (Nugrahani et al., 2014).

*Pantala flavescens* is a cosmopolitan wanderer found in almost any habitat with even contaminated conditions. Very common dragonfly and often present in a swarm, sometimes of hundreds of individuals. They perch infrequently and are easily found in open areas (Setiyono et al., 2017). The dragonfly is most commonly found in Dawuk, a vegetative reserve on Mount Picis and dominated by the grass (*Imperata cylindrica*). The relatively lowest abundance value of 0.17% belongs to 3 species of dragonfly, known as *Drepanosticta sundana*, *Diplacodes trivialis*, and *Orthetrum testaceum*. The species of dragonflies are found only in 1 location in the river area leading to Toyo Marto's Waterfall. *Drepanosticta sundana* is a rare dragonfly, while *Diplacodes trivialis* and *Orthetrum testaceum* have an easy encounter. But as a limited data intake area approaches a wildlife preserve with a property trait consistent with a *Diplacodes trivialis* and *Orthetrum testaceum*, both species are identified only in a small number of individuals.

On the Mount Sigogor Natural Reserve, 5 species of endemic dragonfly from Javanese island were founded: *Vestalis luctuosa*, *Heliocypha fenestrata Euphaea variegata*, *Drepanosticta sundana*, and *Heliogomphus drescheri*. *Drepanosticta sundana* is the biggest Javan Platystictid, has a striped black and white with black-green eyes. This species can be found in forest streams with low light intensity and humid air. The dragonfly with the genus *Drepanosticta* is unique in that all species of this genus are endemic dragonflies. *Heliocypha fenestrata* has a black abdomen with the blue-spotted on segment 1 until segment 5. Wings are black with pink reflections when exposed to the sunlight (Setiyono et al., 2017). According to (Nugrahani et al. 2014), in addition to *Vestalis luctuosa*, *Zygonix ida* and *Drepanosticta sundana* are dragonflies sensitive to pollution. Therefore, discovering the dragonfly from *Vestalis luctuosa*, *Zygonix ida,* and *Drepanosticta sundana* species suggests that the Mount Sigogor and Picis Natural Reserves have well-preserved water conditions. Some species of an endemic dragonfly, such as *Depanosticta sundana* and *Heliogomphus drescheri* are rare frequencies and have a smaller population than other species; thus, maintaining river conditions can preserve the presence of an endemic dragonfly.

**Table 1.** Environmental conditions at the location where the dragonfly diversity is observed in The Natural Reverse Area of Mount Sigogor and Mount Picis, Ponorogo, Indonesia

| Location | Coordinate | Altitude | Vegetation types |
|---|---|---|---|
| Japan’s Cave | 7º47’15.3” S; 111º40’47.8” E | 1202 m | Foreshadowed |
| Wates | 7º 47’12.4” S; 111º14’32.2” E | 1130 m | Foreshadowed |
| Ngesep | 7º47’37.0” S; 7º40’31.4” E | 1207 m | Foreshadowed |
| Dawuk | 7º47’32.8” S; 111º39’46.7” E | 1402 m | Open area |
| Watu Blandar | 7º47’37.2” S; 111º40’31.7” E | 1189 m | Open area |
| Perhutani River | 7º46’59.1” S; 111º40’27.4” E | 1020 m | Open area |
| Direction to the Waterfall | 7º47’10.9” S 111º40’05.7” E | 944 m | Open area |

**Table 2.** Relative abundance value (KR) of dragonflies in the Mount Sigogor and Mount Picis Natural Reserves, Ponorogo, Indonesia

| Family | Species | Relative abundance value KR (%) | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|
| | | AG | WT | NG | DW | WB | SP | AA | |
| Calopterygidae | *Vestalis luctuosa* | | | 40 | | 25 | 15.3 | 13.7 | 13.43 |
| Chlorocyphidae | *Heliocypha fenestrata* | | | | | | | 7.5 | 1.07 |
| | *Rhinocypha anisoptera* | | | | | 25 | 7 | 3.7 | 5.10 |
| Euphaeidae | *Euphaea variegata* | 100 | 100 | 20 | | 35 | 14.1 | 12.5 | 40.23 |
| Platycnemididae | *Coeliccia membranipes* | | | 33.3 | | | 8.2 | | 5.93 |
| Platystictidae | *Drepanosticta sundana* | | | | | | | 1.2 | 0.17 |
| Corduliidae | *Idionyx montana* | | | | | | 3.5 | | 0.50 |
| Gomphidae | *Heliogomphus drescheri* | | | 6.7 | | | 2.4 | | 1.30 |
| | *Onychogomphus fruhstorferi* | | | | | | 1.2 | 2.5 | 0.53 |
| Libelullidae | *Diplacodes trivialis* | | | | | | 1.2 | | 0.17 |
| | *Orthetrum glaucum* | | | | | | 4.7 | 6.2 | 1.56 |
| | *Orthetrum pruinosum* | | | | | | 5.8 | 7.5 | 1.90 |
| | *Orthetrum sabina* | | | | 31.4 | | 11.8 | 20 | 9.03 |
| | *Orthetrum testaceum* | | | | | | 1.2 | | 0.17 |
| | *Pantala flavescens* | | | | 65.7 | | 18.8 | 22.5 | 15.28 |
| Libelullidae | *Potamarcha congener* | | | | 2.8 | | | | 0.40 |
| | *Rhodothemis rufa* | | | | | | 3.5 | | 0.50 |
| | *Zygonyx ida* | | | | | 15 | 1.2 | 2.5 | 2.67 |

Note: AG: Arah Goa Jepang (Japan’s Cave), WT: Wates, NG: Ngesep, DW: Dawuk, WB: Watu Blandar, SP: Sungai Perhutani (Perhutani River), AA: Arah Air Terjun (Direction to the Waterfall)

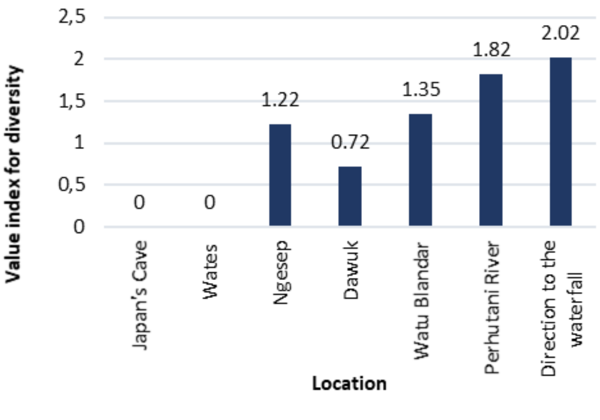



**Figure 3.** Value of dragonfly diversity index (H’) in the Mount Sigogor and Picis Natural Reserves

In addition to the relative abundance index, the study also calculated the diversity index value using the Shannon-Wiener diversity index. The highest biodiversity value belongs to the rivers that lead to the waterfall (2.02). This is because the river is a reasonably swift stream with a rocky torso and high sunlight intensity. This condition is the preferred habitat of dragonflies (Susanti 1998). The second place with a great diversity of dragonflies is the Perhutani river. The Perhutani (Figure 3) river’s condition is almost similar to the rover leading to the Toyo Marto’s Waterfall. Still, the vegetation in the Perhutani river is denser and shady because around the river are planted with coffee plants. In the Mount Picis Natural Reserve, observation was made in Dawuk; this area is a hill with a low peak, a high intensity of sunlight, and wind. In the Natural Reserve of Mount Picis, rivers have not been found in the park, so the dragonfly species was found less than at the Mount Sigogor Natural Reserve. Therefore, Dawuk has low numbers of dragonfly biodiversity. The lowest value index of biodiversity is located in The Wates Region, leading to Japan’s Cave, where no dragonflies have been found. Wates and the terrain leading to Japan’s Cave provide an area of trees with a large canopy, making it difficult for sunlight to reach the ground, and there’s no river.

In all, Mount Sigogor and Mount Picis Natural Reserves in seven surveillance locations have a 1.466 diet-level value index that is moderate value. However, insufficient time, reasonably dangerous terrain conditions, and a limited amount of observational time in a day do not preclude the possibility that there are still unknown species of dragonflies in the study.

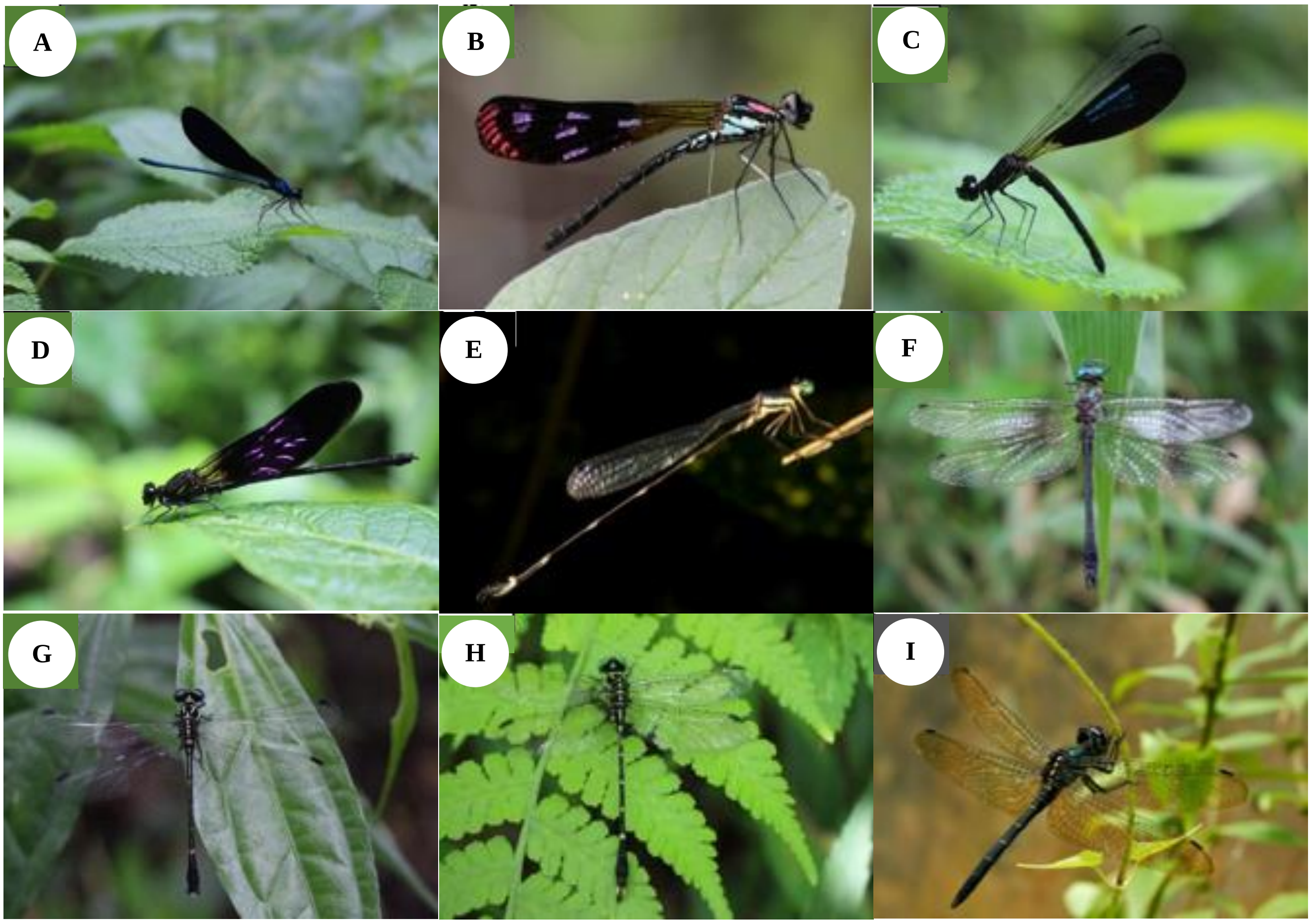



**Figure 4.** Some species of dragonfly have been found in and around Natural Reserves of Mount Sigogor and Mount Picis, Ponorogo District, Indonesia: A. *Vestalis luctuosa*, B. *Heliocyphafenestrata*, C. *Rhinocypha anisoptera*, D. *Euphaea variegata*, E. *Drepanosticta sundana*, F. *Idionyx montana*, G. *Heliogomphus drescheri*, H. *Onychogomphus Fruhstorfer*, I. *Zygonix ida*

In conclusion, this research could provide preliminary data on the dragonfly biodiversity database in the Mount Sigogor and Mount Picis Natural Reserves and the surrounding areas. Some species of dragonflies found are endemic dragonflies with a lack of information. Like *Heliogomphus drescheri*, this species is not listed in IUCN Redlist website data. However, because of the time limit in data retrieval, researchers have not been able to list dragonfly species in all areas of Mount Sigogor and Mount Picis Natural Reserves. Therefore, other species of dragonflies can be discovered using the same method. The exploration method can also be used to list organisms besides dragonflies, like a butterfly (Lepidoptera), orchids, etc.

## REFERENCES

Balai Besar Konservasi Sumber Daya Alam jawa Timur. 2012. Cagar Alam Gunung Picis dan Cagar Alam Gunung Sigogor. http://bbksdajatim.org/cagar-alam-gunung-picis-2. [Indonesian]

Baskoro K, Irawan F, Kamaludin N. 2018. Odonata Semarang Raya. Universitas Diponegoro. Semarang, Indonesia. [Indonesian]

Cai Y, Ng CY, Ngiam RJW. 2018. Dragonflies' diversity, distribution, and habitat characteristics in Nee Soon Freshwater Swamp Forest, Singapore. Gard Bull Singap 70 (1): 123-153. DOI: 10.26492/gbs70(suppl.1).2018-07.

Corbet PS. 1999. Dragonflies: Behavior and Ecology of Odonata. Cornell University Press, New York.

Gillot C. 2005. Entomology, 3rd ed. Springer, Netherland.

Kulkarni AS, Subramanian KA. 2013. Habitat and Seasonal Distribution of Odonata (Insecta) of Mula and Mutha River Basins, Maharastra, India. J Threatened Taxa 5 (7): 4084-4095. DOI: 10.11609/JoTT.o3253.4084-95.

Lieftinck MA. 1954. Handlist of Malaysian Odonata: A Catalogue of The Dragonflies of The Malay Peninsula, Sumatra, Java, and Borneo Including The Adjacent Small Island. Treubia, Bogor.

Nugrahani MP, Nazar L, Makitan T, Setiyono J. 2014. Peluit Tanda Bahaya, Capung Indikator Lingkungan. Indonesia Dragonfly Society, Yogyakarta, Indonesia. [Indonesian]

Rugayah W, Pratiwi. 2004. Pedoman Data Keanekaragaman Flora. Pusat Penelitian Biologi LIPI, Bogor, Indonesia. [Indonesian]

Samways MJ. 2008. Dragonflies dan Damselflies of South Africa. Pensoft Publisher, Sofia.

Setiyono J, Diniarsih S, Oscilata ENR, Budi NS. 2017. Dragonflies of Yogyakarta. Indonesia Dragonfly Society, Yogyakarta, Indonesia. [Indonesian]

Siregar AZ, Bakti D. 2016. Diversity and distribution of odonata in University Sumatera Utara, Medan, Indonesia. Intl J Sci Technol Res 5 (5): 229-234.

Susanti S. 1998. Seri Panduan Lapangan Mengenal Capung. Puslitbang Biologi-LIPI, Bogor, Indonesia. [Indonesian]

Undang-Undang Republik Indonesia Nomor 5 Tahun 1990. Konservasi Sumber Daya Alam dan Ekosistemnya. [Indonesian]

**BONOROWO WETLANDS**
Volume 9, Number 1, June 2019
Pages: 32-41

P-ISSN: 2088-110X
E-ISSN: 2088-2475
DOI: 10.13057/bonorowo/w090104

# Carbon stocks in the mangrove ecosystem of Rufiji River Delta, Tanzania

**INNOCENT BERNARD LUPEMBE, P.K.T. MUNISHI♥**
Department of Ecosystem Sciences and Management, Sokoine University of Agriculture. P. O. Box 3010 Morogoro, Tanzania. ♥email: pmunishi2001@yahoo.com.

Manuscript received: 2 February 2019. Revision accepted: 13 June 2019.

**Abstract.** *Lupembe IB, Munishi PKT. 2019. Carbon stocks in the mangrove ecosystem of Rufiji River Delta, Tanzania. Bonorowo Wetlands 9: 32-41.* Carbon sequestration is one of the most important ecosystem services provided by mangrove ecosystems. Despite this, most Tanzanian carbon storage research has focused on terrestrial environments. Carbon and volume prediction models for the mangrove ecosystem in Tanzania's Rufiji River Delta were constructed in this study. The created models were utilized to calculate carbon emissions. At various depths, the importance of soil organic carbon as a carbon storage was also evaluated. Using linear regression, a damaging sample of 50 trees spanning various DBH size classes was used to create biomass and volume, prediction models. Wet oxidation was used to determine the amount of organic carbon in the soil. Biomass models for stems, branches, roots, leaves, and twigs and volume prediction models for total volume were constructed. At P0.05 and P0.001, respectively, all linear and power form models constructed were significant. At 0-15 cm, 15-30 cm, and 30-60 cm, organic carbon was 39.61 t ha-1, 28.04 t ha-1, and 32.85 t ha-1, respectively. The surface layer (0-15 cm) had considerably more soil organic carbon (39.61 t ha-1) than that at 15-30 cm (28.04 t ha-1) and 30-60 cm (32.85 t ha-1) depths (P0.05). The most biomass C was contributed by Rhizophora mucronata (39.87%), followed by Avicennia marina (39.86%). (28.06%). The smallest contributions came from Sonneratia alba (2.58%) and Lumnitzera racemosa (1.98%). Rhizophora mucronata contributed 39.3% of the overall volume, whereas Avicennia marina contributed 27.1%. Overall, soil organic carbon (61.6%) was nearly twice that of vegetation carbon (38.4%), highlighting the importance of soil as a carbon storage in mangrove ecosystems.

**Keywords:** Carbon stocks, mangrove ecosystem, Rufiji River Delta, Tanzania

## INTRODUCTION

In fighting against climate change, reducing carbon emissions from deforestation and forest degradation in developing countries is critical (Gibbs et al., 2007). About 20% of global anthropogenic carbon dioxide emissions come from deforestation and land-use change (IPCC 2007). In tropical and subtropical forests, where carbon reserves are depleting at an alarming rate of 1-2 billion tonnes per year, the problem of carbon emissions is becoming increasingly urgent (Subedi et al., 2010). Carbon stocks of forest biomass have fallen by approximately 0,5 Gt per year for 2005-2010 worldwide, mainly due to a reduction in the global forest area (FAO 2010). The one method proposed to reduce these emissions in the developing countries is the Reducing Emissions from Deforestation and forest Degradation (REDD+) (Burgess et al. 2010). Moreover, the UNFCCC mechanism for the post-Kyoto implementation is now on track to reduce deforestation as an important means of reducing Green House Gas (GHG) emissions (Hannah and Lovejoy 2011).

More than 650 billion tonnes, 44% in biomass, 11% in deadwood and litter, and 45% in the soil is stored in the world's forests (FAO 2010). Forests secrete and store more carbon than any other terrestrial ecosystem and constitute a significant natural climate change 'brake' (Gibbs et al., 2007). Mangrove forests may be a key strategy in various climate mitigation strategies like REDD+ because of their large carbon sinks (Kauffman et al. 2011, Kauffman and Donato, 2012). Mangroves are reported to have a large carbon stock per unit area and have a high potential for sedimentary carbon storage (Twilley et al. 1992).

Mangroves are one of the most productive ecosystems on the planet, and they play a critical part in the global carbon cycle (Twilley et al. 1992; Bouillon et al. 2008; Tibor et al. 2014). However, conversion to agriculture, aquaculture, tourism, urban growth, and overexploitation contribute to the continuous deterioration of mangrove ecosystems (Alongi 2002). The rapid removal and deterioration of mangroves could have detrimental repercussions for the movement of materials into marine systems and alter the composition of the atmosphere and climate (Giri et al., 2011).

The study's specific goals were: (i) to construct and to use allometric models for estimating carbon stocks in the Rufiji River Delta's mangroves, (ii) to build and to use volume prediction models for volume estimation in the Rufiji River Delta's mangroves, (iii) to determine the stocks of soil organic carbon (SOC) in the mangrove ecosystem.

## MATERIALS AND METHODS

### Study site description

This research was carried out in the mangrove ecosystem in the Rufiji River Delta, Rufiji District, Tanzania (Figure 1). The delta, which is situated between latitudes 7°50' and 8°03' S and longitudes 39°15' and

32°17'E7.47° E, comprises 53,255 acres (Semesi 1989 as reported by Mwalyosi 2002). It is situated about 178 km south of Dar es Salaam. Tropical forest and grassland vegetation cover the majority of the Rufiji District. The Rufiji River Delta is part of the Rufiji River basin, 177.000 $km^2$ in size (Mwalyosi, 2002; Taylor et al., 2003). The Delta is home to East Africa's biggest region of estuarine mangroves, which supply nursery grounds for over 80% of Tanzania's prawn fishing business (Pethick and Spencer 1990). *Rhizophora mucronata* Poir., *Sonneratia alba* J.E. Smith., *Ceriops tagal* (Perr.) C.B. Robinson., *Avicennia marina* (Forsk.) Vierh., and *Bruguiera gymnorrhiza* (L.) Savigny is common mangrove species in the Rufiji River Delta (Mwalyosi 2002). *Lumnitzera racemosa* Wild., *Heritiera littoralis* Aiton, and *Xylocarpus granatum* Koen are other species.

Rufiji District has a year-round temperature range of 13 to 41°C, with two rainy seasons ranging from 750 to 1250 mm: short rains (October-December) and long rains (February-May). The district's population is over 182,000 people, with the Ndengereko the leading ethnic group (Mkindi and Meena 2005). In the Rufiji floodplain and Delta, agriculture is the primary source of income (93% of households). Rice is the primary diet for 76% of the households in the lower Rufiji River Valley and was grown with different crops. *Oryza sativa* (rice), *Zea mays* (maize), *Ipomoea batatas* (sweet potatoes), *Eleusine coracana* (millet), and fruits such as *Mangifera indica* (mangoes), *Citrus sinensis* (oranges), *Ananas comosus* (pineapples), *Carica papaya* (papaya), and *Artocarpus heterophyllus* (jack fruit) are primarily grown for subsistence. Still, a small% age is grown for (Mkindi and Meena 2005).

## Sampling design

This study used a stratified random sampling design for carbon inventory, as MacDicken (1997) recommended and Kauffman and Donato (2012), which deliver more precise estimates than alternative designs. According to species distribution, the study area was divided into six strata. As a result, each stratum was designated by the dominating species or species type. *Heritiera littoralis, Avicennia marina*, *Rhizophora mucronata*, *Ceriops tagal*, *Sonneratia alba*, and *Bruguiera gymnorrhiza* represented these strata. Transects were created at right angles to the boundaries of the mangrove forest in each stratum from the forest margins. Plots were 100-150 meters apart, while transects were 500-750 meters apart. Accessibility issues caused by mud and canals required such distance alterations (Mattia and Malimbwi 1999). *Xylocarpus granatum and Lumnitzera racemosa*, the other two species, do not form strata/pure stands in the studied region. As a result, when they were discovered in different strata during inventory, they were included and purposefully selected during destructive sampling. The strata were allocated using vegetation maps mixed with ground-truthing. Each stratum's sampling plots were laid systematically, with the starting point chosen at random.

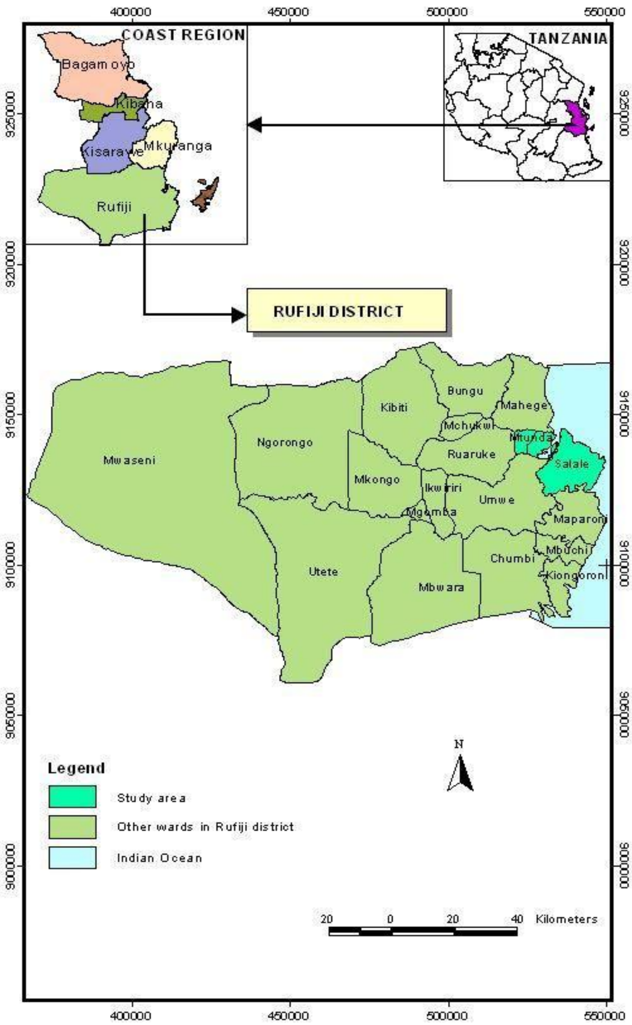



**Figure 1.** Location of the study site in the Rufiji River Delta, Rufiji District, Tanzania

## Sample size determination

Before the fieldwork, a pilot study was conducted to assess the study area's DBH size classes and species distribution. The number of sampling plots was selected using the size of the forest and a predetermined sampling intensity of 0.01%, resulting in 59 plots (equation 1).

N = (TA * Si)/Ps * 100)............................................(1)

Where: N: Number of sample plots, TA: Total area of the forest, Si: Sampling intensity, Ps: Plot size.

## Data collection for aboveground carbon estimation

With a randomly chosen starting position, a total of 59 rectangular plots measuring 20 m x 40 m (Munishi et al. 2010b) were established methodically (Malimbwi et al. 1994). Each plot was broken into eight 10 m × 10 m sub-plots for convenient parameter measurements. For R. mucronata, all trees having a DBH of less than 5 cm in each subplot had their DBH measured using a diameter tape at 1.3 m from the ground and 30 cm above the highest prop root (Komiyama et al. 2005). With the help of a local botanist and a mangrove ecosystem management plan, these trees were identified by their native and scientific names. Three to five sample trees were measured for total height in each plot, after which a height/diameter connection was constructed, and the equation was used to predict the height of all other trees measured for DBH only.

**Model development**

The allometric models were created using a destructive sampling method. For the construction of the biomass and volume models, 50 trees were felled at random. A pilot study determined that the selected trees had a 5 to 56 cm diameter at breast height. These trees were felled, divided into stems and branches, and then cut into little billets with top and bottom diameters roughly the same (Figure 2). The billets were measured for mid diameters and length independently for volume estimations (Figure 3). Following that, the billets were weighed and recorded for fresh weight using a hanging scale with a capacity of 100 kg. Tree billets that could be easily lifted were weighed after tied together with a sisal rope. Branches were given the same treatment as stems. Finally, small sample discs about 2 cm thick were cut from each sample tree's stems, roots, and branches to determine wet to dry weight conversion factors, as advised by Malimbwi et al. (1994); Munishi et al. (2010a); Ebuy et al. (2011); Ong and Gong (2013). Huber's formula was used to calculate the volume of each part (equation 2). Twigs and leaves were collected and weighed fresh then small samples were taken for laboratory examination. By adding the volumes of the individual billets, the total volume of the stems and branches was calculated.

$$V = \pi d^2/40000 * L \quad \text{(2)}$$

Where:
V: volume ($m^3$)
d : diameter of the billet (cm)
L: Length of the billet (m)

**Estimation of root biomass**

The surface soils around the stump were dug with spades, shovels, and hoes to expose all roots. The root collar diameter (RCD) was measured on all roots. All roots were excavated and measured for new weights for stumps that were straightforward to unearth (Figure 4). Only three roots were calculated for the remaining stumps for fresh weights: small, medium, and large. The roots were taken from the stump, cleansed to eliminate mud, and then cut into little billets that were weighed and recorded fresh. For laboratory study of wet to dry conversion factors, small samples of around 2 cm thick were obtained (Snowdon et al. 2002; Ritson and Sochacki 2003).

**Collection and handling of soil samples**

Three types of variables were assessed to obtain an accurate inventory of organic carbon stocks in the organic soil: soil depth (cm), soil bulk density (g $cm^{-3}$), and organic carbon concentrations (% C) inside the sample, as recommended by Pearson et al. (2007) and Murdyarso et al. (2010). A 98.125 $cm^3$ steel core sampler collected soil samples from each plot center at three depths: 0-15 cm, 15-30 cm, and 30-60 cm. Undisturbed soil cores, as indicated by Munishi and Shear (2004), were taken to assess soil bulk density. The soil corer was pushed into the soil to the depths listed above before being removed. The soil samples were placed in plastic sealable tubes, labeled, weighed, and transferred to the soil organic carbon examination laboratory.

**Determination of soil organic carbon (SOC)**

The soil cores were taken from the tubes in the laboratory, and the wet mass was measured. Cerón-Bretón et al. (2011) oven dried the materials to a constant weight at 103 ± 2°C. For each sample, soil BD was calculated as a ratio of oven-dry weight to soil core volume (98.125 $cm^3$). Soil samples were air-dried and then crushed to determine C concentrations. After that, the samples were sieved through a 2-mm filter to eliminate any gravels, roots, or other debris. SOC content was determined using the Wet Oxidation method (through the Walkley-Black method). Total soil carbon storage per unit area was calculated by multiplying the organic carbon content of the soil by the bulk density and depth of the soil (equation 3).

$$\text{Total C (t C ha}^{-1}) = (\text{soil B.D (g cm}^{-3}) \text{ x soil depth (cm) x\%C)} \quad \text{(3)}$$

**Data analysis**

*Development of allometric models*

The stem, branch, and root discs from the field were soaked in water for eight days before being weighed for green weight in the lab. After that, all samples were oven-dried to a consistent dry weight at 105°C. The basic density of the samples was estimated as a ratio of mass (g) to volume (L) ($cm^3$). The water displacement method was used to determine the volume of the samples. The biomass ratio for the stem and branch samples was computed by dividing the oven-dry weight by the green weight of the wood samples (Malimbwi et al. 1994; Munishi and Shear 2004, Munishi et al. 2010a), and then averaging by component and by species. The leaves and twigs samples were oven-dried to a consistent weight at 70°C. The biomass ratio (equation 4) was used to calculate the biomass of stems, branches, leaves, and twigs based on their green weights (Snowdon et al., 2002).

$$\text{Biomass (kg)} = \text{Green weight (kg) x Biomass ratio} \quad \text{(4)}$$

*Estimation of root biomass*

Root samples were oven-dried at 80°C to a consistent weight in the lab. Because just a few roots were measured in the field for fresh weight, an RCD-biomass connection was created to estimate the biomass of the remaining roots (equation 5). To obtain biomass prediction models, the estimated biomass was regressed on DBH.

$$B = \text{Exp}\{-5.241+2.527 \ln(RCD)\}, (R^2 = 0.81, SE = 0.83, N = 52) \quad \text{(5)}$$

Where: B: biomass (kg), RCD: root collar diameter (cm)

**Figure 2.** Cross-cutting a tree of *Avicennia marina* into manageable billets in Rufiji River Delta, Tanzania (Photo: Lupembe 2013)

**Figure 3.** Recording diameters of billets before weighing in Rufiji River Delta, Tanzania (Photo: Lupembe 2013)

**Figure 4.** Pulling out a root stump of *Ceriops tagal* in Rufiji River Delta, Tanzania (Photo: Lupembe 2013)

*Fitting and selection criteria for the best fit models*

Biomass and volume data were processed using a Statistical Packages for Social Sciences and a Microsoft Excel spreadsheet running on Windows 7. (SPSS Version 16 software). To generate biomass/carbon and volume prediction models, the biomass and volume were regressed against DBH, a combination of DBH and height, and DBH, height, and wood density (Malimbwi et al. 1994; Munishi et al. 2001; Munishi et al. 2010b). The best fit models for the biomass and volume components were determined using least squares regression analysis. The models with the greatest fit were chosen based on the following criteria: lowest standard error of estimate (SEE), highest coefficient of determination (R2), and best performance in graphical analysis of residuals.

The following general kinds of biomass/volume equations were fitted and tested in the development of the biomass and volume models:

(i) $Ln(Y) = b_o + b_1 Ln(DBH)$ ……………………… (6)
(ii) $Ln(Y) = b_o + b_1 Ln(DBH) + b_2 Ln(H)$ ………….... (7)
(iii) $Y = b_o + b_1(DBH^2 H)$ ……………………..…….. (8)
(iv) $Ln(Y) = b_o + b_1 Ln(dDBH^2 H)$ ……………..……… (9)
(v) $Y = aX^b$ …………………..…… ….……………… (10)

Where: Y: biomass (kg $stem^{-1}$) or volume ($m^3$ $stem^{-1}$), DBH: diameter at breast height (cm), H: total tree height (m), d: wood basic density (g $cm^{-3}$), and a, b, $b_0$, $b_1$ and $b_2$ are regression constants.

*Computation of biomass and volume*

The plot tree diameter data were utilized to predict biomass/carbon storage and volume using allometric models constructed with DBH as a predictor variable (Malimbwi et al. 1994; Munishi et al. 2010a). Because it is expected that around half of biomass is carbon, the amount of carbon was calculated by multiplying the plot biomass by 0.50. (Malimbwi et al. 1994; Munishi et al. 2001; Munishi and Shear 2004; Basuki et al. 2009).

Stem density and basal area computations

The DBH tally from the sample plots was used to determine the average stocking for the mangrove species (equation 11);

$N = (1/n)\ (x_i/a_i)$ ……………………….....……….. (11)

Where: N: average number of stems per hectare, n: number of plots, $x_i$: number of stems in plot I, $a_i$: area of plot i.

The mean basal area ($m^2$ $ha^{-1}$) was estimated from sample plot area and DBH tally (equation 12);

$G = (1/n)\ (gi)/a$ ………………..………………….. (12)

Where: G: Basal area per hectare

$g_i = (\pi/4)/d_i^2$

Where: a and $d_i$ area sample plot area (ha) and diameter of the $i^{th}$ stem in the plot respectively for n plots.

## RESULTS AND DISCUSSION

### Allometric models for carbon prediction

Table 1 shows the allometric equations for the dry weight of stems and roots, which generally fit the data well and had more than 80% coefficients of determination. All of the models were statistically significant (p<0.05). Although substantial, the biomass/carbon prediction models for branches, leaves, and twigs were not as powerful as the stems and roots. Munishi et al. (2010a) found that the biomass/carbon prediction models created for branches and twigs in Miombo woods were not strong but significant.

Wood basic density

Stems had a basic density of 0.33 to 0.69 g $cm^{-3}$, with a mean of 0.59 ± 0.042 g $cm^{-3}$ (Table 2). Wood basic density for branches ranged from 0.32 to 0.65 g $cm^{-3}$, with a mean of 0.57 ± 0.038 g $cm^{-3}$. Basic density for roots varied from 0.18 ± 0.021 to 0.72 ± 0.037 g $cm^{-3}$, with a mean of 0.47 ± 0.055 g $cm^{-3}$. Roots had a lower fundamental density than branches for the overall pattern (Table 2). The roots of *R. mucronata*, on the other hand, showed a greater basic density (0.72 ± 0.037 g $cm^{-3}$) than the stems and branches. The basic root density of *L. racemosa* was the lowest, at 0.18 ± 0.021 g $cm^{-3}$.

### Biomass characteristics of the mangrove species in Rufiji River Delta

The biomass of mangrove species was concentrated in trunks (55.63%) rather than branches (9.62%), leaves, and twigs (2.80%). The BGB (31.95%) was roughly half that of the AGB. The biomass of stilt roots in *R. mucronata* was likewise higher than some branches and leaves. Compared to other mangrove species, *R. mucronata* and *A. marina* showed the most significant regressions. The strongest relationships with DBH were stems and BGB (R=0.9, P<0.01). The biomass of branches, leaves and twigs had a weak positive connection with DBH (R=0.6, P<0.01). Carbon contents of the mangrove ecosystem in Rufiji River Delta.

The Rufiji River Delta's total C stock was estimated to be 160.15 t $ha^{-1}$. The soil contributed the most carbon to the overall carbon pool, with 98.57 t $ha^{-1}$. Soil C alone accounted for around 62% of the ecosystem's overall C estimates. A total of 40.5 t $ha^{-1}$ of aboveground carbon was estimated (25.29%). Stems made the most contribution (55.34%), followed by branches (8.22%). Leaves and twigs supplied the least to total aboveground C stocks (2.21%). The Rufiji River Delta's belowground C pool (roots) was calculated to be 21.08 t $ha^{-1}$, or 13.16% of the overall C stock (Figure 5). In the Rufiji River Delta, Tanzania, belowground C (roots and soils) accounted for 74.71% of the total C supply.

### Proportional contribution to c stocks by different species

On a hectare basis, the following tree species contributed to total carbon stocks: R. *mucronata* (39.87%) stored the most carbon per unit area, followed by *A. marina* (28.06%), *B. gymnorrhiza* (15.61%), *H. littoralis* (4.90%), *C. tagal* (4.11%), and *S. alba* (2.58%). *L. racemosa* provided the least total carbon stocks (1.98%) (Figure 6).

### Carbon Storage at Different DBH size classes

In different DBH classes, mangrove species have variable carbon storage capabilities (Figure 6). DBH class 25-29.9 cm provided the most carbon, accounting for 30.85% of total carbon stores, followed by DBH class >34.9 cm, which produced 23.25% of total carbon stocks. DBH class 5-9.9 cm (4.08%) contributed the least carbon, followed by DBH class 10-14.9 cm (5.76%). This means that little trees may not provide much carbon to the ecosystem, but they are critical in preserving future carbon reserves.

**Table 1.** Carbon prediction models for stems, branches, roots, and leaves and twigs in Rufiji mangrove ecosystem, Rufiji River Delta, Tanzania

| Component | Model | $R^2$ | SE | P-value |
|---|---|---|---|---|
| Stems | B=Exp{-1.949+2.226ln(DBH)} | 0.81 | 0.4573 | <0.05 |
| Branches | B=Exp{-3.463+2.103ln(DBH)} | 0.57 | 0.7606 | <0.05 |
| Roots | B=Exp{-2.758+2.328ln(DBH)} | 0.85 | 0.4130 | <0.05 |
| Leaves and twigs | B=Exp{-4.081+1.881ln(DBH)} | 0.38 | 1.0670 | <0.05 |

Note: B: biomass**,** $R^2$: coefficient of determination, SE: standard error from the ANOVA of regressions

**Table 2.** Basic density (mean ± SE) of the mangrove species in Rufiji River Delta, Tanzania

| Species | Stems (g $cm^{-3}$) | Branches (g $cm^{-3}$) | Roots (g $cm^{-3}$) |
|---|---|---|---|
| *Heritiera littoralis* | 0.59 ± 0.018 | 0.54 ± 0.009 | 0.42 ± 0.004 |
| *Rhizophora mucronata* | 0.67 ± 0.006 | 0.62 ± 0.022 | 0.72 ± 0.037 |
| *Bruguiera gymnorrhiza* | 0.69 ± 0.007 | 0.63 ± 0.025 | 0.52 ± 0.009 |
| *Ceriops tagal* | 0.68 ± 0.012 | 0.65 ± 0.008 | 0.57 ± 0.022 |
| *Xylocarpus granatum* | 0.55 ± 0.011 | 0.56 ± 0.014 | 0.49 ± 0.006 |
| *Sonneratia alba* | 0.57 ± 0.004 | 0.56 ± 0.017 | 0.38 ± 0.006 |
| *Lumnitzera racemosa* | 0.33 ± 0.009 | 0.32 ± 0.012 | 0.18 ± 0.021 |
| *Avicennia marina* | 0.65 ± 0.011 | 0.64 ± 0.025 | 0.50 ± 0.012 |
| Mean | 0.59 ± 0.042 | 0.57 ± 0.038 | 0.47 ± 0.055 |

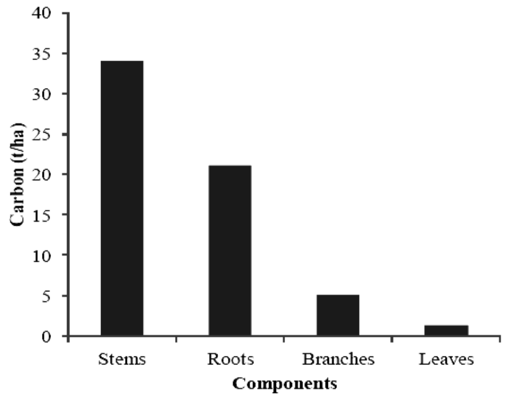



**Figure 5.** Carbon stocks as contributed by different tree components in the mangrove ecosystem of Rufiji River Delta, Tanzania

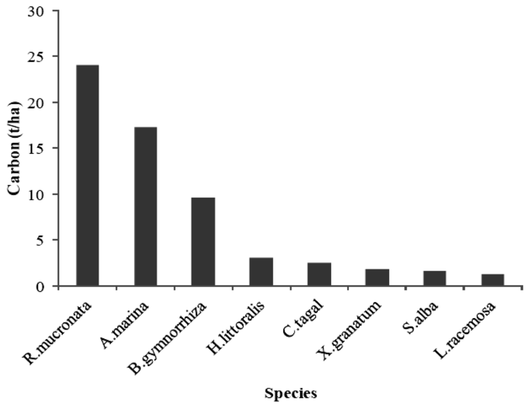



**Figure 6.** Carbon stocks as contributed by different mangrove species in Rufiji River Delta, Tanzania

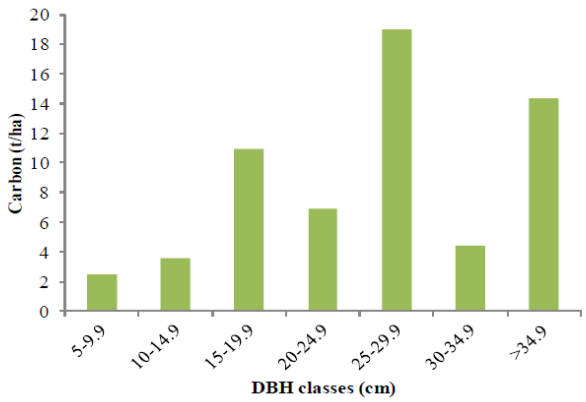



**Figure 7.** Mangrove tree carbon storage at different DBH classes in Rufiji River Delta, Tanzania

**Wood volume, stocking rate, and basal area estimation for the mangroves of Rufiji River Delta, Tanzania**

For linear models (P<0.05) and a power model (<P0.001), all produced volume equations were significant (Table 3). The first two equations simply employed DBH as a predictor variable, but the third equation included DBH and height. DBH class 5-9.9 cm had the most stocking (37.45%), followed by DBH class 15-19.9 cm (21.33%). Several trees with a DBH of less than 5 cm, particularly for *C. tagal*. DBH class 30-34.9 cm (2.12%) produced the lowest stocking, suggesting the presence of huge trees. DBH class 25-29.9 cm (30.12%) had the highest basal area, whereas DBH class 5-9.9 cm had the lowest basal area (5.46%) (Figure 7).

The current analysis calculated a volume of 168.85 ± 8.299 $m^3$ $ha^{-1}$. The most abundant species was R. mucronata (39.26%), followed by *A. marina* (27.10%). *L. racemosa* and *S. alba* contributed the lowest, 2.24% and 2.47%, respectively (Table 5). The volume of trees in the DBH class 25-29.9 cm made up 30.13% of the overall tree volume. 5.43% and 6.75% of the wood volume were given by DBH classes 5-9.9 cm and 10-14.9 cm, respectively (Table 4). Trees with smaller diameters had lesser volume per unit area, while larger ones had higher volumes per unit area.

**Soil organic carbon**

The soil's bulky density (BD) ranged from 0.53 to 1.17 g $cm^{-3}$, with a mean of 0.89 ± 0.17 g $cm^{-3}$. Between sampling stations, there were no significant differences in soil BD (P>0.05). With a mean of 2.52 ± 0.272, carbon concentrations varied from 0.72 to 5.88%. There was no significant variation in carbon concentration between 15-30 and 30-60 cm layers (P>0.05). The top (0-15 cm) layer, on the other hand, had a considerably greater% C than the different layers (P<0.05). The pH of the soil varied from 2.34 to 7.46, with a mean of 5.78 ± 0.214. (Figure 8). This means that the soils were very strongly acidic to mildly alkaline, with clay as the predominant soil texture.

The average depth of soil organic C storage in the mangrove habitat was 33.5 ± 3.356 t $ha^{-1}$ (Figure 8). Overall, the average soil organic C of the Rufiji River Delta mangrove habitat was 98.57 t $ha^{-1}$ at all depths. The surface layer (0-15 cm) had a higher amount of soil organic C (39.61 ± 2.979 t $ha^{-1}$) than the lower layers, with a total of 39.61 ± 2.979 t $ha^{-1}$. The mean soil organic C in the middle layer (15-30 cm) was 28.04 ± 1.817 t $ha^{-1}$, lower than the mean soil organic C in the bottom layer (30-60 cm) of 32.85 ± 2.579 t $ha^{-1}$. This disparity is due partly to the nature of mangrove soils, which are extremely unstable and soft compared to terrestrial ecosystem soils. In mangrove habitats, soils of various layers are frequently mixed. The surface layer of soil organic C differed significantly from the middle and lowest layers (<P0.05). The middle layer's soil organic C did not differ significantly from the bottom layer's (P>0.05).

**Table 3.** Volume equations for estimating total volumes for the mangrove trees of Rufiji River Delta, Tanzania

| Model | $R^2$ | SE | P-value |
|---|---|---|---|
| V=0.04357DBH-0.54967 | 0.92 | 0.125 | <0.05 |
| $V=0.000716DBH^{2.0037}$ | 0.94 | 0.114 | <0.001 |
| $V=0.1025+0.0000297DBH^2H$ | 0.89 | 0.148 | <0.05 |

Note: $R^2$ and SE are as defined in table 1

**Table 4.** Mean (± SE) stem density (N), basal area (G), and volume (V) in the mangroves of Rufiji River Delta, Tanzania

| DBH Classes | N (stems ha$^{-1}$) | G (m2 ha$^{-1}$) | V (m3 ha$^{-1}$) |
|---|---|---|---|
| 5-9.9 | 273 ± 8 | 1.00 ± 0.001 | 9.17 ± 0.027 |
| 10-14.9 | 105 ± 5 | 1.24 ± 0.002 | 11.40 ± 0.013 |
| 15-19.9 | 155 ± 6 | 3.52 ± 0.003 | 32.44 ± 0.034 |
| 20-24.9 | 53 ± 3 | 2.08 ± 0.006 | 19.15 ± 0.019 |
| 25-29.9 | 98 ± 5 | 5.51 ± 0.005 | 50.88 ± 0.041 |
| 30-34.9 | 15 ± 2 | 1.23 ± 0.016 | 11.39 ± 0.007 |
| >34.9 | 29 ± 3 | 3.72 ± 0.071 | 34.43 ± 0.048 |
| Total | 729 ± 34 | 18.30 ± 0.639 | 168.85 ± 5.903 |

**Table 5.** Wood volume (mean ± SE) for different mangrove species of Rufiji River Delta, Tanzania

| Species | Volume (m$^3$ ha$^{-1}$) | % |
|---|---|---|
| *Rhizophora mucronate* | 66.29 ± 0.159 | 39.26 |
| *Avicennia marina* | 45.76 ± 0.259 | 27.10 |
| *Bruguiera gymnorrhiza* | 27.13 ± 0.148 | 16.07 |
| *Heritiera littoralis* | 8.97 ± 0.145 | 5.32 |
| *Ceriops tagal* | 7.74 ± 0.097 | 4.58 |
| *Xylocarpus granatum* | 5.00 ± 0.377 | 2.96 |
| *Sonneratia alba* | 4.18 ± 0.789 | 2.47 |
| *Lumnitzera racemose* | 3.78 ± 0.126 | 2.24 |
| Total | 168.85 ± 8.299 | 100.00 |

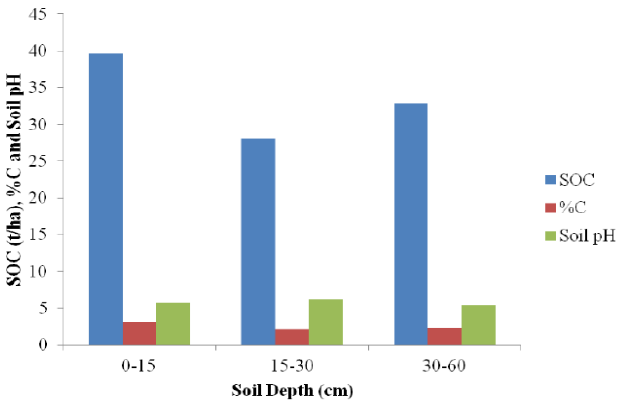



**Figure 8.** Soil organic carbon, carbon concentration, and soil pH at different depths in the mangrove ecosystem of Rufiji River Delta, Tanzania

## Discussion

Carbon stocks in the mangrove ecosystem of Tanzania's Rufiji River Delta were assessed in this study. For the past 20 years, allometric models have been used to study carbon/biomass in mangroves (Komiyama 2005). Allometric models were created in this study by regressing biomass/volume against DBH and/or height as predictor variables. The generated models were used to predict the mangrove ecosystem's aboveground, belowground, and volume in the Rufiji River Delta. The importance of soil organic carbon as a carbon source was also examined.

*Biomass/carbon prediction models for the mangroves of Rufiji River Delta.*

Due to the limitations connected with height measurements in this species, this study exclusively used DBH to estimate biomass in the mangrove ecosystem of the Rufiji Delta. The DBH has been utilized as the only independent variable in several studies that have used regression to explore biomass in mangroves (Ong et al., 2004; Soares et al., 2005). However, other research estimated the aboveground biomass of mangrove species using formulae based on height and DBH (Suzuki and Tagawa 1983; Ross et al. 2001; Abohassan 2012). Other studies have used a combination of DBH, height, and particular wood gravity as predictor variables (Ross et al. 2001; Soares et al. 2005), and some studies have used a combination of DBH, height, and specific wood gravity as predictor variables (Ross et al. 2001; Soares et al. 2005). (Chave et al. 2005). The majority of research has encouraged using models in which tree biomass is determined solely by DBH measurements, which has the advantage of being practical because most inventories contain DBH measurements. DBH is also simple to measure accurately in the field (Segura and Kanninen 2005). Compared to stem and root biomass, the biomass of branches, leaves, and twigs was less predictable. Munishi et al. (2010a), Sawadogo et al. (2010), and Wang et al. (2010) have all found similar findings (2011). As a result, it is easier to anticipate the biomass of large woody components like stems and total aboveground biomass for smaller components like branches and twigs. The branches and leaves are extremely sensitive to light, water, nutrients, and soil conditions, such as microclimate and competition from neighbors (Sawadogo et al., 2010). Carbon biomass in the mangrove ecosystem of the Rufiji River Delta

According to Brown (2002), most hardwood forests contain aboveground biomass of 75-175 Mg ha$^{-1}$ (or 38-90 Mg C ha$^{-1}$). The C estimations of the current study are within this range. The estimated aboveground C storage in the Rufiji River Delta (40.5 t C ha$^{-1}$) is comparable to the 98.4 t ha$^{-1}$ recorded by Faridah-Hanum et al. (2012) in the Marudu Bay forest (approximately 49 t C ha$^{-1}$). *Rhizophora mucronata* had the largest biomass, accounting for almost half of the total TAGB. Suzuki and Tagawa (1983) found that stocking (density), basal area, and height significantly impacted total aboveground biomass. *Rhizophora mucronata* exhibited the maximum basal area (39.25%) and moderate stand density in the Rufiji River Delta. Ross et al. (2001) calculated aboveground biomass to be 22.28 5.18 t ha$^{-1}$ in Dwarf forests and 56.02 11.96 t ha$^{-1}$ in Fringe forests, equating to around 11 t C ha$^{-1}$ and 28 t C ha$^{-1}$, respectively. Aboveground C stocks were found to be greater in the current study. However, if dead forests and trees with a diameter of less than 5 cm were included in the present study, the aboveground C could be considerably higher.

Tamooh et al. (2008) found that belowground C stocks (roots) in the Rufiji River Delta in Gazi Bay vary between 3.8 0.2 C t ha$^{-1}$ and 17.9 0.6 C t ha$^{-1}$, 24.2 0.4 C t ha$^{-1}$ and 37.7 1.0 C t ha$^{-1}$, 19.5 0.4 C t ha$^{-1}$ and 21.9 0.9 C t ha$^{-1}$ for *R. mucronata*, *S. alba*, and *A. marina* stands, respectively.

The amount of C in a mangrove forest is also determined by the type. Root C of 32.4 t $ha^{-1}$, 106.6-173.3 t $ha^{-1}$, and 187.0-272.9 t $ha^{-1}$ have been reported in primary forests of *Sonneratia sp., Bruguiera sp.,* and *Rhizophora sp.*, respectively (Komiyama et al. 1987). Because the mangroves in the Rufiji River Delta are secondary forests, they are unlikely to have the same high C stocks as primary forests. Abohassan et al. (2001) reported aboveground biomass of 14.77 t $ha^{-1}$ and belowground biomass of 67.8 $ha^{-1}$ in the Arid Mangrove Systems on the Red Sea Coast of Saudi Arabia, which corresponds to around 7 and 34 t C $ha^{-1}$, respectively. As can be observed, mangroves in arid places tend to have vast underground reservoirs.

Mangroves, particularly Rhizophora sp., have low R/S biomass ratios in tropical forests (Komiyama 2000). The current study employed an R/S biomass ratio of 0.49, which, if implemented, would result in a belowground C estimate of 19.85 t $ha^{-1}$, which is 1.23 t $ha^{-1}$ less than that derived using the allometric model provided by this study. This R/S biomass ratio can be used to approximate the belowground biomass in mangrove habitats in the Rufiji River Delta, Tanzania because the difference is small.

Volume prediction models for the mangroves of the Rufiji River Delta

In this study, three-volume estimation equations were established (Table 3). The power model was very significant ($P<0.001$), and both linear models were significant ($P<0.05$). DBH was utilized as the single predictor variable in the first two equations, whereas DBH and height were employed in the third equation. The most common predictor variable in allometric models is the diameter (Malimbwi et al. 1994; Munishi et al. 2001; Munishi and Shear 2004; Munishi et al. 2010b). Compared to the other models, the power model explained 94% of the volume variance and had the smallest standard error. As a result, this model was employed to estimate tree volumes in this investigation.

Volume estimates for the mangroves of the Rufiji River Delta

This study's mean tree volume estimate of 168.85 ± 8.299 $m^3$ $ha^{-1}$ (Table 5) was lower than Mattia and Malimbwi's (1999) estimate of 268 ± 6.08 $m^3$ $ha^{-1}$. They also calculated the basal area to be 28 ± 0.44 $m^2$ $ha^{-1}$ and the average tree stocking to be 1,488 ± 2.50 trees per hectare. These were higher than the findings of the current research. The number of stems per hectare previously reported was higher because saplings (trees with less than 5 cm diameter and a height of more than 1 m) were included. Anthropogenic activities may have also contributed to the ecosystem's current decreased volume and basal area. Large portions of the Rufiji River Delta have been cleared for rice farming and selective logging, and this process is currently ongoing (Figure 9 and 10). Rice farming in Tanzania's Rufiji River Delta has resulted in the loss of approximately 1,700 hectares of mangroves. Rice is crucial for the survival of people in the area, and almost 75% of the population considers farming to be their top priority (Taylor et al., 2003).

**Figure 9.** Farmers weeding rice farms in Rufiji River Delta, Tanzania (Photo: Lupembe 2013)

**Figure 10.** Land preparation for planting rice in Rufiji River Delta, Tanzania (Photo: Lupembe, 2013)

*Soil organic carbon in the mangroves of the Rufiji River Delta*

The organic matter concentration of the surface layers in the Rufiji River Delta was higher, especially in undisturbed areas. On the other hand, SOC did not demonstrate a steady reduction in depth from 0-60 cm. The C content of the surface layers (0-15 cm) was higher, whereas the middle layer (15-30 cm) had a lower C content than the bottom layer (0-15 cm) (30-60 cm). These findings contradict those of Pandey and Pandey (2013), who found that there was more C in the lower layers (16 to 30 cm depth) than in the top levels (up to 15 cm depth). Organic C concentrations in the Rufiji River Delta ranged from 0.92 to 5.88%, with a mean of 2.54 ± 0.12%, significantly lower than those found in the Tropical Pacific by Donato et al. (2012). Among other anthropogenic activities, agriculture and selective logging may have contributed to the reduced C content in Tanzania's Rufiji River Delta.

The amount of carbon in soil varies widely amongst mangroves, and is primarily controlled by forest age, tidal exchange, and suspended matter sedimentation (Cerón-Bretón et al., 2011). Mangroves' upper soil layers contain more trash and dead (and living) roots than the lower layers, eventually raising the C content in the top layers (Nguyen et al., 2011). Long periods of tidal flooding combined with slow decomposition result in anoxic conditions and high organic matter content, explaining the increased organic matter concentration in upper mangrove layers (Cerón-Bretón et al., 2011).

The SOC in this study is within the range of 71.8 to 154.8 t C $ha^{-1}$ reported by Matsu et al. (2012). However, SOC in young Kandelia Kandel L. Blanco plantations was higher than that of Nguyen et al. (2009), ranging from 31 to 85 t $ha^{-1}$. Because this plantation was still young, it seemed likely that it had not yet gathered enough organic matter. In dense, intermediate, and sparse mangroves, Pandey and Pandey (2013) found 87.83 t C $ha^{-1}$, 36.99 t C $ha^{-1}$, and 44.08 t C $ha^{-1}$, respectively. These figures were lower than the ones found in the current research. In contrast, soil carbon estimations in the Rufiji River Delta were very low compared to greater C stocks in the Tropical Pacific reported by Donato et al. (2012), ranging from 631 to 754 Mg C $ha^{-1}$. Peat soils showed substantially greater organic carbon concentrations (13-15%) that lasted throughout the soil profile to depths below 1 m, resulting in higher carbon estimates.

In conclusion, the models created for estimating biomass and volume in the Rufiji River Delta mangrove environment should vastly improve the ability and reliability to estimate biomass and tree volume without harvesting trees. (ii) Higher carbon storage has been discovered in mangrove forests in the Rufiji River Delta, implying that conservation can greatly improve carbon stocks and attract large carbon-based funding for land restoration. (iii) Maintaining the health of mangrove forests and their vast carbon reserves is critical for climate change mitigation, which can be achieved by preventing deforestation in the Rufiji River Delta. (iv) Despite continuous deforestation, the large carbon stores in mangrove forests of the Rufiji River Delta, as demonstrated by this study, show that mangrove ecosystems are important conservation areas.

## REFERENCES


Abohassan RAA, Okia CA, Agea JG, Kimondo JM, McDonald MM. 2012. Perennial biomass production in arid mangrove systems on the Red Sea Coast of Saudi Arabia. Environ Res J 6 (1): 22-31.

Alongi DM. 2002. Present state and future of the world's mangrove forests. Environ Conserv 29 (3): 331-349. DOI: 10.1017/S0376892902000231

Basuki TM, van Laake PE, Skidmore AK, Hussin YA. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. For Ecol Manag 257 (8): 1684-1694. DOI: 10.1016/j.foreco.2009.01.027

Bouillon S. Borges AV. Castaneda-Moya E, Diele K, Dittmar T, Duke NC, Kristensen E, Lee SY, Marchand C, Middelburg JJ, Rivera-Monroy VH, Smith TJ III, Twilley RR. 2008. Mangrove production and carbon sink: a revision of global budget estimates. Glob Biogeochem Cycl 22 (2): 1-12. DOI: 10.1029/2007GB003052

Brown S. 2002. Measuring carbon in forests: current status and future challenges. Environ Pollut 116 (3): 363-372. DOI: 10.1016/S0269-7491(01)00212-3

Burgess ND, Bahane B, Clairs T, Danielsen F, Dalsgaard S, Funder M, Hagelberg N, Harrison P, Haule C, Kabalimu K, Kilahama F, Kilawe E, Lewis S, Lovert JC, Lyatuu G, Marshall AR, Meshack C, Miles L, Milledge SAH, Munishi PKT, Nashanda E, Shirima D, Swetnam RD, Willcock S, Williams A, Zahabu E. 2010. Getting ready for REDD+ in Tanzania: a case study of progress and challenges. Fauna Flora Intl Oryx 44 (3): 339-351. DOI: 10.1017/S0030605310000554

Cerón-Bretón JG, Ceron-Cerón-Bretón RM, Rangel-Marron M, Muriel-Garcia M, Cordova-Quiroz AV, Estrella-Cahuich A. 2011. Determination of carbon sequestration rate in soil of a mangrove forest in Campeche, Mexico. Intl J Energy Environ 3 (5): 328-336. DOI: 10.2495/SDP-V5-N3-282-298.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Fo¨ lster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson W, Ogawa H, Puig H, Rie´ra B, Yamakura T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145 (1): 87-99. DOI: 10.1007/s00442-005-0100-x

Donato DC, Kauffman JB, Mackenzie RA, Ainsworth A, Pfleeger A. 2012. Whole-island carbon stocks in the tropical Pacific: Implications for mangrove conservation and upland restoration. J Environ Manag 97: 89-96. DOI: 10.1016/j.jenvman.2011.12.004

Ebuy J, Lokombe JP, Ponette Q, Sonwa D, Picard N. 2011. Allometric equation for predicting aboveground biomass of three tree species. J Trop For Sci 23 (2): 125-132.

FAO. 2007. The World's Mangroves 1980-2005. A Thematic Study prepared in the framework of the Global Forest Resources Assessment 2005. FAO Forest Paper No. 153. ftp://ftp.fao.org/docrep/fao/010/a1427e/a1427e00.pdf

FAO. 2010. Global Forest Resources Assessment 2010. Main report. Food and Agriculture Organization. Forest Paper No. 163. Rome, Italy. http://www.ipex.org/files/global_forest_resources.pdf

Faridah-Hanum I, Kudus KA, Saari NS. 2012. Plant diversity and biomass of Marudu Bay Mangroves in Malaysia. Pak J Bot 44 (Suppl 2): 151-156.

Gibbs HK, Brown S, Niles JO, Foley JA. 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environ Resour Lett 2 (4): 1-13. DOI: 10.1088/1748-9326/2/4/045023

Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecol Biogeogr 20 (1): 154-159. DOI: 10.1111/j.1466-8238.2010.00584.x

Hannah L, Lovejoy T. 2011. Conservation, Climate Change, and Tropical Forests. In: Bush MB, Flenley JR, Gosling WD (eds) Tropical Rainforest Responses to Climatic Change (Second Edition). Springer-Verlag Berlin Heidelberg. DOI: 10.1007/978-3-642-05383-2_16

IPCC. 2007. *Climate change* 2007. The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK.

Kauffman JB, Donato DC. 2012. Protocols for the measurement, monitoring, and reporting of structure, biomass, and carbon stocks in mangrove forests. Working Paper No. 86. Center for International Forestry Research, Bogor, Indonesia.

Kauffman JB, Heider C, Cole TG, Dwire KA, Donato DC. 2011. Ecosystem carbon stocks of micronesian mangrove forests. Wetlands 31 (2): 343-352. DOI: 10.1007/s13157-011-0148-9

Komiyama A, Paungparn S, Kato S. 2005. Common allometric equations for estimating the tree weight of mangroves. J Trop Ecol 21 (4): 471-477. DOI: 10.1017/S0266467405002476

Komiyama A, Havanond S, Srisawatt W, Mochida Y, Fujimoto K, Ohnishi T, Ishihara S, Miyagi T. 2000. Top/root biomass ratio of a secondary mangrove (*Ceriops tagal* (Perr.) C.B. Rob.) forest. For Ecol Manag 139 (1-3): 127-134. DOI: 10.1016/S0378-1127(99)00339-4

Komiyama A, Ongino K, Aksornkoae S, Sabhasri S. 1987. Root biomass of a forest in Southern Thailand.1. Estimation by trench method and zonal structure of root biomass. J Trop Ecol 3 (2): 97-108. DOI: 10.1017/S0266467400001826

Malimbwi RE, Solberg B, Luoga E. 1994. Estimation of biomass and volume in miombo woodlands at Kitulang'alo forest reserve, Tanzania. J Trop For Sci 7 (2): 230-242.

Mattia SB, Malimbwi RE. 1999. Structure of Natural Mangrove Forests at Rufiji Delta, Tanzania. Proceedings of SUA/AUN Workshop on Tanzania Forestry Sector: Problems and Possible Solutions. Olmotonyi, Arusha, Tanzania, 23-26 March 1998.

Mkindi AR, Meena HE. 2005. Rufiji District Residents and Adaptation to Environmental Changes over Time. Envirocare. CEEST Foundation.

Munishi PKT, Mringi S, Shirima DD, Linda SK. 2010a. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. J Ecol Nat Environ 2 (12): 261-269.

Munishi PKT, Shear TH. 2004. Carbon storage in Afromontane Rainforests in the Eastern Arc Mountains of Tanzania: their net contribution to atmospheric carbon. J Trop For Sci 16 (1): 78-93.

Munishi PKT, Mhagama M, Muheto R, Andrew SM. 2001. The role of urban forestry in mitigating climate change and performing environmental services in Tanzania. Tanzania J For Nat Conserv 77: 25-34.

Mwalyosi RBB. 2002. Management of the Rufiji -Delta as a wetland. Institute of Resource Assessment. University of Dar es Salaam. Tanzania http://www.oceandocs.org/bitstream/1834/532/1/Wetlands114124.pdf

Nguyen TC, Ninomiya I, Lon NT, Tri NH, Tuan MS, Hong PN. 2009. Belowground carbon accumulation in young *Kandelia candel* (L.) Blanco plantations in Thai Binh River Mouth, Northern Vietnam. Int J Ecol Dev 12 (W09): 107-117.

Ong JE, Gong WK. 2013. Structure, Function, and Management of Mangrove Ecosystems. ISME Mangrove Educational Book Series No. 2. International Society for Mangrove Ecosystems (ISME) and International Tropical Timber Organization (ITTO), Japan.

Ong JE, Gong WK, Wong CH. 2004. Allometry and partitioning of the mangrove, *Rhizophora apiculata*. For Ecol Manag 188 (1-3): 395-408. DOI: 10.1016/j.foreco.2003.08.002

Pandey CN. Pandey R. 2013. Carbon sequestration by Mangroves of Gujarat, India. Intl J Bot Res 3 (2): 57-70. DOI: 10.5539/jps.v3n1p35.

Pearson TRH, Brown SL, Birdsey RA. 2007. Measurement guidelines for the sequestration of forest carbon. General technical report, NRS-18. Newtown Square, PA, USDA, Forest Service, Northern Research Station. http://www.nrs.fs.fed.us/ DOI: 10.2737/NRS-GTR-18

Pethick J, Spencer T. 1990. Mangrove response to sea level rise. The Rufiji Delta, Tanzania. Frontier Tanzania. Interim Report.

Ritson P, Sochacki S. 2003. Measurement and prediction of biomass and carbon content of *Pinus pinaster* trees in farm forestry plantations, south-western Australia. For Ecol Manag 175 (1-3): 103-117. DOI: 10.1016/S0378-1127(02)00121-4

Ross MS, Ruiz PL, Telesnicki GJ, Meeder JF. 2001. Estimating above-ground biomass and production in mangroves. Wetl Ecol Manag 9 (1): 27-37. DOI: 10.1023/A:1008411103288

Sawadogo L, Savadogo P, Tiveau D, Zida SDDD, Nouvellet Y, Oden PC, Guinko S. 2010. Allometric prediction of above-ground biomass of eleven woody tree species in the Sudanian savanna-woodland of West Africa. J For Res 21 (4): 475-481. DOI: 10.1007/s11676-010-0101-4.

Segura M, Kanninen M. 2005. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica. Biotropica 37 (1): 2-8. DOI: 10.1111/j.1744-7429.2005.02027.x

Snowdon P, Raison J, Grierson P, Adams M, Montagu K, Bi H, Burrows W, Eamus D. 2002. Protocol for sampling tree and stand biomass. National Carbon accounting system technical report No. 31. Australian Greenhouse Office, Canberra. citeseerx.ist.psu.edu/ viewdoc/download? DOI: 10.1.1.116.263

Soares MG, Schaeffer-Novelli Y. 2005. Above-ground biomass of mangrove species.I. Analysis of models. Estuar Coast Shelf Sci 65 (1-2): 1-18. DOI: 10.1016/j.ecss.2005.05.001

Suzuki E, Tagawa H. 1983. Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, Southern Japan. Japn J Ecol 33 (2): 231-234.

Tamooh F, Huxham M, Karachi M, Mencuccini M, Kairo JG, Kirui B. 2008. Below-ground root yield and distribution in natural and replanted mangrove forests at Gazi bay, Kenya. For Ecol Manag 256 (6): 1290-1297. DOI: 10.1016/j.foreco.2008.06.026

Taylor M, Ravilious C, Green EP. 2003. Mangroves of East Africa. UNEP World Conservation Monitoring Centre. Cambridge, United Kingdom.

Tibor Megan J, Linwoo, P, Brian M. 2014. Mangrove Ecosystem Services Valuation: State of the Literature. NI WP 14-06. Duke University, Durham, NC.

Twilley RR, Chen RH, Hargis T. 1992. Carbon sinks in mangroves and their implications to the carbon budget of tropical coastal ecosystems. Water Air Soil Pollut 64 (1): 265-288. DOI: 10.1007/BF00477106

Wang J, Zhang C, Xia F, Zhao X, Wu L, Gadow KV. 2011. Biomass structure and allometry of *Abies nephrolepis* (Maxim) in Northeast China. Silva Fenn 45 (2): 211-226. DOI: 10.14214/SF.113

**BONOROWO WETLANDS**
Volume 9, Number 1, June 2019
Pages: 42-55

P-ISSN: 2088-110X
E-ISSN: 2088-2475
DOI: 10.13057/bonorowo/w090105

# Review: *Rhizophora mucronata* as source of foods and medicines

**AHMAD DWI SETYAWAN[1], P. RAGAVAN[2], M. BASYUNI[3], SARNO SARNO[4,♥]**
[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Jend. Urip Sumoharjo, Surakarta 57128, Central Java, Indonesia
[2]Institute of Forest Genetics and Tree Breeding. P.B. No 1061, R.S.Puram, Coimbatore 641002, Tamil Nadu, India
[3]Department of Forestry, Faculty of Forestry, Universitas Sumatera Utara. Jl. Tri Dharma Ujung No. 1, Medan 20155, North Sumatera, Indonesia
[4]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. Jl. Raya Palembang-Prabumulih Km 32, Indralaya, Ogan Ilir 30662, South Sumatra, Indonesia. Tel.: +62-711-580056, ♥email: sarno_klaten65@yahoo.co.id

Manuscript received: 3 April 2019. Revision accepted: 21 June 2019.

**Abstract.** *Setyawan AD, Ragavan P, Basyuni M, Sarno S. 2019. Review:* Rhizophora mucronata *as source of foods and medicines. Bonorowo Wetlands 9: 42-55. Rhizophora mucronata* Poir is a type of mangrove plant that is widely distributed in the Indo-Pacific (Indian and Pacific Oceans) region. This plant is mainly harvested for its wood for charcoal, firewood, and building materials. In addition, the bark and its propagule are used for natural dyes and leather tanning. However, its use in the food and health sector is still limited. This review intends to collect, compile, and summarize the use of *R. mucronata* as a source of food and medicinal ingredients. As a result, the starch obtained from *R. mucronata* propagule can be used as a carbohydrate source after removing the tannin content. In the health sector, various parts of this plant organ are traditionally used to remedy diarrhea, hepatitis, ulcers, etc. Further research shows that extraction with multiple solvents across multiple plant organs can be an antioxidant, anticancer, anti-inflammatory, anti-diabetic, antimicrobial (antiviral, antifungal, antibacterial). The main constituent of this plant is tannins, alkaloids, and flavonoids, which affect their biological/pharmacological activities. The part of the organ used and the extraction method significantly affects the chemical content produced, thus affecting its effect in treatment.

**Keywords**: Anticancer, antioxidant, food, medicine, *Rhizophora mucronata*

## INTRODUCTION

Mangroves are halophytes plants that thrive in the transition zone between the terrestrial and marine environments (Giri et al., 2011). The word "mangrove" refers to a taxonomically varied collection of trees and shrubs that appear prominent among plant communities in tidal, salty marshes along sheltered tropical and subtropical coasts (Hamilton and Murphy 1988). Mangroves are multipurpose coastal plants; they protect coastal areas from damage environmentally (Hardoko et al. 2016; Kurniadi and Koeslulati 2020). Mangroves thrive in the dense tangle of roots, muck, and tidal water (Duke and Wain 1981). Following the December 2004 tsunami, mangroves became prominent as hotspots of coastal variety. The Indian Ocean region is home to around 55 species of mangroves from 22 genera (Kathiresan and Rajendran 2005). Mangrove swamps, tidal swamp woods, tidal swamp forests, and mangals are all terms used to describe the habitat of mangrove plants. Mangrove trees are found in 121 countries globally (Chandrasekaran et al., 2009).

Due to their unique physical environment, mangroves have evolved a suite of adaptations to cope with extreme environmental circumstances such as high salinity, strong winds, tidal changes, high temperature, and anaerobic tidal bogs. As a result, the mangrove environment is home to a diverse range of species that abundant bioactive compounds and enzymes. Whether it is the extensive supporting roots of *Rhizophora*, the breathing roots of *Avicennia*, the salt excreting leaves, or the viviparous water dispersed seedlings. Everything possesses an exceptional capacity to produce bioactive metabolites for obvious reasons of survival and propagation, thereby providing them with 'chemical signals' to respond to, thwart, or defend 'environmental clues' (Joel and Bhimba 2010).

Mangroves have historically been utilized for their lumber (in furniture, boats, and fishing equipment), fuelwood, charcoal, food, and medicine. Mangrove extracts and chemical components have been employed as insecticides and pesticides, tannins for the leather industry and dyeing, a salt, potassium carbonate, and sodium chloride alternative, tonic, wine, and a fruit beverage, a betel substitute, and a vegetable (Bandaranayake 1998; Alongi 2002). Food and medicine are derived from the roots, stems, leaves, blooms, and fruit of mangrove plants. Utilization was associated with the nutritional (proteins, lipids, carbs, vitamins, and minerals) and bioactive chemical content of mangrove plants (Bandaranayake 1998). Mangrove bark contains between 15% and 36% tannins, resulting in reddish-brown colors used in the tanning and coloring of leather (Duke and Allen 2006; Nazima et al. 2014). It is also used to print silk materials (Nakpathom et al., 2011).

Numerous mangrove plants have also been studied ethnopharmacologically. Mangroves produce various unique natural chemicals or secondary metabolites with substantial pharmacological effects utilized in ethnomedicine to treat multiple diseases (Bandaranayake 2002; Salini 2015). Mangroves have adapted to severe environments, resulting in a plethora of bioactive compounds that are toxicological, agricultural, and ecological (Kokpal et al., 1990). Mangroves adapt to harsh environments so that they contain many bioactive compounds that are toxicological, pharmacological, and ecological (Kokpal et al., 1990). Coastal communities have used extracts and raw materials from mangroves for natural medicinal purposes (Mahmiah et al., 2017). Mangroves have demonstrated their utility throughout history. Mangrove is a traditional Chinese medicine used to treat angina, diabetes, diarrhea, dysentery, hematuria, and hemorrhage (Duke and Wain 1981). It has antibacterial (Chandrasekaran et al. 2009), antiviral (Premanathan et al. 1999a), antifungal (Bose and Bose 2008), and antioxidant properties (Babu et al. 2007). Mangroves are biochemically unique in that they produce a diverse range of natural compounds that can be used to cure a variety of human ailments (Bandaranayake 1998).

For example, the Indian people employed mangroves to cure flatulence, epilepsy, smallpox, diabetes, asthma, rheumatism, stomach aches, fevers, malaria, cholera, hepatitis, cancer, ulcers, and wounds, as well as AIDS (Premanathan et al. 1999b; Prabhakaran et al. 2012; Revathi et al. 2014). Additionally, people in Bangladesh utilized mangrove trees as an antinociceptive, anti-inflammatory, and antipyretic (Shilpi et al. 2012), while people in Myanmar used this plant to treat inflammatory disorders and diarrhea (Rohini and Das 2010a; Shilpi et al. 2012). Additionally, the indigenous Thai people used mangrove bark extract to treat diarrhea, nausea, and vomiting and stop bleeding from newly opened wounds (Boonyapraphat and Chockchaicharaenphorn 1998; Laphookhieo et al. 2004).

*Rhizophora* leaves are traditionally used to treat diarrhea, while the fruit is consumed by those living near mangroves (Hardoko et al., 2015). Bandaranayake (1998) supports this by stating that traditional portions of plants of various types *Rhizophora* are used to treat a variety of ailments. *Rhizophora apiculata* is an antiemetic, antiseptic, diarrhea, hemostatic (bark), hepatitis (bark, flowers, fruit, leaves), typhoid (bark). *Rhizophora lamarckii* as a potential hepatitis drug (flowers, leaves). *Rhizophora mangle* is used to treat angina, boils, and fungal infections (bark), diarrhea, dysentery, elephantiasis, fever, malaria, and leprosy (bark, leaves), minor injuries (bark), plaster for fractured bones, (bark), tuberculosis (bark, leaves). *Rhizophora mucronata* is used to treat elephantiasis and as a febrifuge. It is also used to treat hematoma (bark), hepatitis (bark, flowers, fruit, leaves, and roots), and ulcers (bark). *Rhizophora racemosa* is the point at which the bleeding ceases (flowers, leaves). *Scaevola sericea* is an antiseptic and anti-inflammatory herb used medicinally to treat coughs, diabetes, eye infections, gastrointestinal diseases, headaches, stings, and bites (bark, leaves).

One type of *Rhizophora* that is widely distributed in the Indian and Pacific Oceans is *Rhizophora mucronata* Poir. *Rhizophora mucronata* is a medicinally significant mangrove plant (family Rhizophoraceae) that has been used in traditional medicine to treat diabetes, diarrhea, wounds, ulcers, and liver diseases (Hoppe-Speer et al. 2011; Arumugam et al. 2014; Manilal et al. 2015). The writing of this review is intended to collect, observe, and combine the use of *R. mucronata* as a source of food and medicinal ingredients.

## DISTRIBUTION AND HABITAT

*Rhizophora mucronata* is a member of the Rhizophoraceae family (Schwarzbach and Ricklefs 2000) and is usually referred to as *bakau kurap* or looproot mangrove, red mangrove, or Asian mangrove (Grin 2006; Warui et al. 2020). *Rhizophora mucronata* is found in the coastlines of the tropical and subtropical region (Perry 1980; Rohini and Das 2009). It is located in the Indo-Pacific region on riverbanks and at the sea's edge (Gillikin and Verheyden 2005). It is native to tropical and subtropical coastal areas extending from the east coast of Africa to Asia and Australia and the islands of the eastern Pacific Ocean. Closely related to Atlantic-East Pacific red mangroves, whose natural ranges intersect only on a few southern Pacific islands (Duke 2006).

The plant is found in a variety of nations worldwide. *Rhizophora mucronata* is found in Africa (Egypt, Ethiopia, Kenya, Madagascar, Mauritius, Mozambique, Tanzania, Somalia, South Africa, and Sudan), Asia (Cambodia, India, Indonesia, Malaysia, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand, Taiwan, and Vietnam), and the South Pacific (Solomon Islands, Vanuatu) (Grin 2006). It is the only species of mangrove found in East Africa (Gillikin and Verheyden 2005). Its few small populations in Pakistan are located in the Miani estuary, Baluchistan, and the Indus delta (Atkinson et al. 1967; Saifullah 1982). Introduced to the Hawaiian Islands, it is widespread throughout Southeast Asia (Sulistiono et al. 2015) and is also found in East Africa, Australia, and the Indian Ocean (Gurib-Fakim and Brendler 2004).

Estuaries, tidal streams, and flat coastal environments are preferred habitats of *R. mucronata* because of the species' vulnerability to daily tidal flooding. As a result, it often forms an evergreen buffer zone around mangrove habitats, making it more resistant to floods than other mangrove species (Batool et al., 2014). It is frequently found growing along the banks of rivers and is commonly inundated by high tides (Sulistiono et al., 2015). *Rhizophora mucronata* inhabits a similar environment as *R. apiculata* but is more tolerant of sandier and harder substrates. It grows in clusters along the sides of creeks and tidal estuaries, rarely far from the tides. Growth is optimal in deeply submerged regions, on hard ground, and in areas rich in humus. This is one of the most significant and widespread mangrove species. Throughout the year, flowers bloom. Crabs frequently consume seedlings, limiting new growth. Seeds that have been dried in the shade for a few days before planting are less favorable for crab. This procedure is likely to result in the accumulation of tannins that provide protection. The presence is really prevalent (Giesen et al. 2006).

## BOTANICAL DESCRIPTION

*Rhizophora mucronata* is an erect, 20-30 m tall mangrove tree with a diameter of up to 35-70 cm at the breast.

*Bark*. Barks are light grey, dark grey, light brown or dark to nearly black with horizontal fissures. Scaly bark with small slits that are square shape'.

*Pole*. It is cuneate, with an acute climax, with 16-22 cm in length and 8-11 cm in width.

*Roots*. It features stilt roots and aerial roots that originate from lower branches. Stilt roots buttress the species' trunk.

*Leaves*. It has dark green, thick leaves with a pronounced mucronate apex and an inferior surface covered in minute black dots. It has a green top and a yellowish-green bottom in a single formation. The layout is the opposite. Shape: a round elongated ellipse that stretches upward. Stipules range in length from 5.5 to 8.5 cm. 2.5-4 cm is the length of the petiole. Leaf-blades are broadly elliptic to oblong in shape, measuring 8.5-23 5-13 cm in length, leathery, with a cuneate base and blunt to sharp apex. The petiole is green in color and measures 2.5-5.5 cm in length; leaflets measure 5.5-8.5 cm in length.

*Inflorescences*. 2-3-forked with 2-5(-12)-flowered cymes; 2.5-5-cm peduncle.

*Flowers*. Flowers are sessile, creamy white, and grouped in a fork shape (compound limited type) with 2-3 flowers. Petals: 4, cream to white, lanceolate, 7-9 mm, fleshy, partially enclosing stamens, pilose edges (densely hairy margins). Stamens are eight in number, four at the base of the petals and four on the sepals, measuring 6-8 mm; anthers are sessile. Calyx lobes are four, ovulate 9-14 x 5-7 mm in length, deeply lobed, and cream to yellow. The ovary protrudes considerably beyond the disk; the free section is elongate-conic and is 2-3 mm in length; the style measures 0.5-1.5 mm in length.

*Fruit*. It produces green fruits in the shape of cigars. Fruit is dull, brownish-green, elongate-ovoid, 5-7 2.5-3.5 cm, tuberculate at the base, somewhat constricted at the apex. The hypocotyl is cylindrical, measuring between 30 and 65 cm in length and up to 2 cm in width. The fruit is viviparous, germinating before dropping to the ground. The fruit is formed like a Hypocotyl. The Hypocotyl is coated in lenticel and is green. Size: 60 cm in length and 2 cm in breadth (Gurib-Fakim and Brendler 2004; Setyawan and Ulumuddin 2012; Setyawan et al. 2014; Sulistiono et al. 2015).

## TRADITIONAL USES

*Rhizophora mucronata* can be planted in fish ponds to defend levees and dikes and is also helpful for making fish traps (Giesen et al. 2006). The timber is used to make fuel, construct buildings, and construct fish traps, among other things (Mahmiah et al., 2017). It is dense to highly dense wood that is extremely hard and robust; it shrinks significantly and is relatively difficult to deal with due to its hardness. It is utilized in the production of firewood and charcoal (Giesen et al. 2006). The extraction of tannins is a significant usage of this plant (Rohini and Das 2010b). The tannin in the barks has been used for tanning and dyeing for centuries, most notably to reinforce fishing lines and rigging. The leaves are used to make a dye that is either black or chestnut (Burkill 1966). This mangrove species contain up to 70% tannins (Gurib-Fakim and Brendler 2004). Additionally, it has long been used to treat elephantiasis, hematoma, hepatitis, ulcers, and as a febrifuge (Bandaranayake 2002; Ravikumar et al. 2005), and its antiviral activity has been scientifically demonstrated (Padmakumar and Ayyakkannu 1997). It is occasionally used to treat hematuria (Giesen et al. 2006). Hypocotyl flour is also used as a food source during famines (Bunyapraphatsara et al., 2002).

The fruit of *R. mucronata* is used as food and drink, the young leaves are used as vegetables, the wood and bark are used as tanning and dyeing materials, and the boiled water (extract) of the wood can be used as a slimming, antidiarrheal, and antiemetic agent (Abidin et al. 2013).

## SOURCE OF FOODS

### Chemical characteristic of ripe fruit flour

A fruit is the edible component of mangrove plants. The fruit is dried and ground into flour for various food products (Hardoko et al., 2015). *Rhizophora mucronata*, according to Bunyapraphatsara et al. (2002), contains dietary fiber (29.25% ± 0.4%). According to Meyer et al. (2000), dietary fiber from whole grains protects against the development of diabetes. According to Jenkins et al. (2000), water-soluble dietary fiber is more protective against diabetes than insoluble dietary fiber. Chandalia et al. (2000) believe that adhering to the ADA's recommended intake of dietary fiber, particularly water-soluble fiber, can improve blood sugar management, hyperinsulinemia, and plasma lipid concentrations in people with type 2 diabetes.

Carbohydrates account for 90.67% of ripe *R. mucronata* fruit flour, containing 7.50% soluble dietary fiber and 38.60% insoluble dietary fiber. Qualitatively, ripe *R. mucronata* fruit flour contains flavonoids, steroids, saponins, and tannins. In diabetic rats, ripe *R. mucronata* fruit flour decreased blood glucose levels. Doses of 1,000 mg/day/head, 1,500 mg/day/head, and 2,000 mg/day/head are comparable to the action of glibenclamide (0.09 mg/day/200 g body weight) in diabetic rats (Hardoko et al. 2015).

Hardoko et al. (2015) reported that the chemical composition of ripe *R. mucronata* fruit flour was dominated by carbohydrates (90.67%) was low in protein and fat. Carbohydrates with a high fiber content constituted 38.60% insoluble dietary fiber and 7.50% soluble dietary fiber. Thus, ripe *R. mucronata* fruit flour was classified as having high dietary fiber content. The dietary fiber content of ripe *R. mucronata* fruit flour is higher (29%) than that of *R. mucronata* fruit. Meyer et al. (2000) reported that whole-grain dietary fiber is protective against diabetes. Consumption of soluble dietary fiber is more protective than consumption of insoluble dietary fiber (Jenkins et al., 2000). According to Chandalia et al. (2000), increasing dietary fiber intake, particularly soluble fiber, improves blood glucose management, lowers hyperinsulinemia, and decreases plasma lipid concentrations in patients with type 2 diabetes.

**Toxicity test of fruit flour**

Meyer et al. (1982) and Effendi et al. (2012) classified toxicity into five categories based on the $LC_{50}$ value: (i) substances with $LC_{50}$ values <1 ppm are considered very toxic, (ii) those with $LC_{50}$ values of 100-1,000 ppm are considered moderately toxic, (iii) those with $LC_{50}$ values of 1,000-10,000 ppm are considered low toxic, those with $LC_{50}$ values of 10,000-100,000 ppm are considered nearly non-toxic. Referring to Hardoko et al. (2015), because the $LC_{50}$ value of ripe *R. mucronata* fruit flour was 1,737.80 ppm, it was classified as having a low toxic rate. The low toxicity level is attributed to both HCN (2.97 ppm) and tannin (819 ppm). The safe level of HCN in the diet is 50 parts per million. Additionally, the safe daily intake of tannin is 560 mg/kg body weight. The HCN content, tannin content, and $LC_{50}$ value can all be used to determine the food's level of safety. Yield is a ratio of ripe *R. mucronata* fruit flour to ripe *R. mucronata* fruit. The flour yield was 12.9%. The amount of water and other components lost during processing affects the yield fluctuation. Both the HCN and tannin concentrations of ripe *R. mucronata* fruit flour are within the safe consumption limit and have low toxic levels.

## MEDICINAL USES

Herbal medicines have gained significant attention as a viable alternative to conventional medicine, and demand for these therapies has surged in recent years. Numerous mangrove plants have been used in folk medicine. Extracts from mangroves and mangrove-dependent species have recently been shown to be against human, animal, and plant pathogens. Still, only a few studies have been conducted to characterize the plant parts that are most effective for application and the metabolites responsible for their bioactivities (Lewis and Hanson 1991). Compared to terrestrial plants, mangrove plants contain an immense amount of secondary metabolites. As a result, the World Health Organization (WHO) recommended using plants to control diabetes mellitus and supported scientific investigation of their anti-hyperglycemic characteristics (Nabeel et al. 2010; Rahman et al. 2010; Gurudeeban et al. 2012).

*Rhizophora* genera are known to be beneficial in the treatment of a variety of diseases, including angina, hemorrhage, and hematuria. Interestingly, mature leaves and roots can be used to induce labor (Seepana et al. 2016), ulcers (Krishnamoorthy et al. 2011), diarrhea, fever, and burns (Sur et al. 2016), as well as stings of poisonous fish (Gurib-Fakim and Brendler 2004). Its bark and leaf extracts have been employed in traditional medicine as an astringent, antiseptic, and hemostatic agent with antibacterial, anti-ulcerogenic, and anti-inflammatory properties (Kaur et al., 2018).

*Rhizophora mucronata* possesses a plethora of therapeutic qualities (Perry 1980). Historically, the herb was used to treat diarrhea, constipation, nausea, hematuria, and diabetes (Bibi et al., 2019). *Rhizophora mucronata*'s bark, root, leaves, fruit, and flowers have been used in traditional medicine to treat diabetes, diarrhea, hepatitis, inflammation, sores, and ulcers, among other conditions (Duke 1992; Bandaranayake 1998; Ng and Sivasothi 2001). The leaf has been used in traditional medicine to treat diarrhea and dysmotility of the stomach (Bandaranayake 1998). The decoction of the root is used to treat diabetes and hypertension, while the infusion of the leaves is used to treat fever.

The Indonesians have long used the entire plant as a febrifuge and cure for elephantiasis, hematoma, hepatitis, and an ulcer (Rollet 1981; Nurdiani et al. 2012). The whole plant is used to cure elephantiasis, a disorder caused by tissue swelling induced by filarial worms (Rollet 1981; Nurdiani et al. 2012). Mangrove societies in East Java boil *R. mucronata* leaf to treat diarrhea. The bark of *R. mucronata* is frequently noted in ethnomedicine for its antidiarrheal qualities. However, there has been no noteworthy previously reported on the leaf's antidiarrheal activity. Diarrhea is defined by increased bowel movement frequency, moist stool, and stomach pain. Neurohormonal mechanisms, infections, starvation, chronic disease, and medications all can affect gastrointestinal physiology, resulting in alterations in the intestinal epithelium's fluid output or absorption. Anti-motility agents such as diphenoxylate and anticholinergic agents have been used to treat diarrheal illnesses, but they frequently cause side effects when administered for an extended period (Harrison 2005). Antidiarrheal qualities of medicinal plants have been linked to their tannin and flavonoid content (Rohini et al. 1999). *Rhizophora mucronata* leaf extracts are the most effective natural anti-diarrhea agent. They are natural substances utilized in traditional and modern therapies to improve human health with fewer adverse effects. Leaf extracts demonstrate the presence of new pharmacological compounds that could tackle the threat of human disease. Several studies have been published on this topic (Kuppusamy et al. 2015; Arumugam et al. 2016; Swamy et al. 2016).

The bark of *R. mucronata* has been used traditionally in Burma, India, and China to treat diarrhea, dysentery, fever, angina, diabetes, hematuria, and bleeding (Duke and Wain 1981; Kathiresan and Ramanathan 1997). Poultices of leaves are applied to armored fish injuries (Watt and Breyer-Brandwijk 1962). The Indochinese uses the roots to treat angina and hemorrhage. To help a woman give birth, Malays use old leaves and/or roots. The Burmese use the bark to treat bloody urine, the Chinese and Japanese use it to treat diarrhea and the Indochinese use it to treat angina (Perry 1980; Kusuma et al. 2011).

The indigenous people of Papua New Guinea used the stem to treat constipation, infertility, and menstrual issues (Liebezeit and Rau 2006). *Rhizophora mucronata* has historically been used to treat elephantiasis, hematoma, hepatitis, ulcers, and as a febrifuge (Bandaranayake 2002; Ravikumar et al. 2005). Its leaf is used in folk medicine to alleviate diarrhea and dysmotility of the stomach. The leaf extract of *R. mucronata* is used to treat diarrhea. The bark of *R. mucronata* is frequently noted in ethnomedicine for its antidiarrheal qualities (Harrison 2005).

The bark of *R. mucronata* or the entire plant has traditionally been used in Tamil Nadu, India, to treat angina, dysentery, hematuria, hepatitis, ulcers, diabetes, bleeding, vomiting, and nausea. In Mauritius, the indigenous people use the *R. mucronata* plant as a traditional medication to treat diabetes and hypertension and a natural cure for lowering the blood urea level. The root (5 cm in length) of *R. mucronata*, three entire *Bidens pilosa* plants, ten leaves of *Piper borbonense*, the bark (15 cm in length) of *Erythroxylum laurifolium*, fifteen leaves of *Aphloia jobi*, and ten leaves of *Antidesma madagascariense* are used to make a tea. The tea is consumed to maintain a healthy blood urea level (Gurib-Fakim and Brendler 2004).

The bark, root, leaves, fruits, and flowers of *R. mucronata* have been traditionally used as medicine in the coastal areas of South Asia to treat health problems such as diabetes (Bandaranayake 1998; Sur et al. 2004), diarrhea (Yunita et al. 2012), hepatitis (Ravikumar and Gnanadesigan 2012), inflammation (Rohini and Das 2009), and cognitive function (Suganthy and Devi 2016).

## PHYTOCHEMICAL COMPOSITION

*Rhizophora mucronata* possessed alkaloids, condensed and hydrolyzable tannins, flavonoids, proteins, saponins, steroids, triterpenes, and flavonoids (Basak et al. 1996; Madhu and Madhu 1997). Diverse extraction methods in different parts can give different phytochemical content as well.

The leaves of *R. mucronata* are a natural source of tannins and flavonoids, although their chemical, biological, and pharmacological effects are unknown (Rahim et al., 2008). *R. mucronata* contains up to 70% tannins, which contribute to its therapeutic characteristics, including astringent, anti-diabetic, anti-rheumatoid, and hypotensive properties (Gurib-Fakim and Brendler 2004). Alkaloids, hydrolyzable tannins, polyphenols, flavonoids, triterpenes, inositols, polysaccharides, saponins, and anthocyanidins are some of the chemical constituents of *R. mucronata* (Kolkpol et al. 1990; Ghosh et al. 1995; Anjaneyulu and Rao 2001; Bandaranayake 2002). It possesses antibacterial and antiviral effects (Premanathan et al. 1999a). Although an ethanolic extract of *Rhizophora* has demonstrated anti-diabetic and antihyperglycemic action, the underlying mechanism remains unknown (Sur et al. 2004).

During phytochemical screening, tannin, saponin, flavonoid, and steroids were detected in ripe R. mucronata fruit flour. Ghosh et al. (1995) reported that *R. mucronata* possessed steroid, triterpenoid, alkaloid, flavonoid, tannin, catechin, quinone, and anthocyanidin. Basyuni (2008) reported that *R. mucronata* contains polyphenols at a concentration of 157.4±22.9 mg/g dry weight and free radical scavenging activity of 83.7±2.8 mg/mL (Agoramoorthy et al. 2008), Rhizophorins CE (1-3), Rhizophorin A, (6 R, 11 S, 13 S)-6,11,13-trihydroxy-2,3-seco-14-labden-2,8-olid-3-oic acid and Rhizophorin B, ent-3 β,20-epoxy-3,18-dihydroxy-15-beyerene and unknown activities (Ammanamanchi 2004) and triterpenoids: β-amyrin, lupeol, and tarataxol (Basyuni 2008).

Phytochemistry of the ethyl acetate fraction of *R. mucronata* bark produced compounds such as saponins, steroids, flavonoids, and anthraquinones. The results of the GC-MS analysis showed the presence of seven compounds identified in the ethyl acetate of the stem bark of *R. mucronata*. These compounds include one class of quinones, three classes of steroids, two groups of alkaloids, and one class of aromatics. The most abundant metabolite found in the ethyl acetate of the stem bark of *R. mucronata* is the alkaloid 1H-Purin-6-amine (2-fluorophenyl) methyl) (74.76%) (Mahmiah et al., 2017).

On the crude methanol *R. mucronata* leaf extract, phytochemical screening disclosed the presence of tannins, alkaloid, flavonoid, terpenoid, and saponin. Condensed tannins are present in the crude methanol extract of *R. mucronata* leaf. It included catechin 47.428 parts per million and epigallocatechin 3.150 parts per million. *Rhizophora mucronata* leaf crude methanol extract is used to treat gastrointestinal motility disorders such as diarrhea. It acts directly on smooth muscle cells to reduce ileal motility and acts as an antagonist cholinergic receptor. At a concentration of 0.30 %, a crude methanol extract of *R. mucronata* leaf had a substantial effect. This concentration eased 52% of methacholine-induced ileum contractions (Puspitasar et al., 2012).

The beneficial phytochemicals were more abundant in the methanol and ethanol extracts of *R. mucronata* than in the chloroform extract. Terpenoids and tannins are present in all three extracts. Still, a higher concentration of terpenoids was observed in the chloroform extract, which is consistent with the result of the previous study (Cowan 1999). All *R. mucronata* extracts contained various phytochemical components, including proteins, phenols, flavonoids, saponins, glycosides, terpenoids, and tannins. We previously discovered the presence of steroids in chloroform and methanol extracts and alkaloids in ethanol extracts (Cowan 1999). Phenolic chemicals are one of the most abundant and widely distributed classes of plant metabolites (Singh et al., 2007).

They have significant biological features, including anti-apoptotic, anti-aging, anti-carcinogen, anti-inflammation, anti-atherosclerosis, cardiovascular protection, endothelial function improvement, angiogenesis prevention, and cell proliferation (Han et al. 2007).

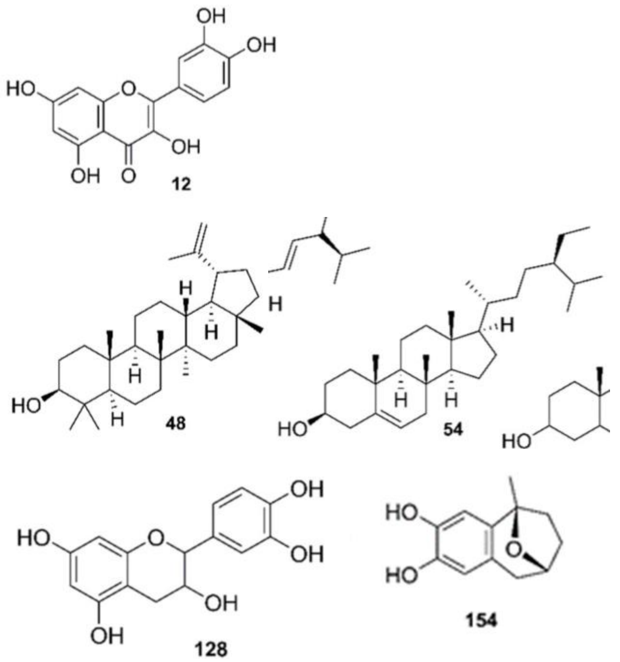


**Figure 1.** Chemical structures of compounds 1-20 isolated from *R. mucronata*

The methanolic leaf extract demonstrated significant anticholinesterase activity (AChE assay) with an $IC_{50}$ value of 59.31±0.35 g/mL and important antioxidant activity (DPPH assay) with an $IC_{50}$ value of 47.39±0.43 g/mL. These noteworthy findings may be related to the presence of a high concentration of flavonoids, particularly catechin (128) (Suganthy and Devi 2016). Due to the presence of phenolics, flavonoids, gallic acid (130), quercetin (12), and coumarin, *R. mucronata* is regarded as a good natural antidiabetic drug (Sur et al. 2016). Additionally, Rohini and Das (2010a) demonstrated that the bark extract of *R. mucronata* possesses excellent anti-inflammatory action due to the presence of the phytoconstituents lupeol (48), quercetin (12), β-sitosterol (54), and caffeic acid. According to Manilal et al. (2015), the primary ingredient extracted from the crude extract, ethanone (1-(2-hydroxy-5-methylphenyl), may play a critical role in the plant's antimicrobial action. The chemical structures of isolated mangrove chemicals are depicted in Figure 1.

## PHARMACOLOGICAL PROPERTIES

Extracts from various mangrove plants and their partners exhibit antimicrobial activity against human and plant infections (Chandrasekara et al., 2009). Mangrove trees include a variety of phytochemicals with antimicrobial characteristics; they are a good source of saponins, alkaloids, and flavonoids (Bandaranayake 1998). Tannins, alkaloids, steroids, anthraquinone glycosides, and flavonoids are found in mangrove plants (Patra et al., 2009). Extracts of mangrove plants have been shown to have biological activity against a variety of human, animal, and plant pathogens, including the Human Immunodeficiency Virus (HIV) (Premanathan et al. 1999b), Semliki Forest virus (Premanathan et al. 1995), Newcastle disease virus (Premanathan et al. 1992), and cancer (Tosa et al. 1997). Chemical compounds and bioactive compounds found in mangrove plants are antimicrobial (Choudhury et al., 2005; Agoramoorthy et al., 2007; Sivaperumal et al. 2010; Abeysinghe 2012; Dhayanithi et al. 2012), anticancer (Prabhu and Guruvayoorappan 2011), antioxidants (Banerjee et al. 2008). Additionally, mangrove plants with bioactive compounds are used as food or functional food (Hardoko et al., 2015).

*Rhizophora mucronata* contains a diverse range of chemical constituents, including sugar, tannins, saponins, alkaloids, flavonoids, steroids, terpenoids, glycosides, and phenolics (Nurdiani et al. 2012; Revathi et al. 2014; Sreedhar and Christy 2015). According to the phytochemical screening test of *R. mucronata*, the alkaloid rhizophorine is a significant component of the plant's leaf (Bandaranayake 2002). In addition, the extract of *R. mucronata* bark had the strongest inhibitory action against α-glucosidase, with an $IC_{50}$ of 0.08±1.82 μg/mL, suggesting that it may be a contender for anti-diabetic therapy (Lawag et al. 2012).

The various portions of *R. mucronata* cure various human illnesses, including angina, dysentery, and hematuria. The existing scientific literature indicates that evidence of the tree's numerous uses dates back to the $17^{th}$ century (Joel and Bhimba 2010). *Rhizophora mucronata* is a widespread mangrove plant that has been utilized as ethnomedicine from prehistoric times (Andikhari et al., 2016). *Rhizophora mucronata* has traditionally been used to treat bleeding, diarrhea, diabetes, angina, bleeding, and inflammation. It has been established that it has anti-HIV action (Kirtikar and Basu 1987; Bandarnayake 2002; Premanathanet al. 1999b).

The present data indicate that *R. mucronata* fresh leaf extract is not hazardous, as no significant alterations in hematological or biochemical parameters were found. Thus, *R. mucronata* fresh leaves extract is regarded as safe for long-term treatment of human illnesses at standard therapeutic concentrations (Babuselvam et al., 2012). Additionally, *R. mucronata* leaf extract has been traditionally used to treat diarrhea (Puspitasar et al., 2012) and as a blood sugar-lowering agent (Gaffar et al., 2011). The root extract of *R. mucronata* acts as an antioxidant and can repair liver damage caused by $CCl_4$ hepatotoxins in experimental rats (Ravikumar and Gnanadesigan 2012).

*Rhizophora mucronata* exhibits a diverse range of pharmacological activities, including antioxidant, anti-inflammatory, antibacterial, antimicrobial, antidiabetic, analgesic, anti-HIV, and anti-cholinesterase activity. Traditional usage of medicinal herbs is associated with no adverse effects, toxicity, and increased efficacy and safety. Significant biological activity investigated in medicinal plant extracts include antioxidant, anti-inflammatory, anti-diabetic, and antiviral properties (Andikhari et al., 2016; Chakraborty and Raola 2017; Aljaghthmi et al. 2018). This compound has antibacterial, antimalaria, antiviral, and antioxidant properties (Abidin et al., 2013; Purwaningsih et al. 2013; Yogananth et al. 2015). The bark of the plant is used as an astringent. Historically, it was used to treat diabetes, diarrhea, nausea, haematuria, hemorrhages, and angina (Khare 2007).

The following is the potential of *R. mucronata* as an antioxidant, anti-diabetic, antimicrobial, anticancer, anti-inflammatory, and analgesic.

## ANTIOXIDANT

Numerous researches have been conducted to determine the antioxidant effects of medicinal plants that are high in phenolic compounds (Krings and Berger 2001). As mentioned in Ali et al. (2008), natural antioxidants are mainly derived from plants in the form of phenolic chemicals such as flavonoids, phenolic acids, and tocopherols. Plant phenolics are a large class of chemicals that act as primary antioxidants or scavengers of free radicals (Potterat 1997). Similarly, terpenoids and vitamins work as metabolic regulators and antioxidants (Soetan 2008). Plant polyphenols are antioxidants with redox characteristics that operate as reductants, hydrogen donors, and singlet oxygen quenchers (Middleton et al., 2000).

*Rhizophora mucronata* functions as an antioxidant because there are secondary metabolites, namely tannins, phenolics, chlorophyll, carotenoids, and alkaloids (Babuselvam et al., 2012; Abidin et al. 2013). Antioxidant activity of plant extracts was based on species, extraction method, season, and sampling area (Budhiyanti et al., 2012). Chakraborty and Raola (2017) determined the $IC_{50}$ value for the crude chloroform leaf extract using the DPPH test to be 1.38±0.03 mg/mL, while Suganthy and Devi (2016) determined the $IC_{50}$ value for the crude chloroform leaf extract using the DPPH assay to be 47.39±0.43 g/mL. Interestingly, Hardoko et al. (2014) discovered that the fruit's ripe flour includes 7.50 % soluble dietary fiber and 38.60 % insoluble dietary fiber. The methanol extract of *R. mucronata* bark was an antioxidant with an $IC_{50}$ value of 438.8349 ppm (Mahmiah et al., 2016).

The most potent antioxidant is a methanol extract of *R. mucronata* leaves. This bodes well for utilizing *R. mucronata* as a source of potent antioxidants (Vigneswaran et al., 2018). The n-hexane leaf extract had an $IC_{50}$ value of 151.13 ppm, while the ethyl acetate extract showed an $IC_{50}$ value of 184.78 ppm, and the methanol extract showed an $IC_{50}$ value of 113.41 ppm. This indicates that methanol extract has the strongest antioxidant activity than ethyl acetate and n-hexane extracts. This is because the total content of phenolics, chlorophyll a, chlorophyll b, and carotenoids are higher than the n-hexane extract and methanol extract (Kuppusamy et al., 2015). These compounds can reduce the activity of free radicals, react directly with free radicals, and turn them into new free radicals that are less reactive and less dangerous (Amic et al., 2003).

Methanol extracts of *R. mucronata* leaves had significantly higher antioxidant activity than other extracts (petroleum ether, benzene, ethyl acetate, and ethanol). The concentration of methanol extract of *R. mucronata* leaves required for 50% inhibition ($IC_{50}$) was 36.17 mg/ml. The extract effectively scavenges free radicals but to a smaller amount than normal ascorbic acid ($IC_{50}$ = 31.04 mg/mL). The $IC_{50}$ value of methanol extract of *R. mucronata* leaves was determined to be 36.47 mg/mL for superoxide radicals and 32.14 mg/ml for ascorbic acid, respectively (Vigneswaran et al. 2018). At low concentrations, the ethanol extract demonstrated excellent reducing power. However, its reducing power was smaller than that of the ethanol extract at greater doses (Vigneswaran et al., 2018).

The leaves of the *R. mucronata* mangrove plant contained more phenolic chemicals than the stem bark and root extracts (Banerjee et al., 2008). The leaves may contain natural antioxidants that may be beneficial in preventing or slowing the progression of aging and age-related oxidative stress-related degenerative illnesses (Palaniyandi et al. 2020). Numerous synthetic medications protect against oxidative stress, but they also have undesirable side effects (Suganya et al., 2017). The hydromethanolic extract of *R. mucronata* leaves included all key phytoconstituents, including alkaloids, phenolics, flavonoids, triterpenoids, steroids, glycosides, saponins, and tannins. It has long been established that phenolics and flavonoids play an important role in diabetes management (Bailey and Day 1989; Bravo 1998; Agoramoorthy et al. 2008). Gallic acid, quercetin, and coumarin found in the leaves of *R. mucronata* provide significant pharmacological evidence for the plant's antioxidant and radical scavenging activities (Bravo 1998; Rohini and Das 2011; Thakker et al. 2011).

## ANTI-DIABETICS

Diverse plant parts of *R. mucronata* contain a diverse array of phytochemicals, including condensed tannins, polyphenols, lipids, inositol, gibberellins, alkaloids, tannins, and proteins (Anjaneyulu and Rao 2003; Ravindran et al. 2005; Nurdiani et al. 2012; Revathi et al. 2014; Chakraborty and Raola 2017). According to Patra et al. (2009) and Odom et al. (2013), a mixture of many fruits containing alkaloid, tannin, saponin, and flavonoid has hypoglycemic (anti-diabetic) efficacy against rat-induced alloxan. Aljaghthmi et al. (2018) show that the bioactive chemicals found in *R. mucronata* reduce blood sugar levels and stimulate insulin production. However, no additional investigations on ripe flour have been undertaken to verify or validate the findings of Hardoko et al. (2014). According to Alikunhi et al. (2012), the anti-diabetic activities of *R. mucronata* stem from the presence of an insulin-like protein in the leaves.

Alkaloids of *R. mucronata* operate as an effective anti-hyperglycaemic and anti-hyperlipidemic drug in insulin-dependent and non-insulin-dependent diabetic patients (Gurudeeban et al., 2016).

Thus, it is reasonable to hypothesize that DCM-F and glibenclamide may augment insulin release or mimic insulin-like action (Gurudeeban et al., 2016). T2DM rats treated with the dichloromethane fraction of *R. mucronata* have considerably lower total cholesterol and triglyceride levels while increasing high-density lipoprotein cholesterol. It elucidates the anti-diabetic and anti-hyperlipidemic functional context of *R. mucronata* (Gurudeeban et al., 2016). However, the complex pathology of non-insulin-dependent diabetes in humans remains unknown. Nicotinamide, a water-soluble vitamin, is beneficial in delaying the onset of type 1 diabetes in non-obese mice (Azooz et al., 2013). Nicotinamide treatment of pre-diabetics results in a person with diabetes with stable metabolic abnormalities and decreased pancreatic insulin (Szkudelska et al., 2014). On the other hand, the extract's hypoglycemic action in rats suggests that it inhibits intestinal glucose absorption and stimulates the glucagon-like peptide (GLP-1), a glucose-dependent insulin secretagogue (Goke 1993).

The ripe *R. mucronata* fruit flour has hypoglycaemic properties and may be functional diabetic food. The effectiveness of ripe *R. mucronata* fruit flour in lowering blood glucose levels is due to its high fiber content (46.10%) and bioactive anti-diabetic properties (Hardoko et al., 2015). Meyer et al. (2000) reported that whole-grain dietary fiber is protective against diabetes. Consumption of soluble dietary fiber is more protective than consumption of insoluble dietary fiber (Jenkins et al., 2000). According to Chandalia et al. (2000), consuming the required amount of dietary fiber, particularly soluble fiber, improves blood glucose management, decreases hyperinsulinemia, and decreases plasma lipid concentrations in patients with type 2 diabetes. According to Dianitami (2009), dietary fiber has physiological effects such as reducing transit time, slowing gastric emptying, prolonging satiety, restoring normal beneficial intestinal flora, increasing pancreatic secretion, increasing short-chain fatty acid production, serum lipid levels, and bile acid-binding. Fiber delays stomach emptying, preventing blood glucose levels from rising. Food is absorbed into the small intestine, and blood glucose levels gradually rise.

*Rhizophora* leaf powder is a strong anti-diabetic agent due to the presence of an insulin-like protein. Additionally, it was comparable to glibenclamide (Alikunhi et al., 2012). Further, by evaluating the average blood sugar level, the effect of mangrove fruit flour as an antidiabetic can be compared to that of the medicine glibenclamide (positive control). According to Davey (2005) and Katzung (2007), glibenclamide is a member of the sulfonylurea class of drugs that enhance pancreatic beta-cell insulin secretion.

According to Hardoko et al. (2015), the larger the wheat doses, the lower the rats' blood glucose levels. The LSD test revealed that oral administration of ripe *R. mucronata* fruit flour at doses of 1,000 mg/day/head, 1,500 mg/day/head, and 2,000 mg/day/head had no significant impact when compared to the positive control (glibenclamide 0.09 mg/day/200 g body weight) ($p<0.05$). Furthermore, ripe *R. mucronata* fruit flour 1000 mg/day/head significantly lowered blood glucose levels in rats treated with alloxan, similar to glibenclamide medication. By slowing the stomach emptying, dietary fiber lowers blood glucose levels and prevents increased blood glucose levels (Dianitami 2009). The extract of *R. mucronata* leaves and glibenclamide effectively maintained the bodyweight of Streptozotocin-induced diabetic rats, although the diabetic rats' bodyweight decreased (Pandey et al., 2014). The in vivo antidiabetic investigation demonstrated a decrease in blood glucose levels, indicating that the ripe flour of *R. mucronata* is an excellent functional diet for diabetic patients (Hardoko et al. (, 2015).

Numerous scientific publications support its potential use as an anti-diabetic medication; however, additional research is required (Ramanathan et al., 2008; Ray et al., 2014). Additionally, the chemical identification of *R. mucronata* has been determined, as well as the presence of secolabdane diterpenoid (rhizophorin A) (Anjaneyulu and Rao 2001), phomoxanthone (Shiono et al. 2013), lupeol, beta-sitosterol (Rohini and Das 2011), gallic acid, coumarin, quercetin (Sur et al. 2015) and tannins (Joel and Bhimba 2010).

## ANTIMICROBIALS

### Antibacterial

*Rhizophora mucronata* appears to possess a broad antibacterial spectrum of activity. Among the five solvents evaluated (ethanol, petroleum ether, acetone, methanol, and ethyl acetate), it was concluded that ethyl acetate was the best solvent for isolating bioactive secondary metabolites. *R. mucronata* foliar crude ethyl acetate extracts (50 µL) exhibited significant antibacterial activity with inhibition zones, particularly against *Escherichia coli*, *Staphylococcus aureus*, *Proteus vulgaris*, *Pseudomonas fluorescens*, and *Salmonella typhi* (Joel and Bhimba 2010). Maximum inhibitory action was observed using a methanolic leaf extract of Rhizophora mucronata against *S. aureus* (20 mm diameter) (Ravikumar et al., 2009). *Rhizophora mucronata* had a more significant inhibitory effect on bacterial and fungal infections (Ravikumar et al., 2009). The n-hexane and chloroform extracts of *R. mucronata* leaves were found to have a significant inhibitory effect on *Bacillus subtilis*, *S. aureus*, *Candida albicans*, *Aspergillus fumigatus*, *Aspergillus niger*, and a moderate inhibitory effect on *Pseudomonas aeruginosa* and *P. vulgaris*. The remaining extracts had moderate activity (Kusuma et al., 2011).

The leaves of *R. mucronata* displayed a high inhibitory effect on *B. subtilis*, *S. aureus*, *C. albicans*, *A. fumigatus*, and *A. niger*, and a moderate inhibitory effect on *P. aeruginosa* and *P. vulgaris*. Only the leaves contain various phytochemical substances, even though the tannin and saponin content is negligible. *Rhizophora mucronata* extracts exhibited antibacterial efficacy against *S. aureus* and *E. coli*. It's worth noting that nearly all components demonstrated broad-spectrum antibacterial action. It possesses antibacterial (Chandrasekaran et al. 2009), antiviral (Premanathan et al. 1999a), antifungal (Bose and Bose 2008), larvicidal (Thangam and Kathiresan 1989), and antioxidant properties (Babu et al. 2001).

Chou et al. (1977), Padmakumar (1988), and Akalanka et al. (2002) also observed that *R. mucronata* leaf and bark extracts included antimicrobial components active against a variety of human bacterial infections. The highest antibacterial activity is thought to be due to the presence of phenols such as tannins (Ravikumar and Kathiresan 1993), coumarin and their glycosides, anthraquinones and their glycosides, naphthoquinones, flavones and related flavonoids, and polysaccharides (Trease and Evans 1997); and sulfated compounds such as brugierol, isobrugierol, and 4-hydroxy-1,2m dithiolane (Kokpal and Chittawong 1987) in mangrove halophytes. Phenolic compounds are typically water-soluble, as they are frequently found in combination with sugar as glycosides and are usually found in the cell vacuole (Glossary of Indian medicinal Plants 1992). Flavonoids are hydroxylated phenolic compounds that plants produce in response to microbial infection and have been shown in vitro to be antibacterial agents against a wide variety of microorganisms (Wang et al., 2009).

### Antifungal

*Rhizophora mucronata* mangrove leaf extracts revealed much-increased activity (20 mm) against *Streptococcus lactis*. The average zone of inhibition for bacterial pathogens indicates that Gram-positive bacteria are more vulnerable than Gram-negative bacteria. Compared to leaf extracts, *R. mucronata* bark extracts exhibited the highest inhibitory action (9 mm) against *Bacillus megaterium* (69.2 activity index) and *S. lactis*, respectively. The leaf extract of *R. mucronata* inhibits all bacterial isolates in a broad spectrum. *Rhizophora mucronata* had the most significant inhibitory activity (7 mm) against the fungus *Metarrhizum anisopliae* (Ravikumar et al., 2009). The ethanol bark extracts showed significant antiviral efficacy against Newcastle disease, vaccinia, encephalomyocarditis, and Forest viruses. Additionally, the ethanol flower extract demonstrated beneficial effects for human health (Premanathan et al. 1992).

### Antiviral

Additionally, it has been scientifically demonstrated to possess antiviral properties (Padmakumar and Ayyakkannu 1997). The bark of *R. mucronata* contained an active material composed of acid polysaccharides that inhibits the HIV binding mechanism within cells (Premanathan et al. 1999b). Acid polysaccharides (sulfate polysaccharides) inhibit the binding process by utilizing the electrostatic interaction between the negative and positive charges (Battulga et al., 2019). *Rhizophora mucronata* bark was shown to be the most promising antiviral agent (Premanathan et al. 1992). The honey reported to be poisonous is extracted from the flowers (Khare 2007).

## ANTICANCER

Lung cancer, blood cancer, prostate cancer, breast cancer, cervical cancer, and bone cancer are the most common types of cancer that cause death worldwide (Islam and Rahi 2018). *Rhizophora mucronata* is a plant that is frequently used in traditional medicine to treat a variety of conditions, including cancer. Different solvent extracts of *R. mucronata* leaves (e.g., methanol, ethanol, chloroform) revealed the presence of several bioactive components associated with antioxidant and free radical scavenging activities (Palaniyandi et al. 2020). Numerous components of *R. mucronata* are used to treat a variety of disorders. Mangroves are salt-tolerant plants native to the world's tropical and subtropical intertidal zones. Regardless of their monetary value, mangroves are employed in folk medicine. The plant possesses an acceptable amount of antioxidant and thrombolytic activity, as well as a modest level of cytotoxic activity (Sharmin et al., 2018). *Rhizophora mucronata* contains a high concentration of phytochemicals, including triterpenoids, lipids, alkaloids, and tannins (Sadeer et al., 2019). Additionally, it has the potential to influence cell cycle distribution and drastically reduce cyclin D1 expression (Zhou et al., 2017). The n-hexane: chloroform fraction from the methanolic extract of the bark of *R. mucronata* has successfully had cytotoxic activity on myeloma cancer cells (Harwoko and Utami 2010).

## ANTI-INFLAMMATION

*Rhizophora mucronata* plants have the potential to be a significant source of modern medications for a variety of life-threatening illnesses. Keeping this in mind, we attempted to study the in vitro anti-inflammatory capabilities of several *R. mucronata* plant parts (Kaur et al., 2018). The anti-inflammatory efficacy of the extract was investigated and its potential to suppress protein denaturation. At various doses, it was efficient in suppressing heat-induced albumin denaturation. At stilt root extract, maximum inhibition was observed, and the $IC_{50}$ value was determined to be 296.262 µg/mL. At a 500 µg/mL concentration of aspirin, a standard anti-inflammatory medicine, the maximal inhibition was 268.348%. These findings support the idea that their anti-inflammatory activity is partly mediated by membrane stability. This extract may perhaps stop neutrophils from releasing their lysosomal content at the site of inflammation. These neutrophil lysosomal contents include bactericidal enzymes and proteases, which, when released into the extracellular space, cause more tissue inflammation and injury (Chou 1997).

At concentrations ranging from 100 to 500 µg/mL, the extract protects human erythrocyte membranes from lysis caused by hypotonic solution. At a 500 µg/mL concentration, the extract prevented 327.91% of RBC hemolysis, compared to 285.01% caused by Aspirin at the same concentration. Because the membranes of human red blood cells are comparable to those of lysosomes, the inhibition of hypotonicity-induced HRBC membrane lysis was used to assess the anti-inflammatory effects of medicines. The maximal inhibitory concentrations obtained revealed that methanolic extracts of the root and leaves of *R. mucronata* could strongly and dose-dependently prevent HRBC hemolysis. The study's findings indicate that an extract of *R. mucronata* exhibited anti-inflammatory activity in vitro. However, the rigorous investigation should characterize extracts as having significantly greater activity, searching for an active candidate or chemical molecule primarily responsible for this activity (Kaur et al., 2018).

The methanolic extract of the *R. mucronata* mangrove plant (leaves, bark, and stilt root) exhibits good membrane stability, implying anti-inflammatory activity. Given that the methanolic extract of leaves, bark, and stilt root of *R. mucronata* possesses significant anti-inflammatory properties, further laboratory investigation and chemical isolation of these plant parts (leaves, bark, and stilt root) may confirm an effective drug molecule in pharmacologic terms, in both types of pharmaceutical arenas (Kaur et al. 2018).

## ANALGESICS

Pain is a prevalent noxious phenomenon that contributes to one of the most pervasive healthcare problems and results in various complex physical and psychological disorders (Zareba 2009). Unfortunately, pain therapy with a variety of analgesics provides only symptomatic alleviation. Analgesics are a family of medications that can be broadly categorized into centrally acting analgesics and peripherally acting analgesics. While non-steroidal anti-inflammatory drugs (NSAIDs), steroids, and opiates are currently the most widely prescribed and most commonly used over-the-counter analgesics, they are associated with several adverse effects, including respiratory depression, addiction, and abuse potential in the case of central analgesics and gastric ulceration, gastrointestinal bleeding in the case of NSAIDs (Barua et al. 2011).

Additionally, non-reducing sugars, flavonoids, polyphenols, glycosides, terpenoids, Quercetin, and a significant amount of tannins were detected in the ethanolic extract of *R. mucronata* leaves. In a dose-dependent way, the ethanolic extract demonstrated a considerable analgesic effect in the acetic acid-induced writhing response in mice (Andikhari et al., 2016). Acetic acid injected intraperitoneally elicited visceral pain in the abdomen, triggering a localized inflammatory response that increased pain mediators such as prostaglandins, particularly PGE2, PGF2α, and lipoxygenase-mediated eicosanoids in the peritoneal fluid, resulting in abdominal constriction or writhing in mice (Derardt et al. 1980; Dhara et al. 2000). This model is well-established for assessing peripheral analgesic effectiveness; analgesic drugs act on visceral receptors, suppress pain mediators, and decrease the number of writhes. RME significantly reduced the writhing reaction; thus, it may be concluded that the leaf extract had peripheral analgesic efficacy (Andikhari et al., 2016).

The Eddy's hot plate and immersion of the mice’s tail in hot water are two approved procedures for determining the efficacy of centrally acting analgesics. Thermal stimuli elicit a non-inflammatory, central nociceptive response(D'Amour and Smith 1941; Sewell and Spencer 1976). In the hot plate model, the extract of *R. mucronata* leaves marginally enhanced the reaction time. Additionally, the test sample had a very low response when using the tail immersion procedure and administering the 200 mg/kg body weight dose (orally). As a result, the ethanolic extracts exhibit a lesser degree of central analgesic activity (Andikhari et al., 2016).

The ethanolic extract of *R. mucronata* bark was found to have a significant analgesic effect in doses of 250 mg/kg and 500 mg/kg bodyweight (Howlader et al., 2013). It is generally established that opioid or narcotic analgesics inhibit both peripheral and central pain, whereas non-steroidal anti-inflammatory medications (NSAIDs) inhibit mainly peripheral pain (Pal et al. 1999). The ethanolic extract of *R. mucronata* leaves decreased the acetic acid-induced writhing response in mice dosage dependently but was ineffective in the other two analgesic models. As a result, the extract demonstrated characteristics similar to NSAIDs (Andikhari et al., 2016).

It can be concluded that the ethanolic extract of *R. mucronata* (Sunderban mangrove) leaves possesses potential peripheral analgesic activity, which may be mediated peripherally. This could be because of its phytoconstituents, such as flavonoids, polyphenols, and tannins. Additional research is being conducted to confirm the analgesic efficacy and justify its therapeutic application. In the current investigation, an ethanolic extract of *R. mucronata* leaves was safe in mice at doses up to 2 mg/kg bodyweight (orally). The section at 200 mg/kg bodyweight (orally) inhibited the writhing reaction caused by acetic acid in mice. While the hot plate method extended the delay duration relative to the control by a small amount, the tail immersion test revealed no significant result. The present investigation established that the ethanolic extract of *R. mucronata* (Sunderban mangrove) leaves is high in tannin, flavonoids, and polyphenols and may exert peripheral and modest central analgesic effects (Andikhari et al. 2016).

## CONCLUDING REMARKS

*Rhizophora mucronata* is traditionally used as a source of wood (timber) for building materials, boats and firewood and charcoal, tanning and dying, as well as to treat diseases such as diarrhea. Flour from ripe fruit can be a safe source of carbohydrates for people with diabetes, hepatitis, ulcers, etc. Recent studies have shown that various leaf and bark extracts of *R. mucronata* contain tannins, alkaloids, flavonoids, terpenoids, etc. Recent research has shown that this plant extract acts as an antioxidant, anti-diabetic, antimicrobial (anti-viral, anti-fungal, anti-bacterial), anti-cancer, anti-inflammatory, and analgesic. More research is needed to ground the drug's potential into actual drugs and the possibility of plant breeding to obtain high-quality cultivars of *R. mucronata* as a source of medicine and food.

## REFERENCES


Abeysinghe PD. 2012. Antibacterial activity of aqueous and ethanol extracts of mangrove species collected from Southern Sri Lanka. Asian J Pharm Biol Res 2 (1): 79-83.

Abidin NAZ, Halim NAH, Ropisah. 2013. Basic study of chemical constituents in *Rhizophora mucronata* species. Open Conf Proc J 4 (Suppl-2, M7): 27-28. DOI: 10.2174/2210289201304020027.

Andikhari A, Ray M, Das AK. 2016. Antidiabetic and antioxidant activity of *Rhizophora mucronata* leaves (Indian Sundarbans mangrove)-An in-vitro and in-vivo study. Ayu 37 (1): 76-81. DOI: 10.4103/ayu.AYU_182_15.

Agoramoorthy G, Chen F, Venkatesalu V, Kudo DH, Shea PC. 2008. Evaluation of antioxidant polyphenols from selected medicinal plants of India. Asian J Chem 20 (2): 1311-1322.

Agoramoorthy G, Chandrasekaran M, Venkatesalu V, Hsu MJ. 2007. Antibacterial and antifungal activities of fatty acid methyl esters of the blind-your-eye mangrove from India. Braz J Microbiol 38: 739-742. DOI: 10.1590/S1517-83822007000400028.

Akalanka D, Somasundaram ST, Manavalan R. 2002. Antibacterial activity of leaf and stem bark extract of *Rhizophora mucronata* Poir. Seshaiyana 10: 2.

Ali SS, Kasoju N, Luthra A, Singh A, Sharanabasava H, Sahu A, Bora U. 2008. Indian medicinal herbs as sources of antioxidants. Food Res Intl 41 (1): 1-15. DOI: 10.1016/j.foodres.2007.10.001.

Alikunhi NM, Kandasamy K, Manoharan C, Subramanian M. 2012. Insulin-like antigen of mangrove leaves and its anti-diabetic activity in alloxan-induced diabetic rats. Nat Prod Res 26 (12): 1161-1166. DOI: 10.1080/14786419.2011.562205.

Aljaghthmi O, Heba H, Zeid IA. 2018. Bioactive compounds extracted from mangrove plants (*Avicennia marina* and *Rhizophora mucronata*)-an overview. Pathophysiology 2018: 969. DOI: 10.1016/j.pathophys.2018.09.002.

Alongi DM. 2002. Present state and future of the world's mangrove forests. Environ Conserv 29 (3): 331-349. DOI: 10.1017/S0376892902000231.

Amic A, Davidovic-Amic D, Beslo D, Trinajstic N. 2003. Structure-radical scavenging activity relationships of flavonoids. J Croatica Chem Acta 76 (1): 55-61.

Ammanamanchi SRA, Anjaneyulu V, Rao VL. 2004. New beyerane and isopimarane diterpenoids from *Rhizophora mucronata*. J Asian Nat Prod Res 4 (1): 53-60. DOI: 10.1080/10286020290019703.

Andikhari A, Moumita R, Tapas KS, Satyajyoti K, Ranendra KR, Anup KD. 2016. Analgesic actions of Sunderban mangrove, *Rhizophora mucronata* L. leaves. India: J Med Plants Stud 140 (43): 140-143.

Anjaneyulu AS, Rao VL. 2001. Rhizophorin A, a novel secolabdane diterpenoid from the Indian mangrove plant *Rhizophora mucronata*. Nat Prod Lett 15 (1): 13-19. DOI: 10.1080/10575630108041252.

Anjaneyulu AS, Rao VL. 2003. Ceriopsins f and g, diterpenoids from *Ceriops decandra*. Phytochemistry 62 (8): 1207-1211. DOI: 10.1016/S0031-9422(02)00627-1.

Arumugam G, Swamy MK, Sinniah UR. 2016. *Plectranthus amboinicus* (Lour.) Spreng: botanical, phytochemical, pharmacological, and nutritional significance. Molecules 21 (369): 1-26. DOI: 10.3390/molecules21040369.

Arumugam S, Palanisamy D, Sambandam RT. 2014. Identification of bioactive compounds of *Rhizophora mucronata* Poir. leaves using supercritical fluid extraction and GC-MS. World J Pharm Pharm Sci 3 (10): 1621-1631.

Atkinson MR, Findlay GP, Hope AB, Pitman MG, Saddler HDW, West KR. 1967. Salt regulation in the mangroves *Rhizophora mucronata* Lam. and *Aegialitis annulata* R.Br. J Biol Sci 20 (3): 589-599. DOI: 10.1071/BI9670589.

Azooz MM, Alzahrani AM, Youssef MM. 2013. The potential role of seed priming with ascorbic acid and nicotinamide and their interactions to enhance salt tolerance in broad bean (*Vicia faba* L.). Aust J Crop Sci 7 (13): 2091-2100.

Babu BH, Shylesh BS, Padikkala J. 2001. Antioxidant and hepatoprotective effect of *Acanthus ilcifolius*. Fitoterapia 72 (3): 272-277. DOI: 10.1016/S0367-326X(00)00300-2.

Babuselvam M, Kathiresan K, Ravikumar S, Uthiraselvam M, Rajabudeen E. 2012. Scientific evaluation of aqueous extracts of fresh and dried leaves from *Rhizophora mucronata* Lamk (Rhizophoracea) in rats. Afr J Pharm Pharmacol 6 (11): 814-817. DOI: 10.5897/AJPP11.636.

Bailey CJ, Day C. 1989. Traditional plant medicines as treatments for diabetes. Diabetes Care 12 (8): 553-564. DOI: 10.2337/diacare.12.8.553.

Bandaranayake WM. 2002. Bioactivities, bioactive compounds, and chemical constituents of mangrove plants. Wet Ecol Manag 10 (6): 421-452. DOI: 10.1023/A:1021397624349.

Bandaranayake WM. 1998. Traditional and medicinal uses of mangroves. Mangroves Salt Marshes 2 (3): 133-148. DOI: 10.1023/A:1009988607044.

Banerjee D, Chakrabarti S, Hazra AK, Banerjee S, Ray J, Mukherjee B. 2008. Antioxidant activity and total phenolics of some mangroves in Sundarbans. Afr J Biotechnol 7 (6): 805-810.

Barua CC, Buragohain B, Roy JD, Talukdar A, Barua AG, Borah P. 2011. Evaluation of analgesic activity of hydroethanol extract of *Plantago erosa* Ex Roxb. Pharmacol Online 2: 86-95.

Basak UC, Das AB, Das P. 1996. Chlorophyll, carotenoids, proteins, and secondary metabolites in leaves of 14 species of mangroves. Bull Mar Sci 58 (3): 654-659.

Basyuni M. 2008. Studies on Terpenoid Biosynthesis of Mangrove Tree Species. [Disertation]. Agricultural Sciences, Kagoshima University. [Japan]

Batool N, Ilyas N, Shahzad A. 2014. Asiatic mangrove (*Rhizophora mucronata*)-An overview. Eur J Acad Res 2 (3): 3348-3363.

Battulga T, Tumurbaatar O, Ganzorig O, Ishimura T, Kanamoto T, Nakashima H, Miyazaki K, Yoshida T. 2019. Analysis of interaction between sulfated polysaccharides and HIV oligopeptides by surface plasmon resonance. Intl J Biol Macromol 125: 909-914. DOI: 10.1016/j.ijbiomac.2018.12.010.

Bibi SN, Fawzi MM, Gokhan Z, Rajesh J, Nadeem N, Kannan RR, Albuquerque RDDG, Pandian SK. 2019. Ethnopharmacology, phytochemistry, and global distribution of mangroves-a comprehensive review. Mar Drugs 17 (4): 231. DOI: 10.3390/md17040231.

Boonyapraphat N, Chockchaicharaenphorn C. 1998. Thai Medicinal Plants. Vol.II. Prachachon Ltd., Bangkok. [Thailand]

Bose S, Bose A. 2008. Antimicrobial activity of *Acanthus ilcifolius* (L). Indian J Pharm Sci 70 (6): 821-823. DOI: 10.4103/0250-474X.49134.

Bravo L. 1998. Polyphenols: Chemistry, dietary sources, metabolism, and nutritional significance. Nutr Rev 56 (11): 317-333. DOI: 10.1111/j.1753-4887.1998.tb01670.x.

Budhiyanti SA, Raharjo S, Marseno DW, Lelana IYB. 2012. Antioxidant activity of brown algae sargassum species extract from the coastline of Java Island. Am J Agric Biol Sci 7 (3): 337-346. DOI: 10.3844/ajabssp.2012.337.346.

Bunyapraphatsara N, Srisukh V, Jutiviboonsuk A, Sornlek P, Thongbainoi W, Chuakul W, Fong HHS, Pezzuto JM, Kosmeder J. 2002. Vegetables from the mangrove areas. Thai J Phytopharm 9 (1): 1-12.

Burkill JH. 1966. A Dictionary of Economic Products of the Malay Peninsula. Art Printing Works, Kuala Lumpur. [Malaysia]

Chakraborty K, Raola VK. 2017. Two rare antioxidant and anti-inflammatory oleanenes from loop root Asiatic mangrove *Rhizophora mucronata*. Phytochemistry 135: 160-68. DOI: 10.1016/j.phytochem.2016.12.013.

Chandalia M, Garg A, Lutjohann D, Von-Bergmann K, Grundy SM, Brinkley LJ. 2000. Benefficial effects of high dietary fiber intake in patients with type 2 diabetes mellitus. New England J Med 342 (19): 1392-1398. DOI: 10.1056/NEJM200005113421903.

Chandrasekaran M, Kannathasan K, Venkatesalu V, Prabhakar K. 2009. Antibacterial activity of some salt marsh halophytes and mangrove plants against methicillin resistant *Staphylococcus aureus*. World J Microbiol Biotechnol 25 (1): 155-160. DOI: 10.1007/s11274-008-9869-1.

Chou FY, Kubo KH, Nakamshi K. 1977. Isolation of an insect anti-feedent N-methyl flindesine and several Benz (c) phrnantherine alkaloids from East African plants a comment on chelethrine. Heterocycles 7: 969-977. DOI: 10.3987/S-1977-02-0969.

Chou CT. 1997. The antiinflammatory effect of *Tripterygium wilfordii* Hook. f. on adjuvant-induced paw oedema in rats and inflammatory mediators release. Phytother Res 11 (2): 152-154. DOI: 10.1002/(SICI)1099-1573(199703)11:2<152::AID-PTR45>3.0.CO;2-L.

Choudhury S, Sree A, Mukherjee SC, Pattnaik P, Bapuji M. 2005. In vitro antibacterial activity of extracts of selected marine algae and mangroves against fish pathogens. Asian Fish Sci 18 (3/4): 285-294. DOI: 10.33997/j.afs.2005.18.3.009.

Cowan MM. 1999. Plant products as antimicrobial agents. Clin Microbiol Rev 12 (4): 564-582. DOI: 10.1128/CMR.12.4.564.

D'Amour FE, Smith DL. 1941. A method for determining loss of pain sensation. J Pharmacol Exper Therap 72 (1): 74-79.

Davey P. 2005. At a Glance Medicine. Erlangga, Jakarta. [Indonesian]

Dhayanithi NB, Kumar TTA, Murthy RG, Kathiresan K. 2012. Isolation of antibacterials from the mangrove *Avicennia marina* and their activity against multi drug resistant *Staphylococcus aureus.* Asian Pac J Trop Biomed 2 (3): S1892-S1895. DOI: 10.1016/S2221-1691(12)60516-4.

Derardt R, Jongney S, Delvalcee F, Falhout M. 1980. Release of prostaglandins E and F in an algogenic reaction and its inhibition. Eur J Pharmacol 61 (1): 17-24. DOI: 10.1016/0014-2999(80)90377-5.

Dhara AK, Suba V, Sen T, Pal S, Chaudhuri AK. 2000. Preliminary studies on the anti-inflammatory and analgesic activity of methanolic fraction of the root of *Tragia involucrata*. J Ethnopharmacol 72 (1-2): 265-268. DOI: 10.1016/S0378-8741(00)00166-5.

Dianitami R. 2009. Effect of Seaweed *Eucheuma* sp. on Blood Glucose Levels and Platelet Counts Induced Wistar Rats Alloxan. [Research Final Report]. Universitas Diponegoro, Semarang. [Indonesian]

Duke JA, Wain KK. 1981. Medicinal Plants of the World. Computer Index with more than 85,000 Entries, p. 3 Vols.

Duke JA. 1992. Handbook of Biologically Active Phytochemicals and Their Activities. CRC Press, Boca Raton, Florida.

Duke NC, Allen JA. 2006. *Rhizophora mangle, R. samoensis, R. racemosa, R. harrisonii* (Atlantic-East Pacific Red Mangrove). Species Profiles for Pacific Island Agroforestry. www.traditionaltree.org

Duke NC. 2006. *Rhizophora apiculata, R. mucronata, R. stylosa, R. × annamalai, R. × lamarckii* (Indo-West Pacific Stilt Mangroves). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources, Hōlualoa, Hawai'i, USA

Effendi H, Emawan AH, Wardiatno Y, Krisanti M. 2012. Acute toxicity ($LC_{50}$) powder drill (cuttings) to *Daphnia* sp. J Bumi Lestari 12 (2): 321-326. [Indonesian]

Gaffar MUl, Morhed MA, Uddin A, Roy S, Hannan JMA. 2011. Study the efficacy of *Rhizophora mucronata* Poir leaves for diabetes therapy in long evans rats. Intl J Biomol Biomed 1 (1): 20-26.

Ghosh A, Mishra S, Dutta AK, Chowdhury A. 1985. Pentracyclic triterpenoids and sterols from seven species of mangrove. Phytochemistry 24 (8): 1725-1727. DOI: 10.1016/S0031-9422(00)82541-8.

Gillikin D, Verheyden A. 2005. *Rhizophora mucronata* Lamk. 1804. A Field Guide to Kenyan mangroves. https://minerva.union.edu/gillikid/mangrove_14May2020/r_mucronata.htm.

Giesen W, Stephan W, Max Z, Scholten L. 2006. Mangrove Guidebook for Southeast Asia. FAO and Wetlands, International, Bangkok, Thailand.

Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Glob Ecol Biogeogr 20 (1): 154-159. DOI: 10.1111/j.1466-8238.2010.00584.x.

Glossary of Indian Medicinal Plants. 1992. Part 1. Publication and Information Directorate, CSIR, New Delhi. [India]

Goke R, Fehmann HC, Linn T, Schmidt H, Krause M, Eng J, Göke B. 1993. Exendin-4 is a high potency agonist, and truncated exendin-(9-39)-amide an antagonist at the glucagon-like peptide 1-(7-36)-amide receptor of insulin-secreting beta-cells. J Biol Chem 268 (26): 19650-19655. DOI: 10.1016/S0021-9258(19)36565-2.

GRIN 2006. *Rhizophora mucronata.* Information from NPGS/GRIN. Taxonomy for Plants. USDA, ARS, National Genetic Resources Program, National Germplasm Resources Laboratory, Beltsville, Maryland, USA.

Gurib-Fakim A, Brendler T. 2004. Medicinal and Aromatic Plants of Indian Ocean Islands: Madagascar, Comoros, Seychelles, and Mascarenes. Medpharm GmbH Scientific Publishers, Stuttgart. [Germany]

Gurudeeban S, Kaliamurthi S, Thirugnanasambandam R. 2016. Positive regulation of *Rhizophora mucronata* Poir extracts on blood glucose and lipid profile in diabetic rats. Herb Med 2: 2. DOI: 10.21767/2472-0151.100016.

Gurudeeban S, Satyavani K, Ramanathan T, Ravikumar P. 2012. Dipeptidyl peptidase IV inhibitors derived from a mangrove flora *Rhizophora mucronata*: An in silico approach. Bangladesh J Pharmacol 7 (3): 203-210. DOI: 10.3329/bjp.v7i3.11636.

Hamilton LS, Murphy DH. 1988. Use and management of nipa palm (*Nypa fruticans*, Arecaceae): A review. Econ Bot 42 (2): 206-213. DOI: 10.1007/BF02858921.

Han X, Shen T, Lou H. 2007. Dietary polyphenols and their biological significance. Intl J Mol Sci 8 (9): 950-988. DOI: 10.3390/i8090950.

Hardoko, Bambang BS, Yunita EP. 2016. Antidiabetic and antioxidant activities of tannin extract of *Rhizophora mucronata* leaves. J Chem Pharm Res 8 (3): 143-148.

Hardoko ES, Puspitasari Y, Amalia R. 2015. Study of ripe *Rhizophora mucronata* fruit flour as functional food for antidiabetic. Intl Food Res J 22 (3): 953-959.

Harrison TR. 2005. Diarrhea and Constipation. In: Principles of Internal Medicine 16th Edition. McGraw Hill, New York.

Harwoko H, Utami ED. 2010. Cytotoxic activity of fraction n-heksana: Chloroform from methanolic extract of *Rhizopora mucronata* stem barks on myeloma cell-lines. Majalah Obat Tradisional 15 (2): 51- 55. [Indonesian]

Hoppe-Speer SCL, Adams JB, Rajkaran A, Bailey D. 2011. The response of the red mangrove *Rhizophora mucronata* Lam. to salinity and inundation in South Africa. Aquat Bot 95 (2): 71-76. DOI: 10.1016/j.aquabot.2011.03.006.

Howlader SI, Ahmed J, Kabir ANMH, Uddin G, Hossain K. 2013. Antibacterial, cytotoxic, analgesic, and diuretic activities of *Rhizophora mucronata* Lam. bark. Indian J Nat Prod Resour 4 (3): 229-232.

Islam MS, Rahi MS. 2018. In-vivo anticancer activity of *Basella alba* leaf and seed extracts against Ehrlich's Ascites Carcinoma (EAC) cell line. Evid-Based Complement Altern Med 2018: 1-11. DOI: 10.1155/2018/1537896.

Jenkins DJA, Axelsen M, Kendall CWC, Augustin LSA, Vuksan V, Smith U. 2000. Dietary fibre, lente carbohydrates, and the insulin-resistant diseases. British J Nutr 83 (1): S157-S163. DOI: 10.1017/S0007114500001100.

Joel EL, Bhimba V. 2010. Isolation and characterization of secondary metabolites from the mangrove plant *Rhizophora mucronata*. Asian Pac J Trop Med 2010: 602-604. DOI: 10.1016/S1995-7645(10)60146-0.

Kathiresan K, Rajendran N. 2005. Mangrove ecosystems of Indian Ocean. Indian J Mar Sci 34 (1): 104-113.

Kathiresan K, Ramanathan T. 1997. Medicinal Plants of Parangipettai Coast. Annamalai University, Parangipettai. [India]

Katzung, B.G. 2007. Basic and Clinical Pharmacology, 10th Edition. The McGraw Hill Companies, Singapore.

Lawag IL, Aguinaldo AM, Nahed S, Mosihuzzaman M. 2012. α-glucosidase inhibitory activity of selected Philippine plants. J Ethnopharmacol 144 (1): 217-219. DOI: 10.1016/j.jep.2012.08.019.

Kaur S, Ali MS, Anuradha V, Suganya V, Ashashalini A, Bhuvana P. 2018. In vitro anti-inflammatory activity of mangrove plant *Rhizophora mucronata* Lam. (Malpighiales: Rhizophoraceae). Brazilian J Biol Sci 5 (10): 417-426. DOI: 10.21472/bjbs.051018.

Khare CP. 2007. Indian Medicinal Plants: An Illustrated Dictionary. Springer, New York, USA. DOI: 10.1007/978-0-387-70638-2.

Kirtikar KR, Basu BD. 1987. Indian Medicinal Plants, 2nd Edition, International Book Distributors and Book Sellers, Dehradun. [India]

Kokpal V, Miles DH, Payne AM, Chittarwong V. 1990. Chemical constituents and bioactive compounds from mangrove plants. Stud Nat Prod Chem 7: 175-199.

Kokpal U, Chittawong V. 1987. Chemical constituent of *Acanthus illicifolius* Linn and biology activity. UNESCO, Regional Seminar on Chemistry of Mangrove Plants, Bangkok. [Thailand]

Krings U, Berger RG. 2001. Antioxidant activity of some roasted foods. Food Chem 72 (2): 223-229. DOI: 10.1016/S0308-8146(00)00226-0.

Krishnamoorthy M, Sasikumar J, Shamna R, Pandiarajan C, Sofia P, Nagarajan B. 2011. Antioxidant activities of bark extract from mangroves, *Bruguiera cylindrica* (L.) Blume and *Ceriops decandra* Perr. Indian J Pharmacol 43 (5): 557. DOI: 10.4103/0253-7613.84972.

Kuppusamy P, Yusoff MM, Parine NR, Govindan N. 2015. Evaluation of in-vitro antioxidant and antibacterial properties of *Commelina nudiflora* L. extracts prepared by different polar solvents. Saudi J Biol Sci 22 (3): 293-301. DOI: 10.1016/j.sjbs.2014.09.016.

Kurniadi R, Koeslulati EE. 2020. Short Communication: Willingness to participate in planting and protecting mangrove forest: community response related to mangrove fruit product utilization in Pariti, Timor Island, Indonesia. Trop Drylands 4: 1-4. DOI: 10.13057/tropdrylands/t040101.

Kusuma S, Kumar PA, Boopalan K. 2011. Potent antimicrobial activity of *Rhizophora mucronata*. J Ecobiotechnol 3 (11): 40-41.
Laphookhieo S, Karalai C, Ponglimanont C. 2004. New sesquiterpenoid dan triterpenoids from the fruits of *Rhizophora mucronata*. Chem Pharm Bull 52 (7): 883-885. DOI: 10.1248/cpb.52.883.
Lewis DA, Hanson PJ. 1991. Antiulcer drugs of plant origin. In: Ellis GP, West GB (eds) Progress Medicinal Chemistry, Elsevier Science Publishers, London, UK. DOI: 10.1016/S0079-6468(08)70365-5.
Liebezeit G, Rau MT. 2006. New Guinean mangroves-Traditional usage and chemistry of natural products. Senck Marit 36 (1): 1-10. DOI: 10.1007/BF03043698.
Madhu K, Madhu R. 1997. Biotoxicity of mangroveson fingerlings of *Liza macrolepis* (Smith). J Andaman Sci Assoc Port Blair 13 (1&2): 59-65.
Mahmiah, Giman, Aminah NS, Tanjung M. 2016. Antioxidant activity of methanol extracts from the stem bark of mangrove plant *Rhizophora mucronata*. Proceeding of 1st International Conference on Medicine and Health Sciences 2016.
Mahmiah, Sudjarwo GW, Hukmiyah OMM. 2017. Kandungan senyawa metabolit sekunder dari fraksi etil asetat kulit batang *Rhizopora mucronata* L. Seminar Nasional Kelautan XII “Inovasi Hasil Riset dan Teknologi dalam Rangka Penguatan Kemandirian Pengelolaan Sumber Daya Laut dan Pesisir. Fakultas Teknik dan Ilmu Kelautan Universitas Hang Tuah, Surabaya, 20 Juli 2017. [Indonesian]
Manilal A, Merdekios B, Idhayadhulla A, Muthukumar C, Melkie M. 2015. An in vitro antagonistic efficacy validation of *Rhizophora mucronata*. Asian Pac J Trop Dis 5 (1): 28-32. DOI: 10.1016/S2222-1808(14)60622-8.
Meyer BN, Ferrigni NR, Putman JE, Jacbsen LB, Nicols DE, McLaughlin JL. 1982. Brine shrimp: A convenient general bioassay for active plant constituents. Plant Medica 45 (5): 31-34. DOI: 10.1055/s-2007-971236.
Meyer KA, Kushi LH, Jacobs DRJr, Slavin J, Sellers TA, Folsom AR. 2000. Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. Am J Clin Nutr 71 (4): 921-930. DOI: 10.1093/ajcn/71.4.921.
Middleton EJr, Kandaswami C, Theoharides TC. 2000. The effects of plant flavonoids on mammalian cells: Implications for inflammation, heart disease, and cancer. Pharmacol Rev 52 (4): 673-751.
Nabeel MA, Kathiresan K, Manivannan S. 2010. Antidiabetic activity of the mangrove species *Ceriops decandra* in alloxan-induced diabetic rats. J Diabetes 2 (2): 97-103. DOI: 10.1111/j.1753-0407.2010.00068.x.
Nakpathom M, Somboon B, Narumol N. 2011. Pigment printing of natural dye from red mangrove bark on silk fabrics. Mater Sci Forum 695: 279-282. DOI: 10.4028/www.scientific.net/MSF.695.279.
Nazima B, Noshin I, Armghan S. 2014. Asiatic mangrove (*Rhizophora mucronata*): An overview. Eur Acad Res 2 (3): 3348-3363.
Ng PKL, Sivasothi N. 2001. A Guide to Mangroves of Singapore. Raffles Museum of Biodiversity Research, National University of Singapore and Singapore Science Centre, Singapore.
Nurdiani R, Firdaus M, Prihanto AA. 2012. Phytochemical screening and antibacterial activity of methanol extract of mangrove plant (*Rhizophora mucronata*) from Porong River Estuary. J Basic Sci Technol 1 (2): 27-29.
Odom TC, Udensi EA, Ogbuji CA. 2013. Evaluation of hypoglycmic properties of *Mucuna cochichinensis* unripe, *Carica papaya*, and unripe *Musa paradisiaca* flour blends. Eur J Biol Med Sci Res 1 (1): 15-22.
Padmakumar K. 1988. Bioactive Substances from Marine Algae and Mangroves. [Thesis]. Annamalai University, Tamil Nadu. [India]
Padmakumar K, Ayyakkannu K. 1997. Antiviral activity of marine plants. India J Virol 13 (1): 33-36.
Pal S, Sen T, Chaudhuri AK. 1999. Neuropsychopharmacological profile of the methanolic fraction of *Bryophyllum pinnatum* leaf extract. J Pharm Pharmacol 51 (3): 313-318. DOI: 10.1211/0022357991772312.
Palaniyandi T, Sivaji A, Thirugnanasambandam R, Durairaj P, Reddy RK, Vishwanathan S. 2020. Isolation and identification of anti-oxidant fraction from active extract of *Rhizophora mucronata* Poir. leaves. Pharm Chem J 54 (4): 380-385. DOI 10.1007/s11094-020-02208-9.
Pandey AK, Gupta PP, Lai VK. 2014. Hypoglycemic effect of *Rhizophora mucronata* in streptozotocin induced diabetic rats. J Complement Integr Med 11 (3): 179-183. DOI: 10.1515/jcim-2012-0057.
Patra JK, Panigrahi TK, Rath S, Dhal NK, Thatoi H. 2009. Phytochemical screening and antimicrobial assessment of leaf extracts of *Excoecaria agallocha* L.: A mangal species of Bhitarkanika, Orissa, India. Adv Nat Appl Sci 3 (2): 241-246.
Perry LM. 1980. Medicinal Plants of East and Southeast Asia. MIT Press, Cambridge.
Portha B, Blondel O, Serradas P, McEvoy R, Giroix MH, Kergoat M, Bailbe D. 1989. The rat models of non-insulin dependent diabetes induced by neonatal streptozotocin. Diabete Metab 15 (2): 61-75.
Potterat O. 1997. Antioxidants and free radical scavengers of natural origin. Curr Org Chem 1 (4): 415-440. DOI: 10.2174/1385272801666220126162734.
Prabhakaran J, Kavitha D. 2012. Ethnomedicinal importance of mangrove species of Pitchavaram. Intl J Res Pharm Biomed Sci 3 (2): 611-614.
Prabhu V, Guruvayoorappan C. 2011. Anti-inflammatory and anti-tumor activity of the marine mangrove *Rhizophora apiculata*. J Immunotoxicol 9 (4): 1-12. DOI: 10.3109/1547691X.2012.660997.
Premanathan M, Arakaki R, Izumi H, Kathiresan K, Nakano M, Yamamoto N. 1999. Antiviral properties of a mangrove plant *Rhizophora apiculata* Blume, against human immunodeficiency virus. Antivir Res 44 (2): 113-122. DOI: 10.1016/S0166-3542(99)00058-3.
Premanathan M, Kathiresan K, Yamamoto N, Nakashima H. 1999. In vitro anti-human immunodeficiency virus activity of polysaccharide from *Rhizophora mucronata* Poir. Biosci Biotech Biochem 63 (7): 1187-1191. DOI: 10.1271/bbb.63.1187.
Premanathan M, Kathiresan K, Chandra K. 1995. Antiviral evaluation of some marine plants against Semliki Forest virus. Pharm Biol 33 (1): 75-77. DOI: 10.3109/13880209509088153.
Premanathan M, Chandra K, Bajpai SK, Kathiresan K. 1992. A survey of some Indian marine plants for antiviral activity. Bot Mar 35: 321-324. DOI: 10.1515/botm.1992.35.4.321.
Purwaningsih S, Salamah E, Sukarno YP, Deskawati E. 2013. Aktivitas antioksidan dari buah mangrove (*Rhizophora mucronata* Lamk.) pada suhu yang berbeda. JPHPI 16 (3): 199-206. [Indonesian]
Puspitasar YA, Hartiati AM, Suprayitno E. 2012. The potency of *Rhizophora mucronata* leaf extract as antidiarrhea. J Appl Sci Res 8 (2): 1180-1185.
Rahim AA, Emmanuel R, Jean S, Kassim MJ, Ibrahim MS, Osman H. 2008. Antioxidant activities of mangrove *Rhizophora apiculata* bark extracts. Food Chem 107 (1): 200-207. DOI: 10.1016/j.foodchem.2007.08.005.
Rahman M, Siddika A, Bhadra B, Rahman S, Agarwala B, Chowdhury MH. 2010. Antihyperglycemic activity studies on methanol extract of *Petrea volubilis* L. (Verbenaceae) leaves, and *Excoecaria agallocha* L. (Euphorbiaceae) stems. Adv Nat Appl Sci 4 (3): 361-364.
Ramanathan T, Hariharan B, Ganesan K. 2008. Antidiabetic activity of a coastal mangrove leaves of *Rhizophora mucronata*. Intl J Plant Res 8 (2): 931-933.
Ravikumar S, Ramanathan G, Subhakaran M, Inbaneson SJ. 2009. Antimicrobial compounds from marine halophytes for silkworm disease treatment. Intl J Med Med Sci 1 (5): 184-191.
Ravikumar S, Gnanadesigan M. 2012. Hepatoprotective and antioxidant properties of *Rhizophora mucronata* mangrove plant in $CCl_4$ intoxicated rats. J Exp Clin Med 4 (1): 66-72. DOI: 10.1016/j.jecm.2011.11.012.
Ravikumar S, Kathiresan K. 1993. Influence of tannins, amino acids, and sugar on fungi of marine halophytes. Mahasagar 26 (1): 21-25.
Ravikumar S, Nazar S, Shiefa AN, Abideen S. 2005. Antibacterial activity of traditional therapeutic coastal medicinal plants against some pathogens. J Environ Biol 26 (2): 383-386.
Ravindran K, Venkatesan K, Balakrishnan V, Chellappan K, Balasubramanian T. 2005. Ethnomedicinal studies of Pichavaram mangroves of east coast, Tamil Nadu. Indian J Tradit Knowl 4: 409-411.
Ray M, Andikhari A, Sur TK, Mondal C, Pathak A, Das AK. 2014. Pharmacognostic and anti-hyperglycemic evaluation of the leaves of Sunderban mangrove, *Rhizophora mucronata*. Pharmanest 5 (5): 2289-2294.
Revathi P, Jeyaseelan ST, Thirumalaikolundusubramanian P, Prabhu N. 2014. An overview of antidiabetic profile of mangrove plants. Intl J Pharm Pharm Sci 6 (3): 1-5.
Rohini RM, Das AK. 2009. A comparative evaluation of analgesic and anti inflammatory activities of *Rhizophora mucronata* bark. Pharmacol Online 1: 780-791. DOI: 10.1080/14786410903315069.
Rohini RM, Das AK. 2011. Determination of lupeol, beta-sitosterol, and quercetin from ethyl acetate extract of *Rhizophora mucronata* bark by HPTLC technique. Asian J Pharm Clin Res 4: 103-105.

Rohini R, Das A. 2010a. Antidiarrheal and anti inflammatory activities of lupeol, quercetin, β-sitosterol, adene-5-en-3-ol, and caffeic acid isolated from *Rhizophora mucronata* bark. Der Pharm Lett 2 (5): 95-101.

Rohini RM, Das AK. 2010b. Triterpenoids from the stem bark of *Rhizophora mucronata*. Nat Prod Res 24 (2): 197-202. DOI: 10.1080/14786410903315069.

Rollet B. 1981. Bibliography on Mangrove Research 1600-1975; UNESCO, Paris, France.

Sadeer NB, Mahomoodally MF, Zengin G, Jeewon R, Nazurally N, Kannan RR, Albuquerque R, Pandian SK. 2019. Ethnopharmacology, phytochemistry, and global distribution of mangroves-a comprehensive review. Mar Drugs 17 (231): 1-82. DOI: 10.3390/md17040231.

Saifullah SM. 1982. Mangrove ecosystem of Pakistan. In the Third Research on Mangroves of Middle East. Japan Cooperative Centre for the Middle East. Publ No 173 (3): 69-80.

Salini G. 2015. Pharmacological Profile of mangrove endophytes-A review. Intl J Pharm Pharm Sci 7 (1): 6-15.

Schwarzbach AE, Ricklefs RE. 2000. Systematic affinities of Rhizophoraceae and Anisophylleaceae, and intergeneric relationships within Rhizophoraceae, based on chloroplast DNA, nuclear ribosomal DNA, and morphology. Am J Bot 87 (4): 547-564. DOI: 10.2307/2656599.

Seepana R, Perumal K, Kada NM, Chatragadda R, Raju M, Annamalai V. 2016. Evaluation of antimicrobial properties from the mangrove *Rhizophora apiculata* and *Bruguiera gymnorrhiza* of Burmanallah Coast, South Andaman, India. J Coast Life Med 4 (6): 475-478. DOI: 10.12980/jclm.4.2016J6-52.

Setyawan AD, Ulumuddin YI. 2012. Species diversity of *Rhizophora* in Tambelan Islands, Natuna Sea, Indonesia. Biodiversitas 13 (4): 172-177. DOI: 10.13057/biodiv/d130402.

Setyawan AD, Ulumuddin YI, Ragavan P. 2014. Mangrove hybrid of *Rhizophora* and its parental species in Indo-Malayan region. Nusantara Biosci 6 (1): 69-81. DOI: 10.13057/nusbiosci/n060111.

Sewell RDE, Spencer PSJ. 1976. Anti-nociceptive activity of narcotic agonist and partial agonist analgesics and other agents in the tail-immersion test in mice and rats. Neuropharmacology 15 (11): 683-688. DOI: 10.1016/0028-3908(76)90037-X.

Sharmin S, Kabir MT, Islam MN, Jamiruddin MR, Rahman I, Rahman A, Hossain M. 2018. Evaluation of antioxidant, thrombolytic, and cytotoxic potentials of methanolic extract of *Aporosa wallichii* Hook. f. leaves: An unexplored phytomedicine. J Appl Pharm Sci 8 (7): 51-56. DOI: 10.7324/JAPS.2018.8709.

Shilpi JA, Islam ME, Billah M, Islam KMD, Sabrin F, Uddin SJ, Nahar L, Sarker SD. 2012. Antinociceptive, anti-inflammatory, and antipyretic activity of mangrove plants: A mini review. Adv Pharmacol Sci 2012: 1-7. DOI: 10.1155/2012/576086.

Shiono Y, Sasaki T, Shibuya F, Yasuda Y, Koseki T, Supratman U. 2013. Isolation of a phomoxanthone A derivative, a new metabolite of tetrahydroxanthone, from a *Phomopsis* sp. isolated from the mangrove, *Rhizhopora mucronata*. Nat Prod Commun 8 (12): 1735-1737. DOI: 10.1177/1934578X1300801220.

Singh R, Singh SK, Arora S. 2007. Evaluation of antioxidant potential of ethyl acetate extract/fractions of *Acacia auriculiformis* A. Cunn. Food Chem Toxicol 45 (7): 1216-1223. DOI: 10.1016/j.fct.2007.01.002.

Sivaperumal P, Ramasamy P, Inbaneson SJ, Ravikumar S. 2010. Screening of antibacterial activity of mangrove leaf bioactive compounds against antibiotic resistant clinical isolates. World J Fish Mar Sci 2 (5): 348-353.

Soetan KO. 2008. Pharmacological, other beneficial effects of Antinutritional: Factors in plants- A review. Afr J Biotechnol 7 (25): 4713-4721.

Sreedhar S, Christy PH. 2015. Phytochemical analysis of *Rhizophora mucronata*. Scrut Intl Res Agric Plant Biotechnol Biol Prod 2: 39-43.

Suganthy N, Devi KP. 2016. In vitro antioxidant and anti-cholinesterase activities of *Rhizophora mucronata*. Pharm Biol 54 (1): 118-129. DOI: 10.3109/13880209.2015.1017886.

Suganya V, Anuradha V, Ali MS, Sangeetha P, Bhuvana P. 2017. In vitro anti-diabeticactivity of microencapsulated and non-encapsulated Astaxanthin. Intl J Curr Pharm Res 9 (5): 90-96. DOI: 10.22159/ijcpr.2017v9i5.22147.

Sulistiono, Hestirianoto T, Samosir AM, Zahid A. 2015. Field Guide Fish, Marine Mammal, Sea Turtle, and Mangrove Berau-Bintuni Bay, West Papua. Tangguh LNG & Institut Pertanian Bogor, Bogor. [Indonesian]

Sur TK, Hazra AK, Bhattacharyya D, Hazra A. 2015. Antiradical and antidiabetic properties of standardized extract of Sunderban mangrove *Rhizophora mucronata*. Pharmacogn Mag 11 (42): 389-394. DOI: 10.4103/0973-1296.153094.

Sur TK, Seal T, Pandit S, Bhattacharyya D. 2004. Hypoglycemic properties of a mangrove plant, *Rhizophora apiculata* Blume. Nat Prod Sci 10 (1): 11-15.

Sur TK, Hazra A, Hazra AK, Bhattacharyya D. 2016. Antioxidant and hepatoprotective properties of Indian Sunderban mangrove *Bruguiera gymnorrhiza* L. leave. J Basic Clin Pharm 7 (3): 75. DOI: 10.4103/0976-0105.183262.

Swamy MK, Sinniah UR. 2016. Patchouli (*Pogostemon cablin* Benth.)-Botany, agrotechnology, and biotechno-logical aspects. Indus Crops Prod 87: 161-176. DOI: 10.1016/j.indcrop.2016.04.032.

Szkudelska K, Nogowski L, Szkudelski T. 2014. Adipocyte dysfunction in rats with streptozotocin-nicotinamide-induced diabetes. Intl J Exp Pathol 95 (2): 86-94. DOI: 10.1111/iep.12073.

Thakker VY, Shah VN, Shah UD, Suthar MP. 2011. Simultaneous estimation of gallic acid, curcumin and quercetin by HPTLC method. J Adv Pharm Educ Res 1: 70-80.

Thangam TS, Kathiresan K. 1989. Larvicidal effect of marine plant extracts on mosquito *Culex tritaeniorhynchus*. J Mar Biol Ass India 31 (1-2): 306-307.

Tosa H, Iinuma M, Tanaka T, Nozaki H, Ikeda S, Tsutsui K, Tsutsui K, Yamada M, Fujimori S. 1997. Inhibitoy activity of xanthone derivatives isolated from some guttiferaeous plants against DNA topoisomerases I and II. Chem Pharm Bull 45 (2): 418-420. DOI: 10.1248/cpb.45.418.

Trease CE, WC vans E. 1997. Pharmacognosy, 4th Edition. W.B. Saunders Company, U.K.

Vigneswaran T, Muthu Mohamed HS, Doss A. 2018. Determination of in-vitro antioxidant activity of leaf extracts of *Rhizophora mucronata* Lam. (Rhizophoraceae). J Pharmacogn Phytochem 7 (5): 2251-2255.

Wang C, Jurk D, Maddick. 2009. DNA damage response and cellular senescence in tissues of aging mice. Aging Cell 8 (3): 311-323. DOI: 10.1111/j.1474-9726.2009.00481.x.

Warui MW, Manohar S, Obade P. 2020. Current status, utilization, succession, and zonation of mangrove ecosystem along Mida Creek, Coast Province, Kenya. Bonorowo Wetl 10 (1): 32-43. DOI: 10.13057/bonorowo/w100103.

Watt JM, Breyer-Brandwijk MG. 1962. The Medicinal and Poisonous Plants of Southern and Eastern Africa. Livingstone, London.

Yogananth N, Anuradha V, Ali MYS, Muthezhilan R, Chanthuru A. 2015. Chemical properties of essential oil from *R. mucronata* mangrove leaf against malarial mosquito *Anopheles stephensi* and filarial mosquito *Culex quinquefasciatus*. Asian Pac J Trop Dis 5 (1): 67-79. DOI: 10.1016/S2222-1808(15)60859-3.

Yunita EP, Aniek MH, Eddy S. 2012. The potency of *Rhizophora mucronata* leaf extract as antidiarrhea. J Appl Sci Res 8 (2): 1180-1185.

Zareba G. 2009. Phytotherapy for pain relief. Drugs Today (Barc) 45 (6): 445-467. DOI: 10.1358/dot.2009.45.6.1385751.

Zhou J, Fang L, Liao J, Li L, Yao W, Xiong Z, Zhou X. 2017. Investigation of the anti-cancer effect of quercetin on HepG2 cells in-vivo. Plos One 12 (3): 1-10. DOI: 10.1371/journal.pone.0172838.