International Journal of BONOROWO WETLANDS

| Intl J Bonorowo Wetl | vol. 14 | no. 1 | June 2024 | ISSN 2775-8052 | E-ISSN 2775-8044 |

Riparian ecosystems of tropical peatland photo by Nanang Sujana/CIFOR

International Journal of
BONOROWO WETLANDS

| Intl J Bonorowo Wetl | vol. 14 | no. 1 | June 2024 | ISSN 2775-8052 | E-ISSN 2775-8044 |

Published semiannually **PRINTED IN INDONESIA**

ISSN 2088-110X
E-ISSN 2088-2475

9 772775 804275

International Journal of BONOROWO WETLANDS

| Intl J Bonorowo Wetl | vol. 14 | no. 1 | June 2024 |

ONLINE
http://smujo.id/bw

p-ISSN: 2775-8052, **e-ISSN:** 2775-8044

PUBLISHER
Smujo International

ASSICIATION
Society for Indonesian Biodiversity

INSTITUTION
Institut Pertanian Bogor, Bogor, Indonesia
Universitas Sebelas Maret, Surakarta, Indonesia

OFFICE ADDRESS
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;
email: editors@smujo.id

PERIOD OF ISSUANCE
June, December

Society for Indonesian Biodiversity

Institut Pertanian Bogor, Bogor, Indonesia

Universitas Sebelas Maret Surakarta, 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 *International Journal of Bonorowo Wetlands* **(Intl J Bonorowo Wetl)** (*formerly 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; wastewater disposal; as well as management, laws and regulations, policy and economics.

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

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

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

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

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

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

Free of charge This publication is dedicated entirely to the advancement of science and technology, therefore author(s) or author institution(s) are not subject to publication fees. **Reprint** Authors or other parties may freely download and distribute. However, a printed request will be charged. It 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 sizes can be applied in presenting tables and figures (9 pt). Word processing program or additional software can be used; however, it must be PC compatible, use the template, and be Microsoft Word based (.doc or .rtf; not .docx). **Scientific names** of species (incl. subspecies, variety, etc.) should be written in italics, except in italicized sentences. Scientific names (genus, species, author) and cultivar or strain should be mentioned completely for the first time mentioning it in the body text, especially for taxonomic manuscripts. The genus name can be shortened after the first mention, except in early sentences, or where this may generate confusion; name of the author can be eliminated after the first mention. For example, *Rhizopus oryzae* L. UICC 524 can be written hereinafter as *R. oryzae* UICC 524. Using trivial names should be avoided. **Biochemical and chemical nomenclature** should follow the order of the IUPAC-IUB. For DNA sequences, it is better to use Courier New font. Standard chemical abbreviations can be applied for common and clear used, for example, completely written butilic hydroxyl toluene (BHT) to be BHT hereinafter. **Metric measurements** should use IS denominations, and other systems should use equivalent values with the denomination of IS mentioned first. A dot should not follow abbreviations like g, mg, mL, etc. Minus index (m^{-2}, L^{-1}, h^{-1}) suggested being used, except in things like "per-plant" or "per-plot." **Mathematical equations** can be written down in one column with text; in that case, they can be written separately. **Numbers** one to ten are written in words, except if it relates to measurement, while values above them are written in number, except in early sentences. The fraction should be expressed in decimal. In the text, it should be used "%" rather than "percent." Avoid expressing ideas with complicated sentences and verbiage/phrasing, and use efficient and effective sentences.

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

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

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

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

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

Journal:

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

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

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

Book:

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

Chapter in the book:

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

Abstract:

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

Proceeding:

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

Thesis, Dissertation:

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

Information from the internet:

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

THIS PAGE INTENTIONALLY LEFT BLANK

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 1-8

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140101

Dragonfly (Odonata) diversity in Kedung Klurak Waterfall Area, Mojokerto District, East Java, Indonesia

DEA MA'RIFATUL ZAHRO'[1,♥], TITIS EKA RANI[1], ELSA PUTRI AGUSTIN[1], ABEL SEPTI DWI PERMATASARI[1], MUHAMAD AZMI DWI SUSANTO[1,2,♥♥]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Islam Negeri Sunan Ampel Surabaya. Jl. Ir. Soekarno 682, Gunung Anyar, Surabaya 60294, East Java, Indonesia. Tel./fax.: +62-31-8410298, ♥email: deamarif@gmail.com

[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran Ketawanggede Malang 65144, East Java, Indonesia. ♥♥email: muhammadazmidwi@gmail.com

Manuscript received: 31 October 2023. Revision accepted: 21 February 2024.

Abstract. *Zahro' DM, Rani TE, Agustin EP, Permatasari ASD, Susanto MAD. 2024. Dragonfly (Odonata) diversity in Kedung Klurak Waterfall Area, Mojokerto District, East Java, Indonesia. Intl J Bonorowo Wetlands 14: 1-8.* Kedung Klurak is a tourist spot in Mojokerto District, East Java, Indonesia with a waterfall dominated by pine trees. Furthermore, using Kedung Klurak as a tourist spot increases human activity. This can affect the natural habitat of dragonflies; therefore, this study was conducted to identify the diversity of dragonfly species in the Kedung Klurak Waterfall Area. The sampling method used sweep net and path determination method using transects. The observation location was divided into three stations: waterfall, open area, and pine forest. The results of the study obtained 15 species from seven families. The Diversity Index in Kedung Klurak Waterfall Area is H': 1.605 in the medium diversity category. The highest diversity index is at the waterfall station with H': 1.678, followed by the open area station with H': 1.446, and the lowest diversity index at the pine forest station with H': 1.095. Several factors can affect species diversity differences at the three stations because each station has different environmental conditions, including temperature, light intensity, humidity, and vegetation. Based on the study's results, it can be concluded that the Waterfall station has a habitat following the natural habitat of dragonflies. Some species tolerate the environment and human disturbances, namely *Vestalis luctuosa* and *Euphaea variegata*. Therefore, using Kedung Klurak Waterfall as a tourist attraction can cause a loss of dragonfly diversity due to loss of vegetation, environmental pollution, and human disturbance. These factors cause dragonflies to move away from their habitat, as in the open area station where only five species of dragonflies were found.

Keywords: Anisoptera, habitat, tourism site, Zygoptera

INTRODUCTION

Dragonflies are flying insects belonging to Odonata (Rizal and Hadi 2015). Odonata is derived from the Greek word "jaws" with teeth at the end of the lower lip and sharp protrusions resembling teeth (Pelealu et al. 2022). Odonata comprises two suborders: Anisoptera and Zygoptera (Mendoza-Panagos et al. 2021). The difference between these two suborders can be seen from their morphology; for example, the body size of Anisoptera dragonflies is larger than that of Zygoptera (Salsabiela et al. 2022). The difference between these two suborders can be observed from their morphology; for example, the body size of dragonflies in Suborder Anisoptera is relatively larger when compared to dragonflies in Suborder Zygoptera (Salsabiela et al. 2022). In the dragonfly Suborder Zygoptera, when perched, the position of the wings will be closed upwards. In contrast, in the dragonfly Suborder Anisoptera, the wings will be spread wide to the side (Bybee et al. 2016). In addition to slimmer body size, Zygoptera dragonflies generally have a flying distance close to the ground and are relatively slower than Anisoptera (Wakhid et al. 2014). Dragonflies are insect that have three body parts namely the head, thorax, four wings and six legs attached to the abdomen (Klym and Quinn 2003). The general characteristics of dragonflies are a slender body with two pairs of wings and six legs, short antennae that resemble hair, a chewing mouth, and two compound eyes (Hanum and Salmah 2013; Virgiawan et al. 2015). The body and wings' colors and patterns are one of the characteristics possessed by odonates (Futahashi 2020).

Dragonflies are insects that undergo incomplete metamorphosis, which starts in the egg, nymph, and imago phases (Okude et al. 2017). The nymph cycle in dragonflies can take as long as four years before transforming into imago (Nobles and Jackson 2020). In their life cycle, dragonflies will lay their eggs in waters (Dalia and Leksono 2014) that have a fairly good level of cleanliness (Simbolon 2019). Dragonfly nymphs develop and live in water (Hanum and Salma 2013), and dragonfly nymphs will also transform into imagos in the water (Ubhi and Matthews 2018); even half of the dragonfly life cycle occurs in bottom waters (Maynou et al. 2017; Meland et al. 2019). However, in the imago phase, dragonflies also need terrestrial areas that are used as a place to find food, rest, and mate (Nagy et al. 2019).

Dragonflies have a variety of habitat types, one of which is a habitat close to water areas. Dragonflies generally utilize water areas with clean waters, although some dragonfly species can live in less clean or even polluted waters (Rachman and Rohman 2016). For example, water areas that are habitats for dragonflies are ponds, rivers, lakes, puddles, and rice fields (Goertzen and Suhling 2013). These water cleanliness levels can be observed from the presence of dragonfly species vulnerable to water pollution. Dragonflies play an important and large role in maintaining the balance of the food chain (Jakob and Poulin 2016). Dragonflies are also crucial in biological control in the ecosystem (Lino et al. 2019). One of the roles of dragonflies is as predators of small insects (Letsch et al. 2016), such as mosquitoes and pests in agriculture (Pamungkas and Ridwan 2015). Besides being predators, dragonflies also act as bioindicators of water quality (Chovanec and Raab 1997). Dragonflies are also used as bioindicators of water quality because they tend to tolerate various water qualities (Nasirian and Irvine 2017). The reduction of dragonfly populations in an area can indicate environmental change.

Kedung Klurak is one of the tourist attractions with a waterfall dominated by pine trees in Pacet District, Mojokerto District, East Java. Using Kedung Klurak as a tourist area can increase infrastructure development such as building gazebos on the banks of rivers. There are many activities around the water flow such as swimming, setting up a tent for camping, and photography activities. This pollutes the environment because it can disrupt dragonfly activities and impact the dragonfly's natural habitat. The number of human activities also affects the diversity of dragonfly species. Based on this urgency, this research was conducted to identify the diversity of dragonfly species (Odonata) in Kedung Klurak tourism areas.

MATERIALS AND METHODS

Research time and location

The research was conducted in the Kedung Klurak area in Pacet Sub-district, Mojokerto District, East Java Province, Indonesia, in 3 different habitats, i.e. waterfall, open area and pine forest (Table 1, Figure 1). The research was conducted on 28th-30th September 2023, from 07.00-11.00 am. This time was chosen because dragonflies are active during the day (Koneri et al. 2020). The research methods used were sweeping nets and transects. During the research, abiotic factors, such as temperature, humidity, wind speed, and light intensity, were measured at the location. This study divided the data collection station into three consecutive stations: a waterfall, an open area, and a pine forest. The division of three stations was chosen based on differences in environmental conditions such as water flow, vegetation, canopy types, and human activity. Every day research is carried out at all observation stations.

Data collection method

The path determination method uses a transect and the adult dragonfly sampling method uses a sweep net. This method was done by capturing and storing each species found during observation. Some dragonflies were caught as samples are adult dragonflies. Dragonflies found in the location were documented with a digital camera. In addition, each species encountered was counted in tables, stating the number of species and the location where they were found.

Table 1. Observation data on dragonfly species in Kedung Klurak, Mojokerto District, East Java, Indonesia

Station	Description
Waterfall	The waterfall is the main location at Kedung Klurak. This station has a swift flow and a clear pool of water. The type of vegetation at this station is diverse, with the dominant vegetation being bamboo. The type of canopy at this station includes an open canopy that allows maximum sunlight to enter.
Open area	The open area has a lower height than the waterfall with an open canopy. The dominant vegetation type of this station is dense shrubs; with an open canopy type and shrub vegetation type, the station has less sunlight radiation.
Pine forest	Pine forest is a water stream that has pine vegetation. This station has an open canopy type that allows sunlight radiation.

Figure 1. Location of Kedung Klurak, Mojokerto District, East Java, Indonesia. A. Waterfall; B. Open area, C. Pine forest

After capturing the dragonflies, the identification was conducted with the help of identification books (Irawan and Rahadi 2016; Setiyono et al. 2017). This study was conducted in conjunction with measurements of abiotic factors, including temperature, humidity, and light intensity. In addition, the measurement tools are a thermometer and a lux meter. Abiotic factors measurements were carried out in the morning before starting dragonfly data collection. Observations were also made on the vegetation and canopy types around the dragonfly habitat.

Data analysis

Data that obtained in the field were analyzed using the Shannon-Wiener Diversity index, Evenness index, and Dominance index formula as follows:

Diversity index

$H' = -\sum Pi \ln Pi$
$Pi = (ni/N)$

Where, H': Shannon-Wiener Diversity index; Pi: Proportion of the 1st species in the total sample; ni: number of individuals of a species; N: number of individuals of all species.

Evenness index

E = H'/lnS

Where, E: Evenness index; H': Diversity index; S: number of species.

Dominance index

D = (ni/N)

Where, D: Dominance index; ni: number of individuals of a species; N: number of individuals of all species.

RESULTS AND DISCUSSION

The study results found 15 species identified in Suborder Anisoptera and Zygoptera. In Suborder Anisoptera, 12 species were found from four families, including Libellulidae, Gomphidae, Corduliidae, and Aeshnidae (Table 2). While in Suborder Zygoptera, three species were found from three families: Euphaeidae, Calopterygidae, and Chlorocyphidae.

The results showed that the Anisoptera suborder had more species than the Zygoptera suborder. Almost all stations in this study have aquatic habitats with open canopy types and surrounding tree vegetation, making it a suitable habitat for Anisoptera dragonflies. This is supported by Susanto et al. (2023), who reported that the dragonfly suborder Anisoptera is suitable in habitats with open canopy types. Anisoptera has a high-flying ability to explore areas widely (Susanto et al. 2023). Dragonfly Suborder Zygoptera has fewer species because this suborder is sensitive to habitat changes. This statement is supported by Albab et al. (2019), who reported that Zygoptera has a lower habitat tolerance than Anisoptera. According to Gomez-Tolosa et al. (2022), Zygoptera dragonfly diversity decreases when habitat quality decreases, while Anisoptera diversities can survive on habitat change. Anisoptera has a high roaming ability and its life is not very dependent on the availability of food around the waters (Susanto et al. 2023).

Table 2. Observation data on dragonfly species in Kedung Klurak, Mojokerto District, East Java, Indonesia

Suborder and Family	Species	Relative Abundance (%)			
		Waterfall	Open Area	Pine Forest	Total
Zygoptera					
Calopterygidae	*Vestalis luctuosa* (Burmeister, 1839)	33.962	43.077	52.857	44.149
Chlorocyphidae	*Heliocypha fenestrata* (Burmeister, 1839)	0.000	26.154	10.000	12.766
Euphaeidae	*Euphaea variegata* (Rambur, 1842)	35.849	18.462	32.857	28.723
Anisoptera					
Aeshnidae	*Gynacantha subinterrupta* (Rambur, 1842)	3.774	0.000	0.000	1.064
Corduliidae	*Idionyx montana* (Karsch, 1891)	5.660	0.000	0.000	1.596
Gomphidae	*Heliogomphus drescheri* (Lieftinck, 1929)	0.000	1.538	0.000	0.532
Libellulidae	*Cratilla lineata* (Brauer, 1878)	0.000	0.000	1.429	0.532
	Diplacodes trivialis (Rambur, 1842)	0.000	3.077	0.000	1.064
	Neurothemis ramburii (Brauer, 1866)	3.774	0.000	0.000	1.064
	Orthetrum glaucum (Brauer, 1865)	0.000	0.000	2.857	1.064
	Orthetrum pruinosum (Burmeister, 1839)	3.774	0.000	0.000	1.064
	Pantala flavescens (Fabricius, 1798)	3.774	0.000	0.000	1.064
	Potamarcha congener (Rambur, 1842)	0.000	4.615	0.000	1.596
	Trithemis festiva (Rambur, 1842)	3.774	0.000	0.000	1.064
	Zygonyx ida (Selys, 1869)	5.660	3.077	0.000	2.660

Figure 2. Photo of dragonfly species: A. *Vestalis luctuosa* (Photo: DM Zahro' 2023); B. *Heliocypha fenestrata* (Photo: MAD Susanto 2023); C. *Euphaea variegata* (Photo: EP Agustin 2023); D. *Potamarcha congener* (Photo: MR Zumar 2023); E. *Neurothemis ramburii*; F. *Orthetrum glaucum*; G. *Cratilla lineata*; H. *Trithemis festiva* (Photo: MAD Susanto 2023); I. *Zygonyx ida* (Photo: MR Zumar)

The study shows that the Family in Suborder Anisoptera has the highest number of species from the Family Libellulidae. The family Libellulidae has the highest number of species found. The family Libellulidae has a high level of tolerance for the environment, so it is found in almost all habitat types. This is supported by Patra et al. (2016), who reported that the family Libellulidae has high adaptability. Another study revealed that one of these adaptations can survive in waters with low oxygen (Walia and Singh 2022).

The dragonfly species with the highest relative abundance values are *Vestalis luctuosa* and *Euphaea variegata* (Table 2). The relative abundance value of *V. luctuosa* was at the waterfall station (33.962%), in the open area (43.077%), in the pine forest (52.857%), and total (44.149%). The relative abundance value of *E. variegata* was at the waterfall station (35.849%), in the open area (18.462%), in the pine forest (32.857%), and total (28.723%). Both species were found at all observation stations. The *V. luctuosa* has a common name is dark-blue metalwing. In male dragonflies, the entire body is metallic blue, darker in the eyes and wings, while in females, the eyes are black, the thorax is metallic green, and the abdomen and wings are metallic brown (Setiyono et al. 2017) (Figure 2.B). The *V. luctuosa* is found perched on the leaves or branches of shady plants close to the water.

The *V. luctuosa* and *E. variegata* are species that have almost the same habitat. *E. variegata* has a characteristic metallic black abdomen and wings have a purple and blue metallic rainbow pattern when the wings are folded (Setiyono et al. 2017) (Figure 2.A). The *E. variegata* is perched on leaves, twigs, and rocks near water. The two species often live together due to habitat similarities (Setiyono et al. 2017). The habitat of *V. luctuosa* and *E. variegata* is in clear rivers with open and closed canopy vegetation (Saefullah et al. 2021).

The Kedung Klurak waterfall area is suitable for dragonflies' natural habitat. This is due to the presence of aquatic ecosystems, namely waterfalls and river flows that dragonflies can utilize to become their habitat when laying eggs and becoming nymph. This is supported by Susanto (2022), who reported that dragonflies utilize waters to become a place to continue their life cycles, namely in the egg and nymph phases.

The diversity index in Kedung Klurak is H': 1.605, which is included in the medium diversity category. If the diversity value of H' 1≤H≤3, it is classified as moderate diversity (Rachman and Rohman 2016). Based on the diversity index value obtained, it can be seen that the Kedung Klurak area has an environment that is still maintained and follows a dragonfly habitat. Dragonflies only live in clean and well-maintained water environments.

The evenness index in Kedung Klurak shows a value of E: 0.593, indicating a low evenness category. The dominance index shows a value of D: 0.296, indicating a low category. Evenness values close to one indicate evenness, while values close to zero indicate the presence of a dominating species (Cerda et al. 2011; Aziz and Mohamed 2018).

This study explores three observation stations. The waterfall station has the highest diversity index of the three stations observed, namely H': 1.678 (Figure 3); at the open area station, H': 1.446, while at the pine forest area station, H': 1.095. In addition, the highest evenness index was found at the waterfall station (E: 0.764), the open area station (E: 0.743), and the lowest evenness at the pine area location (E: 0.681) (Figure 4). The dominance index at the waterfall station is D: 0.257; at the open area station, D: 0.292; and the highest dominance value is at the pine area station, E: 0.398. That shows the value of evenness is inversely proportional to the dominance value. The higher the dominance value, the lower the species evenness; for example, the pine area station has a high dominance among the individuals found, but the number of species found is uneven.

The dragonfly species present at the waterfall, open area, and pine forest stations were found to be different. Furthermore, different microclimates and vegetation influence the differences in dragonfly species diversity in a location (Susanto and Bahri 2021). The microclimate is important in providing a habitat for small insects that will become dragonfly prey (Abdillah et al. 2019). The microclimate parameters measured in this study include temperature, humidity, and light intensity.

Micro-climate data showed that temperature, humidity, and light intensity at the waterfall station (31.2°C, 57%, 21300 lx) were lower than at the open area station (34.1°C, 60%, 22100 lx), temperature and humidity at the pine forest station (32.7°C, 62%) were higher than at the waterfall and open area stations, while light intensity at the pine forest station (19800 lx) had the lowest value (Table 3). The temperature results are the average temperature at the station. Temperature measurements at each station aim to determine temperature differences that can affect the presence of dragonflies. Temperature greatly affects dragonfly diversity; according to Koneri et al. (2020), dragonflies require higher temperatures for wing movement; dragonfly venation works effectively when temperature exceed 30°C. The increasing temperature more than 30°C affect the diversity of dragonflies. The higher temperature and humidity affect small insects that are the main food for dragonflies and plants diversity as a place to perch (Susanto and Zulaikha 2021).

Open vegetation affects the incoming light intensity dragonflies require (Koneri et al. 2022); the more open the vegetation, the greater the light intensity. Meanwhile, a more closed canopy and the number of trees around it can obstruct the air flow rate (Susanto and Zulaikha 2021). Dragonflies require light intensity for activities such as basking and foraging (Susanto and Zulaikha 2021). According to Susanto et al. (2023), sunlight intensity affects the species richness and abundance of dragonflies; the higher the light intensity, the lower the species richness and abundance.

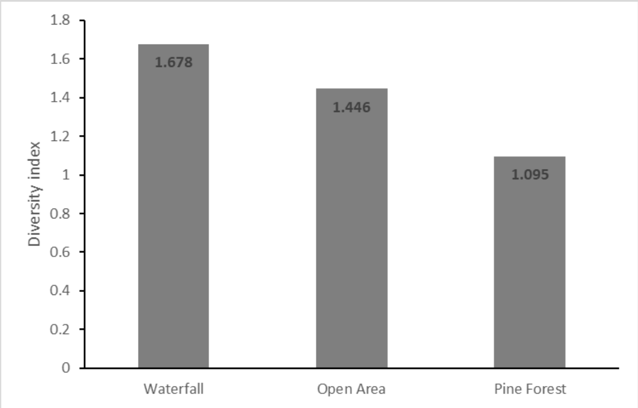


Figure 3. Result of Diversity Index

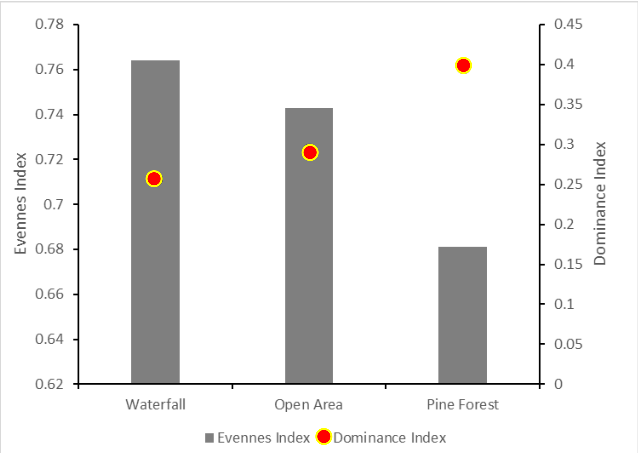


Figure 4. Results of Evenness Index and Dominance Index

Table 3. Abiotic factors in Kedung Klurak, Mojokerto District, East Java, Indonesia

Location	Temperature (°C)	Humidity (%)	Light intensity (lx)
Waterfall	31.2	57	21300
Open area	34.1	60	22100
Pine forest	32.7	62	19800

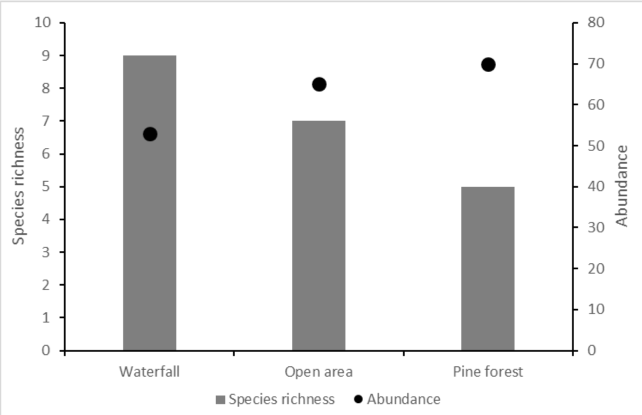


Figure 5. Species richness and abundance values

The waterfall station is the mainstream in the Kedung Klurak area. At this station, there is a clear stream and puddle. The dominant vegetation around the waterfall is bamboo plants with an open canopy. The open canopy determines the intensity of light entering and affects the surrounding air temperature (Susanto and Zulaikha 2021). The waterfall has the highest diversity index value (Figure 3) and species richness (Figure 5). At the waterfall station, five families were found, with a total of nine species. Species that are only found at the waterfall location are *Orthetrum pruinosum, Neurothemis ramburii, Trithemis festiva, Pantala flavescens, Idionyx montana,* and *Gynacantha subinterrupta.*

The *O. pruinosum, T. festiva,* and *P. flavescens* are members of the Family Libellulidae only found at the waterfall station. The *O. pruinosum* perched on plants with open canopies near open areas with calm currents. The *P. flavescens* was found in as many as two individuals flying high above the water with an open canopy; based on research from Susanto and Zulaikha (2021) reported that *O. pruinosum* is suitable to live in open habitats with high light intensity during the day and *P. flavescens* is suitable to live in habitats that have open canopies. The *T. festiva* perches on branches close to water and rocks with surrounding bamboo forest vegetation. This is in line with the findings of Irawan and Rahadi (2016), who reported that *T. festiva* was found in a rocky river with fast flow and diverse vegetation surrounding.

The *N. ramburii* was found perched on vegetation exposed to direct sunlight. This species likes open habitats such as waterfall stations. This is supported by Yen (2019), which reports that *N. ramburii* is found in open habitats. In addition Ilhamdi et al. (2021) also reported the same; the highest relative abundance of *N. ramburii* was found at stations with open canopies.

The *G. subinterrupta* is only found at the waterfall station, perched on bamboo plants with a closed canopy. This is in line with Abdillah et al. (2019), who reported that *G. subinterrupta* is found in aquatic habitats with thick canopies. In addition (Zaman et al. 2022) also reported that *G. subinterrupta* was found in a relatively good river with dense vegetation. Vegetation density and light intensity affect dragonfly wing pigmentation because *G. subinterrupta* has dark wings to absorb calories from the environment (Abdillah et al. 2019). Male dragonflies need the canopy to wait for female dragonflies to arrive or to trap other insects to become prey (Zaman et al. 2022).

The *I. montana* at the waterfall station was found flying around bamboo vegetation with a closed canopy. This is supported by Susanto and Bahri (2021), who reported that *I. montana* was found flying near a stream with many trees. This follows the findings of Herlambang et al. (2016) which reported that *I. montana* is a species only found in forest habitats, namely found perched on tree branches in the forest.

The open area station is a flow path from the waterfall with shrub habitats. The diversity value at this location is in the medium category. Five families were found, with seven species at this station. Several species are only found at the open area station: *Potamarcha congener, Diplacodes trivialis,* and *Heliogomphus drescheri.*

The pine forest area station is a water stream with pine vegetation. This location is included in a tourist area where there are human activities. The diversity value at the pine area station is medium diversity category. The low habitat diversity is due to the unavailability of food and disturbed habitat due to human activities. Dragonflies are very sensitive to human disturbance, and their diversity decreases with each pollution and disturbance (Kemabonta et al. 2017). Four families were found with a total of five species, and the species that were only found in pine area stations were *Orthetrum glaucum* and *Cratilla lineata*. Due to low water quality, the *O. glaucum* was only found in pine forest stations. This is supported by Leksono et al. (2017), who reported that *O. glaucum* is commonly found in low-water quality.

The location of the pine forest vegetation is a tourist area with quite a lot of human activity around the river, such as camping and swimming, which causes the environment at this location to be polluted. Polluted environments can disrupt natural habitats of dragonflies. Human disturbance in river flows can affect dragonfly communities, leaving only species that are tolerant of habitat changes (Calvão et al. 2018). Dragonflies that are tolerant of the environment and human disturbances found at this station are *V. luctuosa* and *E. variegata*. This is aligned with (Rachman and Rohman 2016), who reported that dragonflies *V. luctuosa* and *E. variegata* were found in locations with many pollutants and human disturbances.

The conclusion based on research conducted in the Kedung Klurak Waterfall Area, there are 15 species from seven families. The highest relative abundance was *V. luctuosa* with a value of 44.149% and *E. variegata* with a value of 28.723%. Waterfall station has the highest index diversity value and species richness value, while pine forest has the lowest index diversity value and species richness. The difference in results is because the waterfall station and the pine forest station have different environmental conditions, pine forests have pine tree vegetation and areas with a lot of human activity.

ACKNOWLEDGEMENTS

The authors thank to all those who have helped with this research. Thank you to KUTRIK and ECODIV, who have helped in providing research tools and writing preparation. Thanks also to Muhammad Rifqi Zumar, Oki Rahmatirta Wibisana, Muhammad Afi Maslukh, and Siti Zulaikha for helping with data collection.

REFERENCES

Abdillah MM, Prakarsa TBP, Tyastirin E. 2019. Odonata diversity at sumber clangap and sumber mangli Puncu Village Sub District of Puncu District of Kediri. Jurnal Biodjati 4 (2): 236-243. DOI: 10.15575/biodjati.v4i2.4823.

Albab AU, Leksono AS, Yanuwiadi B. 2019. Land use analysis with odonata diversity and composition using the arcgis in Malang and Batu, East Java. Indones J Environ Sustain Dev 10 (2): 73-83. DOI: 10.21776/ub.jpal.2019.010.02.01.

Aziz MAA, Mohamed M. 2018. Diversity and species composition of Odonates (Insecta: Odonata) of Hutan Lipur Soga Perdana, Batu Pahat, Johor, Malaysia: A green lung. J Sci Technol 10 (2): 1-9. DOI: https://10.30880/jst.2018.10.02.001.

Bybee S, Córdoba-Aguilar A, Duryea MC, Futahashi R, Hansson B, Lorenzo-Carballa, MO, Wellenreuther M. 2016. Odonata (dragonflies and damselflies) as a bridge between ecology and evolutionary genomics. Front Zool 13 (1): 1-20. DOI: 10.1186/s12983-016-0176-7.

Calvão LB, Juen L, Junior DOJMB, Batista JD, Júnior DMP. 2018. Land use modifies Odonata diversity in streams of the Brazilian Cerrado. J Insect Conserv 22: 675-685. DOI: 10.1007/s10841-018-0093-5.

Cerda X, Angulo E, Ccaut S, Courchamp F. 2011. Ant community structure on a small Pacific Island: Onlyone native species living with theinvaders. Biol Invasions 14 (1): 323-339. DOI: 10.1007/s10530-011-0065-0.

Chovanec A, Raab R. 1997. Dragonflies (Insecta, Odonata) and the ecological status of newly created wetlands-examples for long-term bioindication programmes. Limnologica 27 (3): 381-392.

Dalia BPI, Leksono AS. 2014. Interaksi antara capung dengan arthropoda dan vertebrata predator di Kepanjen, Kabupaten Malang. Biotropika 2 (1): 26-30. [Indonesian]

Goertzen D, Suhling F. 2013. Promoting dragonfly diversity in cities: Major determinants and implications for urban pond design. J Insect Conserv 17: 399-409. DOI: 10.1007/s10841-012-9522-z.

Gomez-Tolosa M, Mendoza-Cuenca L, Rivera-Velazquez G, Rioja-Paradela TM, Tejeda-Cruz C, Perez-Farrera MA, López, S. 2022. Using the ecological relationships of Odonata with a habitat integrity index to test the biodiversity ecosystem function framework. J Insect Conserv 26 (2): 191-203. DOI: 10.1007/s10841-022-00377-4.

Hanum SO, Salmah S. 2013. Jenis-jenis capung (Odonata) di kawasan Taman Satwa Kandi Kota Sawahlunto, Sumatera Barat. Jurnal Biologi Universitas Andalas 2 (1): 71-76. DOI: 10.25077/Jbioua.2.1.%25p.2013. [Indonesian]

Herlambang AEN, Hadi M, Tarwotjo U. 2016. Struktur komunitas capung di kawasan wisata Curug Lawe Benowo Ungaran Barat. Bioma Berkala Ilmiah Biologi 18 (2): 70-78. DOI: 10.14710/bioma.18.2.70-78. [Indonesian]

Ilhamdi Ml, Agil AI, Santoso D, Hadiprayitno G, Syazali M. 2021. Species richness and conservation priority of dragonflies in the Suranadi Ecotourism Area, Lombok, Indonesia. Biodiversitas 22 (4): 1846-1852. DOI: 10.13057/biodiv/d220430.

Irawan A, Rahadi WS. 2016. Capung Sumba. Balai Taman Nasional Manupeu Tanah Daru dan Laiwangi Wanggameti dan Indonesia Dragonfly Society, Sumba. [Indonesian]

Jakob C, Poulin B. 2016. Indirect effects of mosquito kontrol using ikan on dragonflies and damselflies (Odonata) in the camargue. Insect Conserv Divers 9 (2): 161-169. DOI: 10.1111/icad.12155.

Kemabonta KA, Adu BW, Ohadiwe AC. 2017. Impact of human disturbance on the abundance, diversityand distribution of Odonata in the University of Lagos, Akoka, Lagos, Nigeria. Appl Trop Agric 21 (3): 143-150. DOI: 10.1080/13887890.2020.1768156.

Klym M, Quinn MA. 2003. Introduction to Dragonfly and Damselfly Watching. Texas Parks and Wildlife, Austin.

Koneri R, Nangoy M, Maabuat PV. 2020. Composition and diversity of dragonflies (Insecta: Odonata) in Tunan waterfall area, North Minahasa, North Sulawesi, Indonesia. Pak J Zool 52 (6): 2091-2100. DOI: 10.17582/journal.pjz/20181214071225.

Koneri R, Nangoy MJ, Elfidasari D. 2022. Odonata diversity in the Laine waterfall area, Sangihe Islands, North Sulawesi, Indonesia. AACL Bioflux 15 (3): 1083-1095.

Leksono AS, Feriwibisono B, Arifianto T, Pratama AF. 2017. The abundance and diversity of odonata along an altitudinal gradient in East Java, Indonesia. Entomol Res 47 (4): 248-255. DOI: 10.1111/1748-5967.12216.

Letsch H, Gottsberger B, Ware JL. 2016. Not going with the flow: A comprehensive time-calibrated phylogeny of dragonflies (Anisoptera: Odonata: Insecta) provides evidence for the role of lentic habitats on diversification. Mol Ecol 25 (6): 1340-1353. DOI: 10.1111/mec.13562.

Lino J, Koneri R, Butarbutar RR. 2019. Keanekaragaman capung (Odonata) di tepi sungai kali desa kali Kabupaten Minahasa Sulawesi Utara. Jurnal MIPA 8 (2): 59-62. DOI: 10.35799/Jmuo.8.2.2019.23767. [Indonesian]

Maynou X, Martín R, Aranda D. 2017. The role of small secondary biotopes in a highly fragmented landscape as habitat and connectivity providers for dragonflies (Insecta: Odonata). J Insect Conserv 21 (3): 517-530. DOI: 10.1007/s10841-017-9992-0.

Meland S, Gomes T, Petersen K, Håll J, Lund E, Kringstad A, Grung M. 2019. Road related pollutants induced dna damage in dragonfly nymphs (Odonata, Anisoptera) living in highway sedimentation ponds. Sci Rep 9 (1): 16002. DOI: 10.1038/s41598-019-52207-4.

Mendoza-Penagos CC, Calvão LB, Juen L. 2021. A new biomonitoring method using taxonomic families as substitutes for the suborders of the Odonata (Insecta) in amazonian streams. Ecol Indic 124: 1-12. DOI: 10.1016/j.ecolind.2021.107388.

Nagy HB, László Z, Szabó F, Szőcs L, Dévai G, Tóthmérész B. 2019. Landscape-scale terrestrial factors are also vital in shaping Odonata assemblages of watercourses. Sci Rep 9 (1): 1-8. DOI: 10.1038/S41598-019-54628-7.

Nasirian H, Irvine KN. 2017. Odonata larvae as a bioindicator of metal contamination in aquatic environments: Application to ecologically important wetlands in Iran. Environ Monit Assess 189: 436. DOI: 10.1007/s10661-017-6145-6.

Nobles, Jackson CR. 2020. Effects of life stage, site, and species on the dragonfly gut microbiome. Microorganisms 8 (2): 1-16. DOI: 10.3390/Microorganisms8020183.

Okude G, Futahashi R, Tanahashi M, Fukatsu T. 2017. Laboratory rearing system for *Ischnura senegalensis* (Insecta: Odonata) enables detailed description of larval development and morphogenesis in dragonfly. Zool Sci 34 (5): 386-397. DOI: 10.2108/zs170051.

Pamungkas DW, Ridwan M. 2015. Keragaman jenis capung dan capung jarum (Odonata) di beberapa sumber air di Magetan, Jawa Timur. Pros Sem Nas Masy Biodiv Indon 1: 1295-1301. DOI: 10.13057/psnmbi/m010606. [Indonesian]

Patra D, Roy S, Chowdhury S. 2016. Diversity and abundance of Odonata fauna in Midnapore and surrounding areas, West Midnapore, West Bengal. J Entomol Zool Stud 4 (6): 553-558.

Pelealu GVE, Nangoy MJ, Tarore D. 2022. Keanekaragaman capung di sungai rayow, Desa Kembes, Kecamatan Tombulu, Kabupaten Minahasa. Zootec 42 (1): 25-32. DOI: 10.35792/Zot.42.1.2022.39008. [Indonesian]

Rachman HT, Rohman A. 2016. Dragonflies diversity (Odonata) in Menoreh Karst Central Java-Yogyakarta. J Adv Agric Environ Eng 3 (2): 255-258. DOI: 10.15242/IJAAEE.U0516214.

Rizal S, Hadi M. 2015. Inventarisasi jenis capung (Odonata) pada areal persawahan di Desa Pundenarum Kecamatan Karangawen Kabupaten Demak. Bioma Berkala Ilmiah Biologi 17 (1): 16-20. DOI: 10.14710/bioma.17.1.16-20. [Indonesian]

Saefullah AA, Latifah L, Sa'adah M, Salsabila N, Muslimah S. 2021. The inventory of dragonfly species in Kedung Kopong and Banyak Angkrem Areas in Kalirejo Village, Salaman-Magelang. Proceeding International Conference on Science and Engineering. Yogyakarta, 27 October 2020.

Salsabiela N, Novitasari A, Windianingsih AC, Alfian RB, Setyaningrum A, Yudharta BE, Safa'ah OA, Sukirno S. 2022. Effect of altitude on odonata biodiversity in the paddy field of Sleman Regency, Special Region of Yogyakarta. Proceedings International Conference on

Biological Science (ICBS 2021). Yogyakarta, 14-15 October 2021. DOI: 10.2991/absr.k.220406.026. [Indonesian]
Setiyono J, Diniarsih S, Oscilata ENR, Budi NS. 2017. Dragonflies of Yogyakarta: Jenis capung Daerah Istimewa Yogyakarta. Indonesia Dragonnfly Society, Yogyakarta. [Indonesian]
Simbolon P. 2019. Studi Jenis-jenis capung di Kawasan Gunung Nanggarjati Hutapadang Kabupaten Tapanuli Selatan. Jurnal Educ Dev 7 (1): 99-99. DOI: 10.37081/ed.v7i1.793. [Indonesian]
Susanto MAD, Bahri S. 2021. Diversity and abundance dragonflies (Odonata) at Mount Sigogor Nature Reserve Area, Ponorogo Regency, East Java, Indonesia. Jurnal Biota 7 (2): 101-108. DOI: 10.19109/Biota.v7i2.8160.
Susanto MAD, Firdhausi NF, Bahri S. 2023. Diversity and community structure of dragonflies (Odonata) in various types of habitat at Lakarsantri District, Surabaya, Indonesia. J Trop Biodivers Biotechnol 8 (2): 76690. DOI: 10.22146/jtbb.76690.
Susanto MAD, Zulaikha S. 2021. Diversity and community structure of dragonfly and damselfly (Odonata) at the Selorejo Waterfall Area, Ponorogo Regency, East Java Indonesia. Jurnal Riset Biologi dan Aplikasinya 3 (1): 30-37. DOI: 10.26740/jrba.v3n1.p30-37.
Susanto MAD. 2022. Diversity and composition of dragonfly (Odonata) at the Punden Sumur Bumi Area, Surabaya, East Java. Intl J Appl Biol 6 (2): 43-55. DOI: 10.20956/ijab.v6i2.20126.
Ubhi R, Matthews PG. 2018. The transition from water to air in Aeshnid dragonflies is associated with a change in ventilatory responses to hypoxia and hypercapnia. J Insect Physiol 106: 172-178. DOI: 10.1016/j.jinsphys.2017.09.010.
Virgiawan C, Hindun I, Sukarsono. 2015. Studi keanekaragaman capung (Odonata) sebagai bioindikator kualitas air sungai brantas Batu-Malang dan sumber belajar biologi. Jurnal Pendidikan Biologi Indonesia 1 (6): 11-21. DOI: 10.22219/jpbi.v1i2.3330. [Indonesian]
Wakhid W, Koneri R, Tallei T, Maabuat PV. 2014. Kelimpahan populasi capung jarum (Zygoptera) di Kawasan Taman Nasional Bogani Nani Wartabone, Sulawesi Utara. Jurnal Bios Logos 4 (2): 41-47. DOI: 10.35799/jbl.4.2.2014.5234. [Indonesian]
Walia GK, Singh H. 2022. A review on intraspecific karyomorphological variations of m chromosomes in family Libellulidae (Anisoptera: Odonata). J Basic Appl Zool 83 (1): 1-11. DOI: 10.1186/s41936-022-00310-w.
Yen CC. 2019. Odonata fauna of Imbak Canyon Conservation Area, Sabah. J Trop Biol Conserv 16: 1-8. DOI: 10.51200/jtbc.v16i0.2021.
Zaman MN, Fuadi BF, Luthfika M. 2022. Struktur komunitas capung dan capung jarum di sungai Gajah Wong segmen perkotaan Daerah Istimewa Yogyakarta. Jurnal Biologi Biodiveritas 1 (1): 31-36. DOI: 10.14421/bioveritas.v1i01.4154. [Indonesian]

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 9-18
P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140102

Physico-chemical properties and mycoflora profile in some coastal wetlands of Akwa Ibom State, Nigeria: Potential challenges for agro-ecological and public health

ABIASAMA TOBY TOBY[1], INEMESIT NDARAKE BASSEY[1], MICHAEL ESSIEN EFFIONG[2], EMILY OSA IDUSERI[3], DAVID NWAZUO ENYIUKWU[4,♥], SAMUEL ROBERT OSU[5]

[1]Department of Botany and Ecological Studies, University Of Uyo. PMB 1017 Uyo, Akwa IbomState, Nigeria
[2]Community Secondary Commercial School. Ifiayong Usuk, Uruan, Akwa Ibom State, Nigeria
[3]National Open University of Nigeria (NOUN). Plot 91, Cadastral Zone Nnamdi Azikiwe Expressway Jabi, Federal Capital Territory, Abuja, Nigeria
[4]Department of Plant Health Management, Michael Okpara University of Agriculture. Umudike, PMB 7267 Umuahia, Abia State, Nigeria. Tel.: +234-0-9027427974, ♥email: enyidave2003@gmail.com
[5]Department of Biology, School of Science, College of Education Afaha Nsit. PMB 1019, Etinan, Akwa Ibom State, Nigeria

Manuscript received: 7 February 2024. Revision accepted: 26 March 2024.

Abstract. *Toby AT, Bassey IN, Effiong ME, Iduseri EO, Enyiukwu DN, Osu SR. 2024. Physico-chemical properties and mycoflora profile in some coastal wetlands of Akwa Ibom State, Nigeria: Potential challenges for agro-ecological and public health. Intl J Bonorowo Wetlands 14: 9-18.* This study assessed physico-chemical properties as it affects the distribution and diversity of mycoflora in different wetlands (Ibeno, Itu, Nsit-Ibom and Uyo) of Akwa Ibom State. The sediments and water samples were collected and cultured on Potato Dextrose Agar (PDA) and Sabouraud Dextrose Agar (SDA). Pure cultures of the mycotic isolates were identified using a molecular technique based on PCR amplification, sequencing of the internal transcribed spacer, and phylogenic analysis. At the same time, the physico-chemical properties of the specimens were determined using standard analytical methods. The results of the physico-chemical analysis showed that temperature and pH ranged from 27.27±0.33-29.21±003ºC and 5.17±009-7.30±0.17 respectively per samples per locations. The presence of Cr, Cd, Pb, Mn, Zn, Fe, Ca, nitrates, sulfates, phosphates, vanadium, suspended solids, and dissolved solids amongst other variables were detected in the water bodies, thus indicating possible agro-anthropogenic pollution. The results also showed that *Candida tropicalis, Aspergillus niger, A. terreus, A. aculeatus, A. tamarii, Penicillium citrinum, P. rolsfi, A. flavus, A. nominus* and *Trametes polyzona* were associated with the wetlands. The most commonly isolated fungi from the four locations were species of the genera *Aspergillus*. For the sediment, Nsit Ibom was dominated by *T. polyzona* (60%) while Ibeno was dominated by *C. tropicalis* (40%), *Aspergillus* and *P. citrinum* dominated Nsit Ibom (60%) and Uyo (60%) for water samples respectively. The fungal isolates showed differential affinity and adaptation to the ecosystem's heavy metals, ions and physical properties. Recent medical evidence, however, has associated these mycotic species with life threatening health conditions in both immuno-competent and immuno-compromized individuals and, as such, pose a serious menace to agro-ecological and public health. Therefore, this study lends credence to mycoflora diversity to aquatic habitat quality and as well provides baseline information that could spur conservation and proper management of the wetlands.

Keywords: Coastal sediments, myco-contaminants, mycoflora, public health, water quality

INTRODUCTION

Wetlands are ecosystems where the water table is near the edaphic surface or where water covers the surface of the land either perennially or temporarily at certain times of the year. They usually occur along sea, river and stream shorelines, or on lowlands and valley bases (Ekong and Akpan 2014). Wetlands portend extensive food webs and biodiversity (Mitsch and Gosselink 1993; Cummings and Klugs 2000; Pittock et al. 2015; Edo and Albrecht 2021); contributing to timber, medicinal plants, fish, shellfish, arable and paddy crop production (Dapa and Brown 2020; Abraham et al. 2021). Wetlands function as ecological kidneys, and play vital roles in controlling flood intensity and frequency, abating erosion, and improving water quality (Dapa and Brown 2020; Balwan and Kour 2021).

Fungi of the divisions Zygomycota, Basidiomycota, and Ascomycota; and the genera *Fusarium, Alternaria, Trichoderma, Cladosporium, Cryptococcus, Penicillium, Aspergillus, Rhizopus, Curvularia,* etc. have been isolated from shoreline sediments and water from different wetlands (Freed et al. 2019; Adedire et al. 2021). The number and types of mycotic organisms present in wetlands are thought to correlate with the water quality (Jan et al. 2014; Liu et al. 2015; Adedire et al. 2021).

Seasonal variations in environmental factors and anthropogenic activities profoundly affect wetland health (Chesteen 2012; Edo and Albrecht 2021). These factors interact in ways that affect relative abundance and substrate density in wetlands. Though Nigeria is richly endowed with wetlands along its Atlantic coast, the Niger Delta of Nigeria is regarded as the second most critically endangered wetland environment in Africa due to heavy metals and hydrocarbon contamination from crude oil exploration (Sidhoum et al. 2020). These fallouts could alter mycofloral density in wetlands (FAO 1994, 2007;

Ekong and Akpan 2014; Edo and Albrecht 2021; Enyiukwu et al. 2021).

In addition, intensive farming, deforestation, mining, and discharge of industrial sewage near shorelines are reported to spur ecological degradation; affecting the diversity and density of saprophytic decomposer fungi and quality of wetland waters (Ekong and Akpan 2014; Saturday 2015; Dapa and Brown 2020; Edo and Albrecht 2021). For instance, high carbon quality, phosphorus (P), temperature and total nutrient contents (N, K) correlated with high fungal growth, biomass accumulation and diversity in some polluted streams (Liu et al 2015). Conversely, high concentration of hydrogenium ions was reported to seriously decrease mycotic growth and diversity in some studied wetlands (Jan et al. 2014).

In Idah River, Nigeria, high presence of *Aspergillus*, *Fusarium*, *Penicillium* and *Trichoderma* species was directly proportional to high electrical conductivity, turbidity and concentration of sulfur and arsenic ions that emanated from suspended and dissolved solids in the River (Adedire et al. 2021). These genera of mycoflora have been variously implicated in fungi-induced diseases of field crops, and stored agro-products. Also, their mycotoxins harm fish and other aquatic fauna (Onuoha and Obika 2015; Oleveira and Vasconcelos 2020). The rising population of these fungal agents in wetlands portends potential danger to public health in the third world compounding widespread challenges of malnutrition and metabolic or pathogenic diseases especially in sub-Saharan Africa (Enyiukwu et al. 2018a, b, 2020). Lew et al. (2013) stated that mycological diversity and community compositions could be reliable indicators of wetland water quality and ecosystem health.

Therefore, this study generally sought to determine the impact of physico-chemical parameters of wetland environments on the diversity and distribution of mycoflora on coastal wetlands of Akwa Ibom State.

MATERIALS AND METHODS

Study area

This study was conducted in Akwa Ibom State, a major wetland farming State in southern Nigeria; located within geographic coordinates of latitudes 04°32´N and Longitudes 7°25´and 8°25´E. The State occupies a distinct and contiguous area of 8142 square km. Therefore, four wetlands mapped out in 4 Local Councils of Uyo, Itu, Ibeno, and Nsit Ibom (Figure 1) within the State were sampled. They were: (i) Ibeno wetland (latitude 04°32'27"N, longitude 008°00'12"E); (ii) Itu wetland falls within Eniong Creek segment of the Cross River (latitudes 05°13'14" and 05°19"N, and between longitudes 007°56'14" and 007°56'59"E); (iii) Nsit Ibom wetland (Latitude 4°53'0"N and longitude 7°54'0"E); (iv) Uyo wetland is located on (Latitude 5°02'31"N and longitude 7°56'11"E).

Collection of wetland water and sediment samples

Samples of water and sediments were collected from the four wetlands (Ibeno, Nsit Ibom, Itu and Uyo) of Akwa Ibom State, Nigeria, using sterile bottles and Ziploc bags respectively. The bottles were dipped at different locations in each wetland, opened and corked under water to make them air-tight. Two sampling areas were randomly selected within each wetland, and two replicate sediment samples were collected along the bank of each wetland using sterile scapels. The samples were sealed in the Ziploc bags, bagged in brown envelops and immediately taken to the University.

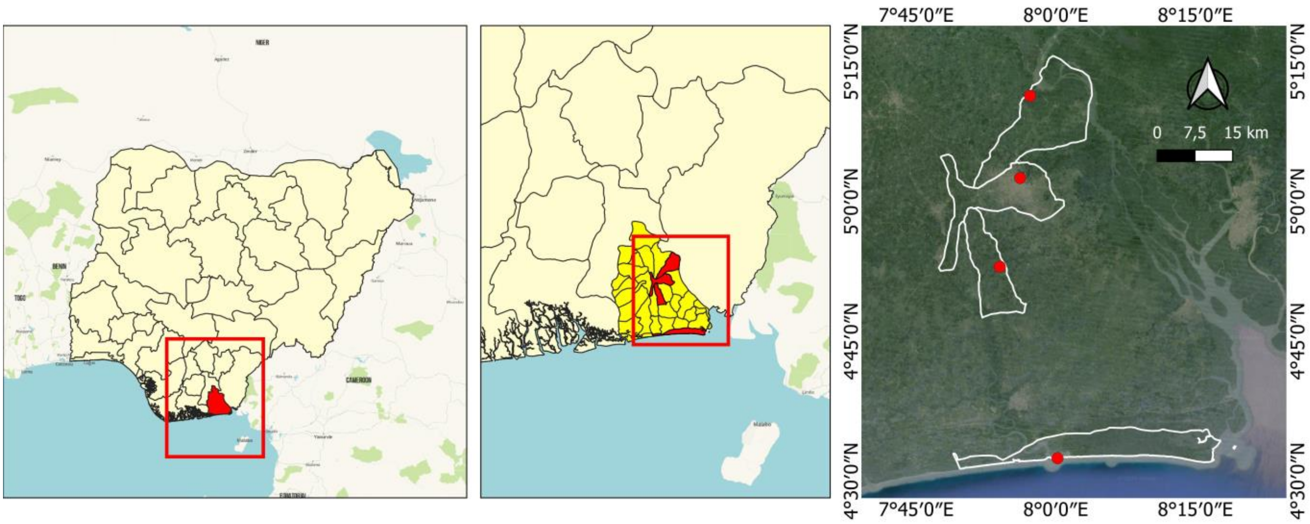


Figure 1. Map of Nigeria showing the study areas of Akwa Ibom State, Nigeria. Map of Akwa Ibom states showing the study council areas indicated by the 4 red dots

Physico-chemical analysis of the water samples

The water quality parameters including electrical conductivity and pH were determined using the conductivity meter and the pH meter respectively (Jan et al. 2014). Yoder (2022) described the standard classical qualitative methods used for testing for total hardness, calcium hardness, magnesium hardness, total solids, total suspended solids and total dissolved solids. The study examined the presence of ions of chlorine, sodium, iron, vanadium, chromium, cadmium, phosphate and sulfate ions in the water samples. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were done according to the protocol by APHA (1998).

Determination of fungal diversity (using a culture-independent method), preparation of culture media and isolation of fungal species

The isolation of fungal species and their diversity was conducted at the Botany and Ecological Studies Laboratory of the University of Uyo using the classical method as adopted by Atoyebi and Ekpo (2020) while the confirmatory molecular identification of the isolates was conducted at the Bioscience and Molecular Laboratory of the University of Nigeria, Nsukka, Enugu State, Nigeria.

Preparation of culture media: A conical flask was sterilized in an autoclave and placed on a sterile working bench. An electronic weighing balance was used to measure 10 g each of Potato Dextrose Agar (PDA) (Thermo Scientific Oxoid, UK) and Sabouraud Dextrose Agar (SDA) (Beena Infotech, India) respectively. Each of these quantities was separately poured into a 250 mL conical flask containing sterile distilled water and mixed properly with a stirring rod, then 0.2 mL of streptomycin (1.0 mg/mL) was introduced into each PDA and SDA media (to prevent bacteria growth), stoppered with a foiled non-absorbent cotton wool and autoclaved for 15 minutes at 15psi (Enyiukwu et al. 2021).

Isolation of fungal species: The isolation of fungal species associated with the wetlands was done using direct plating and serial dilution methods as adopted by Bello and Ukut (2015).

Direct plating method: Using a sterile syringe, about 1mL of the test sediment or wetland water sample was differently introduced into separate Petri dishes containing 10 mL of media (as prepared above) swirled gently to circulate and allowed to solidify. The Petri dishes were made air-tight with masking tape and incubated in the incubation chamber in the Laboratory at room temperature (27°C) and observed daily for 7 days.

Serial dilution method: Five test tubes (10^1-10^4) were prepared with 9 mL of distilled water. Next, 1 mL of water sample was pipetted into the first test tube and shaken to mix. From the first test tube, 1 mL was pipetted into the second, in that order to the fifth test tube. Then 1mL of serial dilution from 10^2-10^4 was pipetted into the Petri dishes. The media were poured into the dishes, swirled gently to circulate and allowed to solidify. The Petri dishes were sealed with masking tape and kept in the incubator at room temperature (28°C). After 7 days, fungal growths were picked with sterile inoculation needle and sub-cultured repeatedly on fresh media to obtain pure cultures which were then maintained in stock McCartney bottles. A record of the types, colony characteristics and number of times each fungus was observed on the respective water or sediment specimens was taken.

Molecular characterization of isolated mycoflora

The genomic DNA of the test fungi was extracted from 3 day-old pure water and sediment cultures using hexadecyltrimethylammonium bromide (CTAB)-based method adopted from Hyde and Lee (1995), Nygren et al. (2008) and Debroas et al. (2017). DNA concentration was determined spectrophotometrically using Nanodrop (Model: Thermo Scientific, Wilmington, DE). PCR amplification of the highly conserved Fungal Internal Transcribed Spacer (ITS) region of the genomic DNA of the test fungi was done using primer pairs ITS1F and ITS4 as described in the studies of White et al. (1990). The amplicons were purified using ethanol sodium acetate precipitation protocol and sequenced (White et al. 1990).

Statistical analysis

This study hypothesized that the distribution of mycoflora is influenced by environmental parameters. For assessment of fungal diversity and evenness in different sediments and water, the Shannon diversity index (H'), Simpson's reciprocal index (1/D) and Pielou index (E) were calculated to represent the spatial diversity indices of mycoflora in each wetland. The Canonical Correspondence Analysis (CCA) ordination technique was used to test this hypothesis; an ordination technique assumes a unimodal distribution of species concerning environmental variables (Ukpong 1997). The fungal species, together with the corresponding wetland versus environmental variable data matrix were subjected to Canonical Correspondence Analysis (CCA) using PAST (Paleontological statistics) software version 3.0 (https://palaeo-electronica.org) to reveal the relationship between the fungal composition and environmental variables.

RESULTS AND DISCUSSION

Physico-chemical analysis of the test specimens

The physical properties and presence of ions/chemical pollutants in the test water specimens from the 4 wetland habitats are presented in Table 1. It indicated the hydrogenium ions levels in the water samples ranged from 5.2 at Itu to 7.30 Nsit Ibom; Itu had the lowest temperature at 27°C, while Uyo recorded at 29.21°C was the highest. Salinity and hardness were highest at Ibeno while Nsit Ibom recorded the apex level of turbidity followed by Itu and Uyo in the water bodies tested. Uyo had very high electrical conductivity and total dissolved solids values. A slight presence of calcium, iron, copper, magnesium, potassium, nitrate and sulfate was detected in all the study's water specimens from all the survey locations. Except for low values of vanadium (V) and lead (Pb) detected at Nsit Ibom and nickel (Ni) and chromium (Cr) at Uyo, all other locations surveyed in this study presented moderate levels of the test ions/radicals in all the water samples from all the test wetlands (Table 1).

Characterization and identification of myco-isolates

A total of 10 fungal isolates belonging to two divisions (Basidiomycota, Ascomycota), and 4 genera namely *Penicillium, Aspergillus, Trametes* and *Candida* were isolated from water and wetland specimens from Ibeno, Itu, Nsit Ibom and Uyo Local Government Areas of Akwa Ibom State (Figure 1). The distribution of fungi isolates in different wetland sediment and water were also captured in Figure 2. Nsit Ibom sediments was dominated by *A. terreus* (60%) and *A. niger* (30%); Ibeno by *C. tropicalis* (40%) and *T. polyzona* (30%); *A. flavus, T. polyzona* and *C. tropicalis* at 30% apiece were the dominant species in Itu sediment while Uyo sediment had *P. rolfsii* and *C tropicalis* at 40% each as prevailing species.

In Ibeno, the water specimen recorded 30% each of *P. citrinum, A. nominus,* and *T. polyzona*, and 20% apiece for *A. tamarii* and *A. terreus. A. flavus, A. nominus*, and *C. tropicalis* were observed at Itu water samples recording 50%, 30% and 20% respectively. Water specimen from Nsit Ibom had a high percentage presence of *A. flavus* (60%) and *C. tropicalis* (40%). Dominant species isolated in Uyo water specimens were *P. citrinum* (60%) and *A. nominus* (30%). However, *A. niger, A. aculeates, P. rolfsii, A. terreus,* on the one hand and *P. rolfsii, P. citrinum, A. tamarii, A. nominus* and *T. polyzona* were conspicuously absent in both water and sediment samples obtained from Itu and Nsit Ibom. Similarly, *T. polyzona, A. flavus* and *A. terreus* were not detected in samples from Uyo whereas *A. flavus* was not isolated from Ibeno specimens (Figure 2).

Table 2 shows the spatial distribution of fungi in water and sediment specimens from the 4 locations surveyed in this study. Nsit-Ibom recorded the highest index values for dominance for fungal species in water specimens (0.5200), followed closely by Uyo (0.4600), while Nsit Ibom with a 0.4600 index represents the highest dominance for sediment specimens. Concerning diversity, Simpson 1-D index values of the test specimens of water and sediment ranging (0.4800-0.7200) translated to low distribution diversity in and between fungal species in both habitats. The Shannon diversity index of the test specimens in the habitats showed that Ibeno water and sediments specimens recorded 1.4180 and 1.3660; followed by 1.0300 and 1.3140 respective components. High Simpson (1-D) (0.7400) and Shannon index values (1.3660) were obtained for Ibeno water specimens, translated to the highest strains on diversity in the habitat.

Table 1. Physical and chemical properties of water samples taken from the different study locations in Akwa Ibom State, Nigeria

Parameters and Survey Locations				
Parameter	**Ibeno**	**Itu**	**Nsit Ibom**	**Uyo**
pH	6.52	5.24	7.30	6.90
Temperature	28.52	27.60	28.00	29.21
Colour	+++	++	++	+
Turbidity	+	+	++++	+++
Salinity (Cl)	++++	++	+	++
Hardness	++	+	+	+
Electrical conductivity	+	++	+++	++++
Dissolved oxygen (DO)	++	+	+	++
BOD	+++	+	+	++
COD	+++	++	+	+++
Ca	++	++	++	++
K	+	+	+	+
Mg	+++	++	++	++
THC	++	++	+	+
Phosphate	+	++	++	+
Sulfate	+	+	+	+
Nitrate	+	+	+	+
TDS	+	++	++	++++
TSS	+	+	+	+
Copper	+	+	+	+
Iron	+	+	+	+
Lead	++	+	-	+
Zinc	+	+	+	+
Cadmium	++	++	+	+
Chromium	+	+	+	-
Nickel	++	++	+	-
V	++	++	-	+
Na	+++	++	+	++
Mn	++	++	+	++

Note: +: slightly present, ++: moderately present, +++: heavily present, ++++: very heavily present. Ca (Calcium), Na (Sodium), E. conductivity (Electrical Conductivity) DO (Dissolved Oxygen) BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), K (Potassium), Mg (Magnesium), THC (Tetrahydrocannabinol), TDS (Total Dissolved Solid), TSS (Total Suspended Solid), Fe (Iron) Cr (Chromium), Mn (Manganese), and V (vanadium).

Table 2. Spatial diversity indices of fungi species in wetland sediment and water sample in some Council Areas of Akwa Ibom State, Nigeria

Parameter	**Parameters, Locations and Specimens**							
	Sediment				**Water**			
	Uyo	**Itu**	**Nsit Ibom**	**Ibeno**	**Uyo**	**Itu**	**Nsit Ibom**	**Ibeno**
Dominance_D	0.3400	0.2800	0.4600	0 2800	0.4600	0.3800	0.5200	0.2600
Simpson_1-D	0.6600	0.7200	0.5400	0.7200	0.5400	0.6200	0.4800	0.7400
Shannon_H	1.1940	1.3140	0.8979	1.4180	0.8979	1.0300	0.6730	1.3660
Evenness_e^H/S	0.8247	0.9301	0.8182	0.8262	0.8182	0.9334	0.9801	0.9801
Brillouin	1.1290	1.2470	0.8535	1.3340	0.8535	0.9827	0.6479	1.2980
Menhinick	0.4000	0.4000	0.3000	0.5000	0.3000	0.3000	0.2000	0.4000
Margalef	0.6514	0.6514	0.4343	0.8686	0.4343	0.4343	0.2171	0.6514
Equitability_J	0.8610	0.9477	0.8173	0.8814	0.8173	0.9372	0.971	0.9855
Fisher_alpha	0.8342	0.8342	0.5823	1.1080	0.5823	0.5823	0.3542	0.8342
Berger-Parker	0.4000	0.3000	0.6000	0.4000	0.6000	0.5000	0.6000	0.3000
Chao-1	4.0000	4.0000	3.0000	5.0000	3.0000	3.0000	2.0000	4.0000

Table 3. Eigenvalue for variables in Uyo, Council area, Nigeria

Axis	Eigenvalue	Percentage
1	0.069547	85.56
2	0.011736	14.44

Table 4. Eigenvalues for variables in Itu Local Government Area, Nigeria

Axis	Eigenvalue	Percentage
1	0.036579	74.51
2	0.012511	25.49

Table 5. Eigenvalue of variables for Ibeno Local Council Area, Nigeria

Axis	Eigenvalue	Percentage
1	0.017341	78.72
2	0.0043462	19.73
3	0.00034047	1.546

Table 6. Eigenvalue for Nsit Ibom, Nigeria

Axis	Eigenvalue	Percentage
1	0.031066	99.99
2	4.241E – 06	0.01365

Canonical Correspondence Analysis (CCA)

The CCA ordination of the relation between fungal community compositions and physico-chemical properties of water samples from Uyo, Itu, Ibeno and Nsit Ibom wetlands is presented in figures 3, 4, 5 and 6 respectively while Eigen values and percentage variances of the principal axis are presented in Tables 3, 4, 5, and 6. In this analysis, Axis 1 and 2 explained 100% of the correlation between the wetland water samples, physico-chemical properties and the fungal communities.

CCA bi-plots indicated that the wetland water physico-chemical variables remarkably influenced fungal communities. In the bi-plots (1, 2, 3, and 4), small thick circles represent the fungal species, while the arrow lines represent the physico-chemical variables (vectors) the species had an affinity for. The length of the arrows is proportional to the magnitude or intensity of charge owing to environmental variables, while the direction of the arrow shows their correlation with the axes. Longer arrows reflect strong effects on fungal communities' establishment and vice versa. Also, the distance of a named species from the vector line connotes its preference or affinity to the vector.

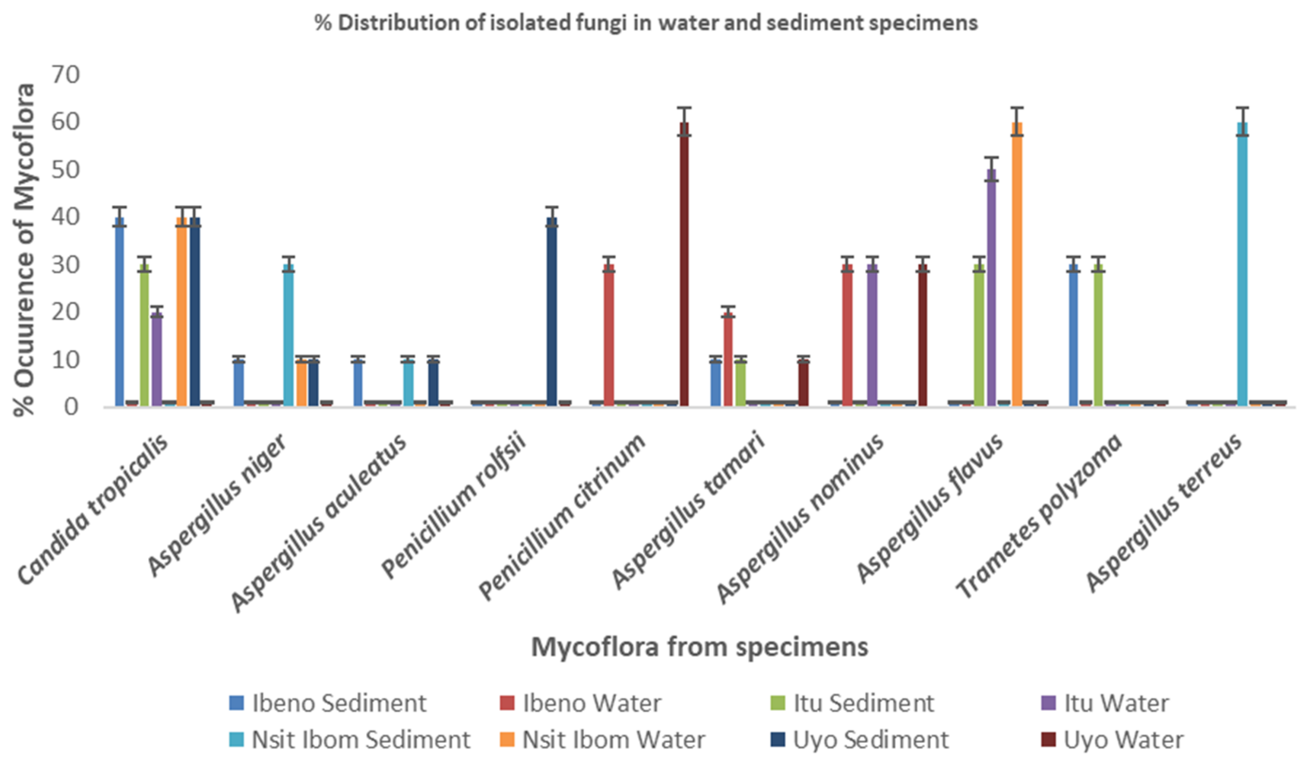


Figure 2. Percentage (%) distribution of fungi isolated from sediments and water samples in different wetlands of Akwa Ibom State, Nigeria

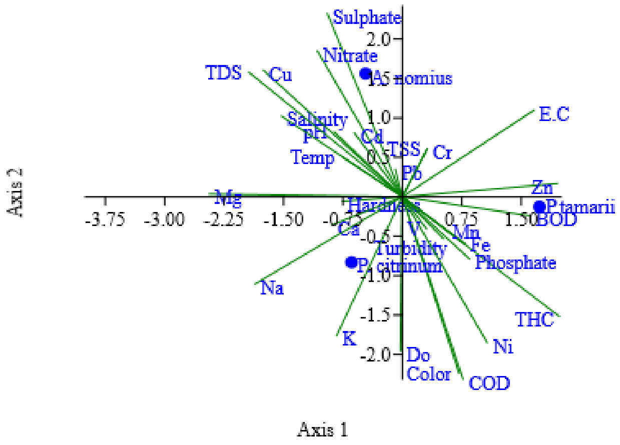


Figure 3. Canonical Correspondence Analysis (CCA) ordination for water samples from Uyo wetland, Nigeria

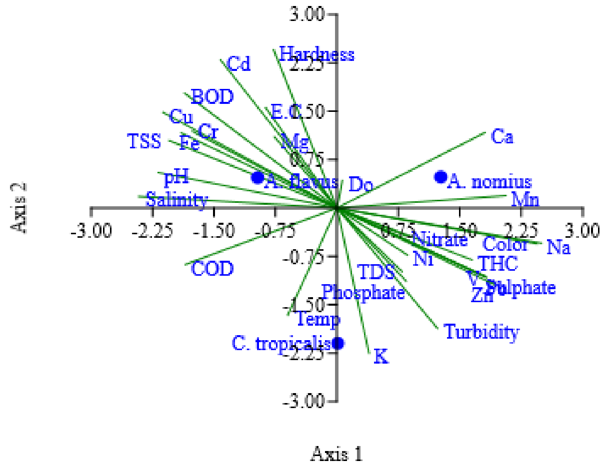


Figure 4. Canonical Correspondence Analysis (CCA) ordination for water samples from Itu wetland, Nigeria

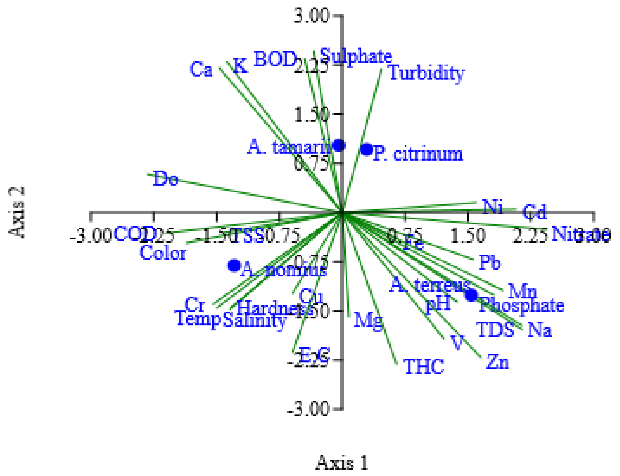


Figure 5. Canonical Correspondence Analysis (CCA) ordination for water samples from Ibeno wetland, Nigeria

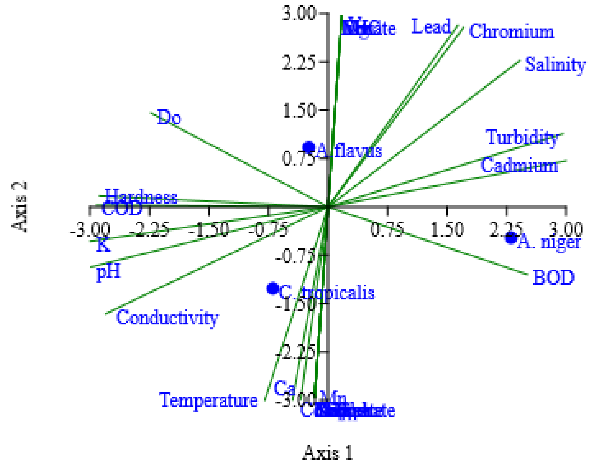


Figure 6. Canonical Correspondence Analysis (CCA) ordination for water samples from Nsit Ibom wetland, Nigeria

Discussion

Physico-chemical properties of the wetland specimens

Several workers believe that temperature, pH, oxygen tension, dissolved organic matter, nitrates, phosphates and sulfates affect the fungal population. Temperature and hydrogenium potential profiles of wetlands are reported to encourage microbes' growth and decomposing activity. The fungal population increases with increasing temperature, while low pH causes the opposite in the growth and activity of mycoflora (Jan et al. 2014; Pietryczuk et al. 2018). Our data indicate that pH values are more or less neutral, and temperature range of 27-29°C is optimal for most aquatic bacteria and mycoflora, a view consistent with other workers (Atoyebi and Ekpo 2020). Turbidity is a measure of the clarity/cloudiness of a water body. It indicates the degree of presence of suspended solids in the water body. High turbidity promotes microbial growth and points to pollution. Our findings show high turbidity in Nsit Ibom and Uyo samples, conforming to the report of Adedire et al. (2021). However, it deviates from Bassey (2022) who noted turbidity ranges in Ikpa River far exceeding WHO recommendation.

Electrical conductivity denotes dissolved ions (Cl^-) in water and correlates salinity of the water body. Dissolved oxygen and organic matter influence diversity and activity of fungal species, especially litter decomposition in wetlands (Chesteen 2012; Pietryczuk et al. 2018). Low oxygen tension and organic matter in wetlands translates to poor growth and activity of aquatic mycoflora and vice versa. High and moderate presence or levels of organic matter, EC, salinity, nitrates, phosphates, sulfates point to rising agricultural and anthropogenic pollution in or around wetlands, consistent with Pietryczuk et al. (2018).

Moreover, except for vanadium, the presence of ions of Ca, Mn, Ni, Fe, Cu, Na, Cr, Cd and Mg detected in this study corroborated the reports of other investigators in the same locality and elsewhere (Ukpong and Peter 2012; Pietryczuk et al. 2018; Atoyebi and Ekpo 2020; Umana et al. 2022). Pb, Cr and Ni are used in many industrial processes such as making coins, electronics, batteries, stainless steel (Catainis et al. 2022). These heavy metals are highly soluble in water, and easily consumed by living organisms, they have been detected in the gills, liver and muscles of fish harvested from contaminated aquatic ecosystems, resulting in brain dysfunction and organs damage in mammals when ingested (Kunthia et al. 2020). Ca and Mg contribute to water hardness, and drinking or ingesting food from hard water could precipitate some forms of cardiovascular diseases (Oseji et al. 2019). Sulfates and phosphates are leachates washed into streams from rocks and artificial fertilizers on farmlands around shorelines. High phosphates and organic matter would translate to decreased oxygen tension in water bodies, which in turn is reported to encourage build-up of algae in water (Oseji et al. 2019).

Mycotic profile and distribution

Results obtained from this study showed that members of basidiomycota and ascomycota are the prevalent species in the wetlands. This is congruent with reports of several workers in fresh and marine ecosystems of temperate countries and the Himalayas, where members of the basidiomycetes and ascomycota such as species of *Penicillium, Verticillium, Fusarium,* and *Rhizopus* were the dominant mycotic organisms (Jan et al. 2014; Liu et al. 2015; Freed et al. 2019). This study's findings are also consistent with reports of other workers in Nigeria who found *Aspergillus* spp. *Penicillium* spp. *Candida* spp. *Fusarium* spp. and *T. polyzona* in Idah, Qua Iboe, and Cross Rivers (Bello and Ukut 2015; Okpashi et al. 2018; Bassey and Asamudo 2019; Atoyebi and Ekpo 2020; Adedire et al. 2021) as well as some common shellfishes harvested in estuaries in Local Councils of Akwa Ibom State (Bassey and Effiong 2016. The presence of *T. polyzona* a laccase-producing, dyestuff, and zenobiotic degrading basidiomycete is a sure indicator of anthropogenic and industrial (polyalliphatic hydrocarbons) pollution from within the shorelines (Ezike et al. 2020).

Several of the species in this study are potentially pathogenic. Pathogenic fungi occur and thrive well in polluted river waters (Pietryczuk et al. 2018). Several workers have reported that *Aspergillus* spp. *Penicillium* spp. *Rhizopus* spp. *Mucor* spp. *Alternaria*, and *C. tropicalis* attacked different species of fish and shellfish, causing infection and maceration of their eyes, head, gills, fins, liver and kidneys leading to sudden death (Jalees et al. 2012; Iqbal and Sajjad 2013; Iqbal and Saleemi 2013; Haridy et al. 2018; Adedire et al. 2021). Besides uses of stream-borne water for domestic chores, during dry spells, natives of the study area use them to irrigate their farms as such increasing the chances of crop disease outbreaks and storage losses due to water-borne phyto-fungal spores or propagules (Enyiukwu et al. 2020).

Consumption of food and vegetables contaminated with pathogenic fungi also could harm public health. Many fungi isolated in this study were implicated with human life-threatening infections in tropical locations. *T. polyzona* is associated with serious pulmonary infections (Gauthier et al. 2017), while *C. tropicalis* underscored invasive candidemia, arthritis, and meningitis (Kotharade et al. 2010; de Oliveira Santos et al. 2018; Haridy et al. 2018; Wang et al. 2021). The *Aspergillus* spp., and *Penicillium* spp. cause human localized and invasive *aspergillosis* and varied difficult respiratory and organ fungenamia in humans (Enyiukwu et al. 2020; Adedire et al. 2021). Infection of human tissues is wound requiring, or by ingestion of fungi-contaminated foodstuff; and could occur in immuno-competent or diabetes, HIV, organ transplanted, cancer or chemotherapy immuno-compromised individuals (Enyiukwu et al. 2018b; de Oliveira Santos et al. 2018).

The study showed that amongst the ten fungal isolates (*C. tropicalis, A. niger, A. terreus, A. aculeatus, A. tamarii, P. citrinum, P. rolsfi, A. flavus, A. nominus*, and *T. polyzona*), members of the genius *Aspergillus* was the most commonly encountered and dominant genus in the studied wetland ecosystems. This is consistent with the observations made by some researchers (Hyde and Lee 1995; Okpako et al. 2009; Bassey and Effiong 2016; Bassey and Asamudo 2019). It also revealed that physico-chemical factors strongly influenced the distribution patterns of the mycoflora in the wetlands. This finding affirms the report of Lew et al. (2013) that the diversity, composition and structural patterns of fungal communities are strongly influenced by amounts of dissolved nutrients and pollutants in a water body. Hence, the results suggest that wetland contamination suits pollution-tolerant genii and potentially pathogenic groups; this raises strong concern for human health and the functioning of wetland ecosystems**.** The relative abundance of different fungal species in both habitats (0.8182-0.9801) indicated similar and uneven distribution of species in the test specimens (Table 2). Differences in abundance and diversity of the test species could be ascribed to differences in the type and concentration of carbon sources, nitrogen and pollutants in the wetlands, a view strongly supported by Jan et al. (2014), Liu et al. (2015) and Adedire et al. (2021).

Canonical Correspondence Analysis (CCA)

The results of the affinities of the various myco-organisms with the physico-chemical properties of the test habitats are presented in Figures 3 to 6. The bi-plots of the figures indicate the relationships between particular mycoflora and their site preferences with physicochemical variables of the habitat. Generally, the CCA indicates that the primary and most influential environmental parameters affecting mycoflora growth and distribution in the test wetlands are pH, turbidity, temperature, hardness, salinity, nitrate, zinc, manganese, calcium, iron, TSS, BOD, sulfate, phosphate, chromium. The *A. nominus* exhibited high affinity for nitrate (Figure 3), Manganese and Calcium (Figure 4), hardness, chromium, temperature and salinity (Figure 6). The *C. tropicalis* exhibited a high affinity for temperature (Figures 4 and 6). *A. tamarii* showed higher preferences for BOD and sulfate (Figures 4 and 6). At the same time, the distribution of *P. Citrinum* was greatly influenced by turbidity (Figure 5). The *A. flavus* showed an affinity for nitrate (Figure 6), Iron and pH (Figure 4). *A. terreus* exhibited higher preference for phosphate, pH, manganese, sodium TDS (Figure 5). This study also revealed the genus *Aspergillus* have the highest contribution to microbial contamination in the aquatic ecosystems, a view eminently sustained by Gilna and Khaleel (2011), Parveen et al. (2013) and Sharif and Silva (2021). Generally, *Aspergillus* species are reported to be more tolerant to alkaline hydrogenium ions levels (pH), while *Penicillium* species appear more tolerant to acidic pH (Wheeler et al. 1991). The distribution of *A. terreus* in this evaluation was strongly influenced by pH (Figure 5), confirmed by Pardo et al. (2006).

Booth and Kenkel (1986) suggested that sea temperature was the single most important factor in the geographical distribution of marine fungi; this justifies the influence of temperature on the distribution of *C. tropicalis* (Figures 4 and 6). *Candida* species are more geographically likely to be found in sub-tropical and tropical climates where warm to high temperatures combined with humidity will likely enhance the adaptability of *C. tropicalis* (Chai et al. 2010). According to Pardo et al. (2006), most fungi use nitrate, which is reduced first to nitrite and then to ammonia; this justifies the affinity of *A. nominus* and *A. flavus* to nitrate in this study. Other major nutrients for fungi are sulfur, phosphorous, magnesium, and potassium which can be supplied to most fungi as salts. Nearly all fungi require trace elements like Iron, copper, manganese, and zinc as co-factors for enzymes (Pardo et al. 2006); this justifies the bonding of *A. terreus* to phosphate, manganese, and sodium, while *A. nominus* to manganese and calcium.

In conclusion, this study identified the fungal diversity associated with some wetlands in Akwa Ibom State belonging to the genera *Penicillium*, *Aspergillus*, *Trametes and Candida.* It also indicated the presence of several ions and, other physical variables and, that physico-chemical factors significantly influenced the type and distribution patterns of mycoflora in the aquatic ecosystem. The CCA revealed that the species of the isolated fungal genera exhibited differential affinities and adaptation to physical and chemical properties of the ecosystem, and these mycotic agents could serve as indicators for assessments of the health of water bodies.

Recommendations

This study analysis revealed that the wetlands are being anthropogenically polluted which needs adequate measures to ameliorate the situation. It is therefore recommended that: (i) Deforestation and lumbering activities in and around wetland shorelines should be controlled by relevant governmental agencies. (ii) Disposal of domestic, organic and agricultural wastes by the natives into water bodies should be vehemently discouraged. (iii) Intensive agriculture involving the use of persistent broad-spectrum synthetic pesticides and other agro-chemicals including inorganic fertilizers whose residues and leachates (ions of ammonium, sulfates, phosphates, biphenyls etc.) pollute the aquatic food-web should be monitored and discouraged around shorelines. (iv) Mining for talc, clay and other solid minerals as well as rock quarrying activities along shorelines which result in large-scale debris/dusts being washed into wetlands, and leading to increased suspended and dissolved solids, turbidity, electrical conductivity and ions (phosphates, sulfates, arsenic, lead, copper etc.) levels in wetland waters, should be seriously controlled by relevant agencies. (v) Industrial effluents and discharges into wetlands and similar water bodies should be vigorously monitored and controlled to curtail polluting them with toxic chemical residues such as arsenic, mercury and lead with capacity to harm shellfish, fish and mammals. (vi) Adequate awareness programs should be implemented to sensitize the people/communities along shorelines on the dangers of wetland pollution, which portends harm to agro-ecological and public health. Such harms include low agricultural yields, toxic residue-contaminated agro-produce, mycotoxin contaminated sea-foods, poor air quality etc. Others are health conditions such as bronchitis, aspergillosis, allergies, pneumonia, fusariosis, persistent coughs, cancers etc. (vii) Campaigns to establish greenbelts with the capacity to remediate contaminants and sedimentation in wetland shorelines for improved environmental and public health should be encouraged and vigorously implemented by both governmental and non-governmental organizations.

ACKNOWLEDGEMENTS

The authors wish to profoundly thank the members of staff of the Department of Botany and Ecological Studies University of Uyo, Nigeria especially Drs. Felix Ogbemudia and Richard Ita for their roles in analyzing our data. We also wish to appreciate the technologists and other staff members of the Akwa Ibom State Ministry of Science and Technology Uyo as well as the natives of the wetland communities in Ibeno, Itu, Uyo and Nsit Ibom Local Government Areas who provided various assistances to us in one way or the other in the course of conducting this experiment.

REFERENCES

Abraham CM, Ebong MS, Udoh JC, Williams N-OI. 2021. Evaluating wetland assets in consumptive and non-consumptive dimensional and utilization potentials in Ibeano, Akwa Ibom State, Nigeria. Glob J Ecol 6 (1): 65-72. DOI: 10.17352/gje.000046.

Adedire DE, Jimoh AO, Kashim-Bello Z et al. 2021. Assesment of the physic-chemical qualities and microbial profile of Idah River, Kogi State, Nigeria. Afr J Microbiol Res 15 (7): 377-387. DOI: 10.5897/AJMR2021.9538.

American Public Health Association (APHA). 1998. Standard Methods for the Examination Aquatic Microbial Ecology (2nd ed.) APHA, New York.

Atoyebi B, Ekpo MA. 2020. Microorganisms and physicochemical profile of aquatic ecosystem in Akwa Ibom State. J Appl Life Sci Intl 23 (6): 15-26. DOI: 10.9734/jalsi/2020/v23i630167.

Balwan WK, Kour S. 2021. Wetland – an ecological boon for the environment. East Afr Sch J Agric Life Sci 4 (3): 38-48. DOI: 10.36349/easjals.2021.v04i03.001.

Bassey IN, Asamudo NU. 2019. Comparative studies of fungi associated with sea-food in different wetlands of Akwa Ibom State. J Aquat Sci 34 (1): 41-47. DOI: 10.4313/jas.v34i1.6.

Bassey IN, Effiong MU. 2016. Fungi associated with postharvest deterioration of dried *Clarias gariepinus* vended in some markets in Akwa Ibom State, Nigeria. J Aquat Sci 31(2B): 409-416. DOI: 10.4314/jas.v31i2B.8.

Bassey OB. 2022. Water quality parameter and indices for Ikpa River in Akea Ibom State, Nigeria. Intl J Eng Res Technol 2 (9): 858-870. DOI: 10.17577/IJERTV21S90508.

Bello OS, Ukut EM. 2015. The physicochemical properties and microbial isolates of Cross River estuary soils. Mayfalir J Soil Sci 1 (1): 15-27.

Booth T, Kenkel N. 1986. Ecological studies of lignicolous marine fungi: a distribution model based on ordination and classification. In: Moss ST (eds). The Biology of Marine Fungi. Cambridge University Press, Cambridge.

Catainis I, Tiron Dutu L, Grosu D. 2022. Heavy metals occurrence in lakes of the Danube Delta, Romania. GeoEcoMarina 28: 1-15. DOI: 10.5281/zenodo.7491375.

Chai LY, Denning DW Warn P. 2010. *Candida tropicalis* in human disease. Crit Rev Microbiol 36 (4): 287-998. DOI: 10.3109/1040841x.2010.489506.

Chesteen K. 2012. Determing the Diversity of Wetland Fungi Through Molecular Based Species Identification. [Thesis]. University of Southern Mississippi, Mississippi, USA.

Cummings KW, Klug MJ. 2000. Feeding ecology of stream invertebrate. Ann Rev Ecol Evol System 10: 147-172. DOI: 10.1146/annurev.es.10.110179.001051.

Dapa IN, Brown I. 2020. The boom, the blunder and the brunt of wetlands conversion and urbanization in Port Harcourt municipality. Intl J Hydrol 4 (5): 243-252. DOI: 10.15406/IJH.2020.04.00251.

De Oliveira Santos GC, Vasconcelos CC, Lopes AJO, Cartágenes MDSDS, Filho AKDB, do Nascimento FRF, Ramos RM, Pires ERRB, de Andrade MS, Rocha FMG, de Andrace Monteiro C. 2018. *Candida* infections and therapeutic strategies: Mechanisms of action for traditional and alternative agents. Front Microbiol 9: 1351. DOI: 10.3389/fmicb.2018.01351.

Debroas D, Domaizon I, Humbert J, Jardillier CL, Oudart A, Taib N. 2017. Overview of freshwater microbial eukaryotes diversity: A firstanalysis of publicly available metabarcoding data. FEMS Microbiol Ecol 93: 1056-1060. DOI: 10.1093/FEMSEC/FIX023.

Edo I, Albrecht E. 2021. Threats to Niger Delta wetlands: A case study of Apoi creek forest. Open J Ecol 11: 136-147. DOI: 10. 4236/oje.2021.112012.

Ekong FU, Akpan IU. 2014. Characteristics and methods of wetlands utilization in Ibiono Ibom Local Government Area, Nigeria. J Environ Earth Sci 4 (14): 9-19.

Enyiukwu DN, Bassey IN, Nwaogu GA, Asamudo NU, Chukwu LA, Monday EA, Maranzu JO. 2021. Pig (*Sus scrofa domesticus*) dung and their associated fungi: Potential candidates for bioremediation and nutrients improvement of crude oil contaminated soils. Biodiversitas 22 (8): 3276-3286. DOI: 10.13057/biodiv/d220822.

Enyiukwu DN, Bassey IN, Nwaogu GA, Chukwu LA, Maranzu JO. 2020. Postharvest spoilage and management of fruits and vegetables: A perspective on small-holder agricultural systems of the tropics. Greener J Plant Pathol Entomol 3 (1): 001-017.

Enyiukwu DN, Ononuju CC, Maranzu JO. 2018a**.** Mycotoxins in foods and indoor air: their attendant diseases and modes of injury on biological and human systems. Greener J Epidemiol Public Health 6 (1): 034-051. DOI: 10.15580/GJEPH.2018.1.010818004.

Enyiukwu DN, Ononuju CC, Maranzu JO. 2018b**.** Plant pathogenic fungi -Novel agents of human diseases: Implications for public health. Greener J Epidemiol Public Health 6 (1): 001-019. DOI: 10.15580/GJEPH.2017.8.072817097.

Ezike TC, Ezukwu AL, Udeh JO, Eze SOO, Chilaka FC. 2020. Purification and characterization of laccase *Tramates polyzona* WRFO3. Biotechnol Rep 28: e00566. DOI: 10.1016/j.btre.2020.e00566.

Food and Agriculture Organization (FAO). 1994. Mangrove forest management guidelines. UN, FAO Forest Resource Division, Rome.

Food and Agriculture Organization (FAO). 2007. Status and trend in mangrove Area. UN, FAO Forest Resource Division, Rome.

Freed G, Schlatter D, Paulitz T, Dugan F. 2019. Mycological insights into wetland fungal communities: The mycobiome of *Cassiasia* in the Pacific Northwest. Phytobiomes J 3: 286-299. DOI: 10.1094/PBIOMES-04-19-0022-R.

Gauthier A, Jaubert J, Traversier N, Lemant J, Balu L, Garcia-Hermoso D, Welti S, Favel A, Picot S, Hoarau G. 2017. *Trametes polymyza*, an emerging fiamentous basidiomycete in Reunion Island. Mycoses 60 (6): 412-415. DOI: 10.1111/myc.12609.

Gilna VV. Khaleel KM. 2011. Diversity of fungi in Mangrove ecosystem. J Exp Sci 2 (2): 47-48.

Haridy M, Abdo W, Hashem M, Yanai T. 2018. *Candida parapsilosis* and *C. tropicalis* infections in an Okhotsk snailfish (*Liparis ochotensis*). J Vet Med Sci 80 (11): 1678-1680. DOI: 10.1292/JVMS.18-0133.

Hyde KD, Lee SY. 1995. Ecology of mangrove fungi and their role in nutrient cycling. What gaps occur in our knowledge? Hydrobiologica 295: 107-118. DOI: 10.1007/BF00029117.

Iqbal Z, Sajjad R. 2013. Some pathogenic fungi parasitizing two exotic tropical ornamental fishes. Intl J Agric Biol 15: 595-598.

Iqbal Z, Saleemi S. 2013. Isolation of pathogenic fungi from a freshwater. Sci Intl 25: 851-855.

Jalees MM, Hussain I, Arshad M, Muhammad G, Khan QM, Mahmood SM. 2012. Occurrence of peste des petites ruminants in five districts of Punjab, Pakistan. Pak Vet J 33 (2): 165-169. DOI: 10.1186/s40781-015-0066-0.

Jan D, Mir TA, Kamilli AN, Pandit AK, Aijaz S. 2014. Relationship between fungal community and physicochemical characteristics in the Hokersar wetland, Kashmir Himalayas. Afr J Microbiol 8 (4): 368-374. DOI: 10.5897/AJMR12.1836.

Kotharade R, Kura MM, Valand AG, Panthaki MH. 2010. *Candida tropicalis*: Its prevalence, pathogenicity and increasing resistance to fluconazole. J Med Microbiol 59 (8): 873-880. DOI: 10.1099/jmm.0.013227-0.

Kunthia GK, Ngure V, Beti D, Lugalia R, Wangila A, Kamau L. 2020. Levels of heavy metals in waste water and soil samples from open drainage channels in Nairobi, Kenya: Community health implications. Sci Rep 10: 8483. DOI: 10.1038/s41598-020-65359-5.

Lew S, Lew M, Biedunkiewicz A, Szarek J. 2013. Impact of pesticide contamination on aquatic microorganism populations in the littoral zone. Arch Environ Contam Toxicol 64: 399-409. DOI: 10.1038/s41598-020-65359-5.

Liu J, Wang J, Gao G, Barthlam MG, Wang Y. 2015. Distribution and diversity of fungi in fresh water sediments on a river catchment scale. Front Microbiol 6: 329. DOI: 3389/fmicb.2015.003229.

Mitsch WJ, Gosselink JG. 1993. Wetlands. Van Nostrand Reinhold, NewYork.

Nygren CMR, Eberhardt U, Karlsson M, Parrent JL, Lindahl BD, Taylor AFS. 2008. Growth on nitrate and occurrence of nitrate reductase-encoding genes in a phylogenetically diverse range of ectomycorrhizal fungi. New Phytol 180: 875-889. DOI: 10.1111/J.1469-8137.2008.02618.x.

Okpako E, Osuagwu AN, Duke AE, Ntui VO. 2009. Prevalence and significance of fungi in Satchet water and borehole drinking in Calabar, Nigeria. Afr J Microbiol Res 3 (2): 056-061.

Okpashi VE, Ogugua VN, Chikebuike SU, Ezike TC, Obuegbe CG. 2018. Bacteriological and biochemical monitoring of Qua Iboe River resources of Eket community, Akwa Ibom State, Nigeria. J Ind Pollut Control 34 (1): 1931-1940.

Oleveira M, Vasconcelos V. 2020. Occurrence of mycotoxins in fish feeds and its effects. A review. Toxins 12 (3): 160. DOI: 10.3390/toxins12030160.

Onuoha S, Obika I. 2015. Fungi associated with the deterioration of of postharvest onion bulbs sold in some markets in Awka Nigeria. J Biosci Bioeng 3 (5): 90-94. DOI: 10.13189/bb.2015.030503.

Oseji M, Uwaifo OP, Omogbeme MI. 2019. Assessment of physical and chemical characteristics of surface water from River Niger, Illushi, Edo State, Nigeria. J Appl Sci Environ Manag 23 (1): 195-199. DOI: 10.4314/jasem.v.23i1.29.

Pardo E, Sanchis V, Ramos AJ, Marin S. 2006. Non-specificity of nutritional substrate for ochratoxin A product by isolates of *Aspergillus ochraceus*. Food Microbiol 23: 351-358. DOI: 10.1016/j.fm.2005.05.005.

Parveen B, Ravet V, DJedat C, Mary I, Quiblier C, Debroas D, Humbert JF. 2013. Bacterial communities associated with *Microcystis* colonies differ from free-living communities living in the same ecosystem. Environ Microbiol Rep 5 (5): 716-724. DOI: 10.1111/1758-2229.12071.

Pietryczuk A, Cudowski A, Hanschild T, Swislockka M, Wiecko A, Karpowick M. 2018. Abundance and species diversity of fungi in rives with various contaminants. Curr Microbiol 75: 630-638. DOI: 10.1007/s00284-017-1427-3.

Pittock J, Finlayson M, Arthington AH, Roux D, Matthews JH, Biggs H, Harrison I, Blom E, Flitcroft R, Froend R, Hermoso V, Junk W, Kumar R, Linke S, Nel J, Nunes da Cunha C, Pattnaik A, Pollard S, Rast W, Thieme M, Turak E, Turpie J, van Niekerk L, Willems D, Viers J. 2015. Managing freshwater, river, wetland and estuarine protected areas. In: Worboys GL, Lockwood M, Kothari A, Feary S, Pulsford I (eds). Protected Area Governance and Management. ANU Press, Canberra.

Saturday KU. 2015. Petroleum activities, wetland utilization and livelihood changes in southern Akwa Ibom state, Nigeria 2003-2015. [Thesis]. Lund University, Sweden.

Sharif WR, Silva P. 2021. Fungal diversity in selected coastal mangrove ecosystem in East Berbice Corentyne, Guyana, South America. GCS J Biol Pharm Sci 17 (1): 138-146. DOI: 10.30574/gscbps.2021.17.1.0307.

Sidhoum W, Bahi K, Fortas Z, 2020. The effect of salinity gradient and heavy metals pollution on abscular mycorrhzal fungal community structure in some Algerian wetlands. Acta Bot Croat 79 (1): 3-14. DOI: 10.37427/botcro-2020-001.

Ukpong EC, Peter BU. 2012. Physicochemical and bacteriological analysis of drinking water in Ibeno L.G.A. of Akwa Ibom State. Nig J Technol 31 (2): 116-127.

Ukpong IE. 1997. Mangrove swamp at saline/fresh water interface near Greek Town, Southeastern Nigeria. Catena 29 (1): 61-71. DOI: 10.1016/S0341-8162(96)00058-6.

Umana IM, Neji PA, Agwupuye JA. 2022. Assessment of underground water in Okobo Local Governmant Area of Akwa Ibom State, Nigeria. Appl Water Sci 12: 106. DOI: 10.1007/s13201-022-01614-6.

Wang B, He X, Lu F, Li Y, Zhang M, Huang Y, and Xia J. 2021. *Candida* isolates from blood and other normally sterile foci from ICU patients: Determination of epidemiology, antifungal susceptibility profile and evaluation of associated risk factors. Front Public Health 11: 779590. DOI: 10.3389/publ.2021.779590.

Wheeler KA, Hurdman BF, Pitt JI. 1991. Influence of pH on the growth of toxigenic species of *Aspergillus*, *Pencillium* and *Fusarium*. Intl J Food Microbiol 12: 141-149. DOI: 10.1016/0168-1605(91)90063-u.

White TJ, Bruns TD, Lee SB, Taylor JW. 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (eds). PCR Protocols: Guide to Methods and Applications. Academic Press, San Diego. DOI: 10.1016/B978-0-12-372180-8.50042-1.

Yoder C. 2022. Qualitative analysis of chemical compounds. https://www.wirechemist.com/chemistry/instructional/laboratory-tutorials/qualitative-analysis.

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 19-24

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140103

Characteristics of mangroves and carbon stocks estimation in Sampang and Pamekasan Districts, Madura Island, Indonesia

DIVA GALEH AININDYA[1], KHANSA AFZANAYA RARASTI[1], KHOTROTUN NIDA FARIKHA[1], MUHAMMAD FIRDAUS WIRAATMAJA[1], CHEE KONG YAP[2], AHMAD DWI SETYAWAN[1,3,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57 126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com

[2]Department of Biology, Faculty of Science, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia

[3]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuscript received: 31 December 2023. Revision accepted: 27 March 2024.

Abstract. *Ainindya DG, Rarasti KA, Farikha KN, Wiraatmaja MF, Yap CK, Setyawan AD. 2024. Characteristics of mangroves and carbon stocks estimation in Sampang and Pamekasan Districts, Madura Island, Indonesia. Intl J Bonorowo Wetlands 14: 19-24.* Mangrove forests represent unique coastal ecosystems with inherent characteristics and substantial biological diversity. Flourishing in tidal regions submerged during high tide yet devoid of puddles during low tide, mangroves exhibit remarkable salt tolerance. This complex, diverse, and heterogeneous ecosystem serves diverse functions concerning physical, biological, and socio-economic aspects. Madura Island, Indonesia has extensive mangrove forests, especially along the southern coasts of Sampang and Pamekasan, which serve as centers of robust economic activity. This study aims to elucidate the characteristics and assess the carbon storage and absorption capacity of mangroves in Sampang and Pamekasan Districts, Madura, Indonesia. Employing direct observational methods, this study established plots measuring 10×10 m at four stations in December 2023. The average carbon stock in the study area stands at 42,605 tons/ha, with an estimated sequestration value averaging 1,5625 tons/ha. These findings align with the range prescribed by the IPCC for tropical wet areas, falling between 8.7 and 384 tons/ha. Among the three extant mangrove species, *Sonneratia alba* Sm. emerged as the primary contributor to the high carbon sequestration observed in the region. The study area hosts three mangrove species: *Avicennia marina* (Forssk.) Vierh., *Rhizophora stylosa* Griffith, and *S. alba*. The Importance Value Index (IVI) of *R. stylosa* was 111.91%, *S. alba* was 56.52% and *A. marina* was 25.32%. Mangrove stands with a Diameter at Breast Height (DBH) of less than 10 cm predominate across all stations, comprising 80% of *A. marina*, 98% of *R. stylosa*, and 63% of *S. alba*.

Keywords: Allometric equations, *Avicennia marina*, biomass, carbon sequestration, IVI, *Rhizophora stylosa, Sonneratia alba*

INTRODUCTION

Mangrove forests, thriving in some coastal ecosystem areas, exhibit unique characteristics, such as salinity tolerance achieved through salt secretion in leaves or roots (Srikanth et al. 2016), and have substantial biological wealth potential. Recognized for their relatively high productivity (Dali 2023), these mangrove forests typically flourish in tidal zones flooded at high tide, remaining free of inundation during low tide and having remarkable salt tolerance. Mangroves have complex, diverse, and heterogeneous ecosystem characteristics and are widely found in tropical and subtropical climates (Nauta et al. 2023). The distinctive characteristics of mangrove ecosystems endow mangrove forests with several physical, biological, and socio-economic functions. In terms of their physical function, mangroves serve as protective barriers for coastal areas, mitigating abrasion, waves, wind, seawater intrusion, and the impact of large storms. The structural configuration of mangrove trees, including their trunk and root systems, exerts an attractive force that disperses wave energy and diminishes wave height (Damastuti et al. 2023). In Indonesia, efforts to mitigate climate change have included the conservation and restoration of mangrove ecosystems (Ickowitz et al. 2023). Biologically, mangrove forests function as habitats for various marine species, including crabs and mollusks. Economically, these forests benefit communities through the utilization of wood and non-timber products for handicrafts, construction, medicine, and tourism.

Furthermore, mangrove forests play a vital role in conserving soil and water resources, sequestering carbon, providing wildlife habitats, and maintaining ecological balance (Sobhani and Danehkar 2023). On Madura Island, mangrove forests grow densely and are characterized by moderately sized trees. These ecosystems are typically situated along coastal areas and river estuaries that lead to the sea (Rosadi et al. 2018).

Mangroves, known as wave protection plants found around the coast of Indonesia, including Madura Island (Prihantini et al. 2022), play a crucial role in safeguarding the south coast of Sampang and Pamekasan districts, where economic centers thrive. The economic activity on the Southern coast of Madura Island highlights the significance of mangroves providing essential resources and protection against coastal abrasion. Typically confined to tidal zones, such as estuaries, coastlines, and muddy beaches (Hidayah et al. 2015; Muzaki et al. 2017), mangroves on Madura Island exhibit notable diversity, with the assemblage of species like *Avicennia marina* (Forssk.) Vierh. and

Sonneratia alba Sm., which are represented by pneumatophore root systems and species such as *Rhizophora* spp. and *Bruguiera* spp. having a tap root system. Muzaki et al. (2017) reported 12 true mangroves and around 25 associated mangroves on Madura Island, covering a total area of 15,118 ha, with a dominant density of over 1,500 individuals per hectare (Muhsoni and Pi 2014).

The capacity of mangrove forests to absorb carbon dioxide (CO_2) and release oxygen (O_2) is better than that of terrestrial forests (Shiau and Chiu 2020). Adaptation of mangrove plants to anaerobic environments enhances their ability to store carbon for extended periods. Carbon stocks in mangrove forests are primarily distributed in plant biomass, and only about 11% are stored in sediments (Li et al. 2018). The considerable carbon sequestration potential of mangroves positions them favorably within the Clean Development Mechanism (CDM) program under the Kyoto Protocol (Cui et al. 2018). Trees and plants absorb carbon dioxide (CO_2) through sequestration during photosynthesis, with a portion returning to the atmosphere through respiration, while the rest is stored in leaves, stems, and roots (Hidayah et al. 2022). Given the significant variability in carbon storage and sequestration rates across mangrove locations and districts, this study provides crucial insights into mangrove characteristics and estimates of carbon storage and uptake in Sampang and Pamekasan Districts, Madura Island.

MATERIALS AND METHODS

Study area

This study was conducted in December 2023 within a mangrove area on the south coast of Madura Island, East Java Province, Indonesia. The study was confined to 4 stations, i.e., Taddan and Aeng Sareh Villages in Sampang District, as well as Tlanakan and Branta Tinggi Villages in Pamekasan District (Table 1, Figure 1). Table 1 also presents various abiotic parameters measured at the study site, including temperature, pH, salinity, and humidity. The lowest water and soil temperatures were recorded at Taddan at low tide, where seawater was still present on the surface, with temperatures of 30.67°C and 30.33°C, respectively. Conversely, the highest temperatures were observed in Tlanakan, with water temperature reaching 36°C and soil temperature reaching 35°C. Air temperature varied from 31.7°C in Taddan Village to 37.17°C in Branta Tinggi Village.

Additionally, the pH of water across the four study stations showed alkaline properties in the range of 7.6-8.03, while soil pH ranged slightly acidic, between 6-7.1. Salinity levels ranged from 19.67-32.67 ppt. Salinity and pH have been recognized as limiting factors influencing biodiversity in mangrove areas (Sarker et al. 2019). Ahmed et al. (2022) highlighted that low salinity levels contribute to maintaining the ecological stability of mangroves. Moreover, soil moisture across all stations exceeded 10.

Table 1. Location, coordinates, and abiotic parameters of the sampling station

Station name	Location	Coordinates	Water temp (°c)	Soil temp (°c)	Air temp (°c)	Water pH	Soil pH	Salinity (ppt)	Soil Moist
1	Taddan, Sampang District	7°12'59.6"S 113°16'27.4"E	30.67	30.33	31.7	7.6	6	28.22	>10
2	Branta Tinggi, Pamekasan District	7°13'18.0"S 113°27'13.9"E	34.33	34.33	37.17	7.37	6.97	19.67	>10
3	Tlanakan, Pamekasan District	7°13'17.3"S 113°26'18.2"E	36	35	36.33	8.03	7.1	32.67	>10
4	Song Osong Beach, Aeng Sareh, Sampang District	7°13'19.9"S 113°12'13.4"E	35.67	34.67	36.33	7.53	6.97	19.67	>10

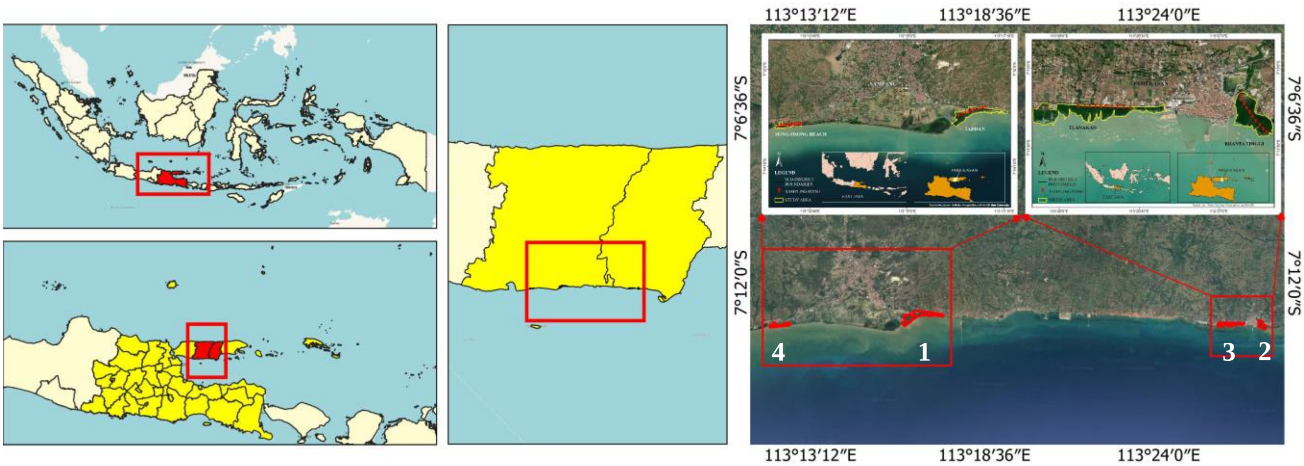


Figure 1. Study area in Madura Island, East Java Province, Indonesia. Note: 1. Taddan, Sampang District, 2. Branta Tinggi, Pamekasan District, 3. Tlanakan, Pamekasan District, 4. Aeng Sareh, Sampang District

Data collection

Data collection involved establishing plots measuring 10 m × 10 m in mangrove area. The study was conducted across four stations, each exhibiting distinct environmental conditions: the first station had muddy terrain subject to flooding, while the second, third and fourth stations had sandy terrain without flooding. Data collection was carried out with 10 repetitions at each station, resulting in a total of 40 plots. Measurements were carried out using the Diameter at Breast Height (DBH) method, where the circumference of mangrove trunks was measured at the height corresponding to an adult's chest (Fatma et al. 2018). Stem diameter measurements were obtained from samples collected at each plot, followed by the assessment of species abundances within each plot at every station. Species names and individual counts were recorded using a tally sheet.

Additionally, abiotic parameters were recorded at the four stations with three in-situ repetitions. These parameters included temperature (water, soil and air), measured using a soil thermometer; pH (water and soil), assessed with a pH meter; salinity, determined using a refractometer; and soil moisture, gauged with a soil moisture meter. The collected data were subsequently averaged.

Importance Value Index (IVI)

One of the objectives of mangrove vegetation analysis is to calculate the Importance Value Index (IVI), as proposed by Bray and Curtis (1957), which is derived from the sum of relative frequency, relative density, and relative dominance (Hanggara et al. 2021). The IVI of a species typically ranges from 0 to 300. This important value provides an overview of the influence or role of a type of mangrove plant in the mangrove community. According to Hidayah et al. (2022), the IVI of each species for each transect is calculated using the following formula:

$$Di = ni/A;\ Rdi = [ni/\Sigma n]\times 100$$

Where :
Di : Species-i density
Rdi : Relative density of species i
ni : Total number of i-species
Σn : Total number of all species
A : Total sampling area (1000 m^2)

$$Fi = pi/\Sigma F;\ RFi = [Fi/\Sigma F]\times 100$$

Where :
Fi : Frequency of species-i
Rfi : The relative frequency of species-i
Pi : Number of plots where species-i found
ΣF : Number of plots on each transect

$$Ci = \Sigma BA/A;\ RCi = [Ci/\Sigma c]\times 100$$

Where :
Ci : Species-i coverage
Rci : Relative coverage of i-species
ΣBA : πd⁄4 (π=3.14; d=DBH)
ΣC : Total coverage of the entire species
A : Total sampling area (1000 m^2)

$$IVI = RDi + RFi + RCi$$

Biomass and carbon stock estimation

This study employed allometric methods incorporating DBH-independent variables to estimate Aboveground Biomass (AGB) and Belowground Biomass (BGB) for each recorded mangrove species. AGB refers to the total mass of a plant's living component located above the ground, including stems, branches, leaves, flowers, and other structures (Xu et al. 2020). Conversely, BGB encompasses the total weight of all plant parts located below the soil surface, such as root systems, bulbs, rhizomes, and others (Dayathilake et al. 2020). The relationship between AGB and BGB is often used to assess the impact of biotic and abiotic effects on the growth and development of individual plants. Table 2 presents an allometric model for estimating the biomass of each species.

Following the assessment of carbon biomass, an estimate of the carbon stock (Cn) and carbon sequestration potential (Sn) was carried out. Several studies have employed specific values tailored to distinct forest types to estimate carbon stocks at various plant structural levels and within plant communities (Zhou et al. 2023). The carbon content value was derived by multiplying the biomass content of mangrove trees by a fixed organic carbon content factor, typically set at 0.47 as established by the National Standardization Agency (BSN: *Badan Standardisasi Nasional*) (Dewanti et al. 2020). Carbon sequestration potential signifies the capacity of plants to bind and store atmospheric carbon for extended periods (Nwankwo et al. 2023). The equation used to determine the values of Sn and Cn derived from Hidayah et al. (2022) is presented below:

Table 2. Allometric equation for calculating biomass (kg)

Species	Species Allometric Model		References
	Aboveground Biomass (kg)	Belowground Biomass (kg)	
Avicennia marina (Forssk.) Vierh.	$0.079211 \times D^{2.478095}$	$0.079211 \times D^{2.478095} \times 0.25$	Sutaryo (2009)
Rhizophora stylosa Griffith	$0.128 \times D^{2.60}$	$0.134 \times D^{2.40}$	Clough and Scott (1989) Gevana and Im (2016)
Sonneratia alba Sm.	$0.251 \times \rho \times D^{2.46}$	$0.3841 \times \rho \times D^{2.101} \times 0.25$	Komiyama et al. (2005)

Note: D: DBH (cm); ρ: density of wood (gr/cm^3); *Avicennia marina* ρ: 0.506; *Sonneratia alba* ρ: 0.475

$$C = B \times 0{,}47$$

$$C_n = \frac{C_X}{1000} \times \frac{10000}{L_{tr}}$$

$$SCO_2 = \frac{MR\ CO_2}{Ar\ C} \times C_n$$

$$S_n = \frac{SCO_2}{1000} \times \frac{10000}{L_{tr}}$$

Where :
C : Carbon stock (kg)
C_x : Total carbons for each transect (kg)
B : Biomass (kg)
Ltr : Total transect area (m^2)
Cn : Carbon per hectare (ton/ha)
MR CO_2: Relative molecular mass (44)
Ar C : Atom mass C (12)
Sn : Carbon sequestration (ton/ha)

RESULTS AND DISCUSSION

Characteristics of mangrove community structure

The Importance Value Index (IVI) analysis revealed that *R. stylosa* exhibits the highest value among all species within the study area. This dominance likely stems from its remarkable adaptation and tolerance to local climatic and soil conditions. The *R. stylosa* thrives in diverse environments, including muddy, sandy, stony soils and even coral areas. Notably, its anchor roots system has an important role, especially in facilitating gas exchange within sediments characterized by low oxygen levels (Azahra et al. 2020). Mangrove habitats are typically characterized by low-oxygen mud, and the lenticels on these anchor roots enable efficient gas exchange.

Additionally, these roots contribute to the species' ability to withstand tidal fluctuations (Mori et al. 2022). This adaptation aligns perfectly with the study area's location in the proximal coastal zone, directly exposed to the sea. Consequently, the species composition within this zone is heavily influenced by seawater presence. For instance, sandy areas tend to be dominated by *S. alba*, while muddy areas favor *A. marina* and *R. stylosa*.

Characteristics of mangrove stands based on Diameter at Breast Height (DBH)

Further analysis of variations in stand characteristics among the three prevalent mangrove species revealed that most individuals possessed DBH of less than 10 cm. This indicates that the mangrove stand at the study site falls within the young vegetation category. Table 4 summarizes the DBH data for all species, presenting minimum and maximum statistical parameters with a range value from 3.18-64.65 cm. The *A. marina* exhibited a DBH range of 4.14-25.48 cm across all stations, while *R. stylosa* ranged from 3.18 cm to 14.65 cm. The *S. alba* demonstrated the widest DBH range, spanning from 3.18 cm to 64.65 cm, across all four stations. In terms of stand density, *R. stylosa* displayed abundance, with 367 individuals at station 2 and 191 individuals at station 3. This dominance likely coincides with the observation from Figure 2 that the majority of *R. stylosa* possesses a DBH of less than 10 cm.

Moreover, Figure 2 visually confirms that young mangroves with DBH less than 10 cm dominate all three species across the stations. On average, 80% of *A. marina*, 98% of *R. stylosa*, and 63% of *S. alba* individuals fall into this young category. Considering the prevalence of mangroves with DBH less than 10 cm in Sampang and Pamekasan districts, the mangrove vegetation at these locations can be classified as relatively young compared to stand characterized by larger DBH values (Hidayah et al. 2022). This notion is further supported by station 2, which exhibits the highest stand density but also the lowest average DBH (5.01 cm), placing it within the young plant category (as shown in Table 4).

Table 3. Characteristics of mangrove species structure in Sampang and Pamekasan Districts, East Jawa, Indonesia

Mangrove Species	Relative Density (RDi)	Relative Frequency (RFi)	Relative Coverage (RCi)	IVI
Sonneratia alba	40.52	16.00	0.01	56.52
Avicennia marina	14.31	11.00	0.00	25.32
Rhizophora stylosa	83.91	28.00	0.00	111.91

Table 4. Statistics of mangrove stands observed in Sampang and Pamekasan Districts, East Jawa, Indonesia

Statistical Parameters of DBH (cm)	Station 1		Station 2	Station 3		Station 4		
	Avicennia marina	*Sonneratia alba*	*Rhizophora stylosa*	*Avicennia marina*	*Rhizophora stylosa*	*Avicennia marina*	*Rhizophora stylosa*	*Sonneratia alba*
Number of stands (N) per 1000 m^2	10	77	367	56	99	6	191	64
Minimum	8.6	3.18	3.18	4.46	3.50	4.14	3.18	4.14
Maximum	16.56	52.23	11.15	25.48	14.65	4.78	13.38	64.65
Median	13.38	11.78	4.46	6.37	6.05	4.30	5.73	7.64
Sample variance	6.34	78.21	2.28	12.62	5.83	0.07	2.13	65.83

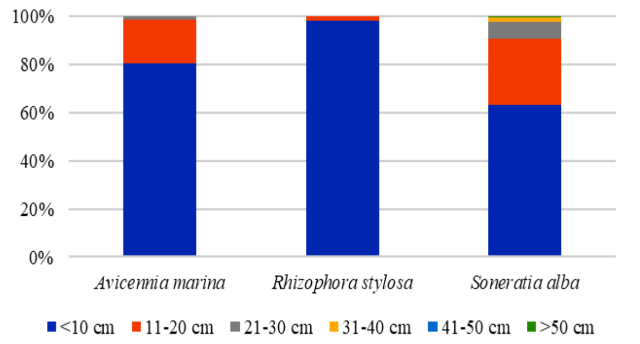


Figure 2. DBH class of mangrove species in Sampang and Pamekasan regencies, East Jawa, Indonesia

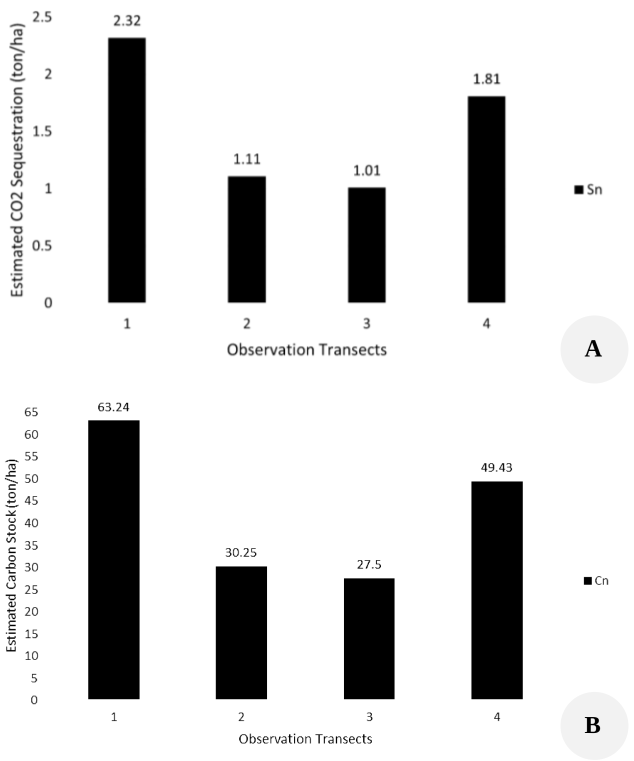


Figure 3. A. Sequestration of carbon and B. CO_2 stocks from 4 stations in Sampang and Pamekasan Districts, East Jawa, Indonesia

Carbon stock and sequestration estimation

Analysis of 40 plots spread across four observation stations revealed a range in AGB of 3,716.10-11,965.53 kg/1000 m^2, with an average value of 6,849.81 kg/1000 m^2. Similarly, BGB ranged from 2,100.27-2,719.42 kg/1000 m^2, with an average value of 2215.2875 kg/1000 m^2. Carbon stock estimates, derived from AGB and BGB values, varied between 27.50-63.24 tons/ha, with an average of 42.605 tons/ha. The estimated sequestration potential ranged from 1.01-2.32 tons/ha, with an average of 1.5625 tons/ha. The spatial distribution of carbon stocks and sequestration values across the transects are depicted in Figure 2.

Discussion

The estimated average carbon stock (42.605 tons/ha) in this study falls within the range established by the IPCC for tropical wet regions (8.7-384 tons/ha) (Alimbon and Manseguiao 2021). However, this value is considerably lower compared to other mangrove ecosystems in Java, Indonesia, such as Karimunjawa (124.44 tons/ha) (Hickmah et al. 2021), Harapan and Kelapa Island, Jakarta (634.54 tons/ha) (Easteria et al. 2022), Damas Beach Trenggalek (200.53 tons/ha) (Nur et al. 2022), Bregasmalang, Central Java (713.13 tons/ha) (Sugiatmo et al. 2023), and Ijo river estuari, Kebumen (1143.31 MgC/ha) (Ningtyas et al. 2023).

Several environmental factors likely contribute to these variations in carbon storage. Data on water, soil, and air temperature parameters were collected across the four study locations. Station 1 exhibited the highest carbon uptake, potentially due to temperatures more favorable for mangrove growth (20-28°C) (Farhaby et al. 2020). Soil and water pH varied from 6-7.1 and 7.37-8.03, respectively, whereas Dewiyanti et al. (2021) have highlighted pH values of 6-7 to be suitable for mangrove growth. Notably, the measured salinity values fell outside the range considered suitable for optimal mangrove growth (23.33-26.33).

The size of mangrove trees is another critical factor influencing biomass and carbon stocks. Older stands have a higher potential for soil carbon storage due to the accumulation of organic matter in sediments (Arif et al. 2017). As evidenced by Figure 2, the majority of mangroves in the study, especially Sampang and Pamekasan districts, possess a DBH of less than 10 cm, suggesting a relatively young stand compared to areas with larger DBH values (Hidayah et al. 2022). This younger stand structure likely contributes to the lower overall carbon stock. Species composition and stand density are also key determinants of carbon stock density (Kauffman et al. 2020). Station 1, dominated by *A. marina* and *S. alba* (with the largest average DBH and high IVI value according to Tables 3 and 4), exhibited the highest carbon stock (Figure 3). Conversely, station 4, containing a mix of three species (*A. marina*, *R. stylosa*, and *S. alba*), had a lower estimated carbon stock. This is different from the research of Purwanto et al. (2021) in the Pangarengan mangrove forest, Cirebon, Indonesia, which shows that carbon stocks on multispecies land are higher than on monospecies land.

In conclusion, a study on mangrove areas on the Southern coast of Madura Island, East Java Province, found an average stock of 42.605 tons/ha and an estimated carbon sequestration value ranging from an average of 1.5625 tons/ha. These values fall within the range set by IPCC for tropical wet regions (8.7-384 tons/ha). Among the three existing species (*A. marina*, *R. stylosa*, and *S. alba*), *R. stylosa* had the highest IVI (111.91%). The dominating stands across the stations were young mangroves with DBH less than 10 cm (an average of 80% for *A. marina*, 98% for *R. stylosa*, and 63% for *S. alba*). The dominance of young mangrove stands suggests the importance of stand maturity for enhancing carbon storage potential in this area.

REFERENCES

Ahmed S, Sarker SK, Friess DA, Kamruzzaman M, Jacobs M, Islam MA, Alam MA, Suvo MJ, Sani MNH, Dey T, Naabeh CSS, Pretzsch H. 2022. Salinity reduces site quality and mangrove forest functions from monitoring to understanding. Sci Total Environ 853: 158662. DOI: 10.1016/j.scitotenv.2022.158662.

Alimbon JA, Manseguiao MRS. 2021. Species composition, stand characteristics, aboveground biomass, and carbon stock of mangroves in Panabo Mangrove Park, Philippines. Biodiversitas 22 (6): 3130-3137. DOI: 10.13057/biodiv/d220615.

Arif AM, Guntur G, Ricky AB, Novianti P, Andik I. 2017. Mangrove ecosystem C-stocks of Lamongan, Indonesia and its correlation with forest age. Res J Chem Environ 21 (8): 1-9.

Azahra NS, Sanini TM, Suryanda A. 2020. Karakteristik Tempat Persebaran *Rhizophora stylosa*. Pendidikan Biologi, Fakultas MIPA, Universitas Negeri Jakarta, Jakarta. [Indonesian]

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

Clough BF, Scott K. 1989. Allometric relationships for estimating aboveground biomass in six mangrove species. For Ecol Manag 27: 117-127. DOI: 10.1016/0378-1127(89)90034-0.

Cui X, Liang J, Lu W, Chen H, Liu F, Xu F, Luo Y, Lin G. 2018. Stronger ecosystem carbon sequestration potential of mangrove wetlands with respect to terrestrial forests in subtropical China. Agric For Meteorol 249 (15): 71-80. DOI: 10.1016/j.agrformet.2017.11.019.

Dali GLA. 2023. Litter production in two mangrove forests along the coast of Ghana. Heliyon 9: e17004. DOI: 10.1016/j.heliyon.2023.e17004.

Damastuti E, van Wesenbeeck BK, Leemans R, de Groot RS, Silvius MJ. 2023. Effectiveness of community-based mangrove management for coastal protection: A case study from Central Java, Indonesia. Ocean Coast Manag 238: 106498. DOI: 10.1016/j.ocecoaman.2023.106498.

Dayathilake DDTL, Lokupitiya E, Wijeratne VPIS. 2020. Estimation of aboveground and below-ground carbon stocks in urban freshwater wetlands of Sri Lanka. Carbon Balance Manag 15: 17. DOI: /10.1186/s13021-020-00152-5.

Dewanti LPP, Subagiyo, Wijayanti DP. 2020. Analysis of biomass and stored carbon stock in mangrove forest area, Taman Hutan Raya Ngurah Rai Bali. Saintek Perikanan: Indonesian J Fish Sci Technol 16 (3): 219-224. DOI: 10.14710/ijfst.16.3.%p.

Dewiyanti I, Darmawi D, Muchlisin ZA, Helmi TZ, Imelda I, Defira CN. 2021. Physical and chemical characteristics of soil in mangrove ecosystem based on differences habitat in Banda Aceh and Aceh Besar. IOP Conf Ser: Earth Environ Sci 674: 012092. DOI: 10.1088/1755-1315/674/1/012092.

Easteria G, Imran Z, Yulianto G. 2022. Carbon stock estimation of rehabilitated mangrove in Harapan and Kelapa Island, Seribu Island National Park, Jakarta. Jurnal Ilmu Teknologi Kelautan Tropis 14 (2): 191-204. DOI: 10.29244/jitkt.v14i2.39861.

Farhaby AM, Safitri Y, Wilanda M. 2020. Kajian awal kondisi kesehatan hutan mangrove di Desa Mapur Kabupaten Bangka. Samakia Jurnal Ilmu Perikanan 11 (2): 108-117. DOI: 10.35316/jsapi.v11i2.789. [Indonesian]

Fatma LY, Jumari J, Utami S. 2018. Keanekaragaman *Dioscorea* spp. dan habitatnya di Kabupaten Kudus, Jawa Tengah. Bioma 20 (1): 17-24. DOI: 10.14710/bioma.20.1.17-24. [Indonesian]

Gevana DT, Im S. 2016. Allometric models for *Rhizophora stylosa* Griff. in dense monoculture plantations in the Philippines. Malays For 79 (1 & 2): 39-53.

Hanggara BB, Murdiyarso D, Ginting YRS, Widha YL, Panjaitan GY, Lubis AA. 2021. Effects of diverse mangrove management practices on forest structure, carbon dynamics and sedimentation in North Sumatra, Indonesia. Estuar Coast Shelf Sci 259: 107467. DOI: 10.1016/j.ecss.2021.107467.

Hickmah N, Maslukah L, Wulandari SY, Sugianto DN, Wirsatriya A. 2021. Kajian stok karbon organik dalam sedimen di area vegetasi mangrove Karimunjawa. Indones J Oceanogr 3 (4): 88-95. DOI: 10.14710/ijoce.v3i4.12494. [Indonesian]

Hidayah Z, Rachman HA, As-Syakur AR. 2022. Mapping of mangrove forest and carbon stock estimation of east coast Surabaya, Indonesia. Biodiversitas 23 (9): 4826-4837. DOI: 10.13057/biodiv/d230951.

Hidayah Z, Rosyid DM, Armono HD. 2015. GIS application in monitoring distribution of mangrove ecosystem of Southern Madura. Ecol Environ Conserv 21 (1): 487-493.

Ickowitz A, Lo MGY, Nurhasan M, Maulana AM, Brown BM. 2023. Quantifying the contribution of mangroves to local fish consumption in Indonesia: A cross-sectional spatial analysis. Lancet Planet Health 7: e819-e830. DOI: 10.1016/S2542-5196(23)00196-1.

Kauffman JB, Adame MF, Arifanti VB, Schile-Beers LM, Bernardino AF, Bhomia RK, Donato DC, Feller IC, Ferreira TO, Garcia MDCJ, MacKenzie RA, Megonigal JP, Murdiyarso D, Simpson L, Trejo HH. 2020. Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. Ecol Monogr 90 (2): e01405. DOI: 10.1002/ecm.1405.

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

Li SB, Chen PH, Huang JS, Hsueh ML, Hsieh LY, Lee CL, Lin HJ. 2018. Factors regulating carbon sinks in mangrove ecosystems. Glob Change Biol 24 (9): 4195-4210. DOI: 10.1111/gcb.14322.

Mori N, Chang CW, Inoue T, Akaji Y, Hinokidani K, Baba S, Takagi M, Mori S, Koike H, Miyauchi M,Suganuma R, Sabunas A, Miyashita T, Shimura T. 2022. Parameterization of mangrove root structure of *Rhizophora stylosa* in coastal hydrodynamic model. Front Built Environ 7: 782219. DOI: 10.3389/fbuil.2021.782219.

Muhsoni FF, Pi S. 2014. Pemetaan Kerusakan Mangrove di Madura dengan Memanfaatkan Citra dari Google Earth dan Citra LDCM. Persembahan Program Studi Ilmu Kelautan untuk Maritim Madura. UTM Press, Madura. [Indonesian]

Muzaki FK, Giffari A, Saptarini D. 2017. Community structure of fish larvae in mangroves with different root types in Labuhan Coastal Area, Sepulu-Madura. AIP Conf Proc 1854 (1): 020025. DOI: 10.1063/1.4985416.

Nauta J, Lammers C, Lexmond R, Christianen MJA, Borst A, Lamers LPM, van Lavieren H, Naipal S, Govers LL. 2023. Habitat complexity drives food web structure along a dynamic mangrove coast. Mar Poll Bull 196: 115597. DOI: 10.1016/j.marpolbul.2023.115597.

Ningtyas SRA, Mu'ali AYF, Putri DNAR, Silaningtyas NW, Tsabita FA, Aprianto MK, Sari SP, Fauziyyah MD, Nugraheni RS, Juniati SD, Isa MN, Nofitasari H, Sutarno, Sugiyarto, IndrawanM, Yap CK, Budiharta S, Setyawan AD. 2023. Estimation of aboveground carbon stock based on mangrove zones in Ijo River Estuary, Ayah Village, Kebumen, Indonesia. Indo Pac J Ocean Life 7: 148-155. DOI: 10.13057/oceanlife/o070204

Nur AAI, Arifiani KN, Ramadhandi AR, Sabrina AD, Nugroho GD, Kusumaningrum L, Ramdhun D, Bao TQ, Yap CK, Budiharta S, Setyawan AD. 2022. Estimation of aboveground biomassand carbon stock in Damas Beach, Trenggalek District, East Java, Indonesia. Indo Pac J Ocean Life 6: 80-86. DOI: 10.13057/oceanlife/o060203

Nwankwo C, Tse AC, Nwankwoala HO, Giadom FD, Acra EJ. 2023. Below ground carbon stock and carbon sequestration potentials of mangrove sediments in Eastern Niger Delta, Nigeria: Implication for climate change. Sci Afr 22: e01898. DOI: 10.1016/j.sciaf.2023.e01898.

Prihantini CI, Fawaid A, Hasbiadi. 2022. Wisata alam kopi mangrove di Desa Lembung, Kabupaten Pamekasan, Madura: Peluang dan tantangan dalam optimalisasi upaya menambah nilai biji mangrove. Agrikultura 33 (33): 379-389. DOI: 10.24198/agrikultura.v33i3.42161. [Indonesian]

Purwanto RH, Mulyana B, Sari PI, Hidayatullah MF, Marpaung AA, Putra ISR, Putra AD. 2021. The environmental services of Pangarengan mangrove forest in Cirebon, Indonesia: conserving biodiversity and storing carbon. Biodiversitas 22: 5609-5616. DOI: 10.13057/biodiv/d221246.

Rosadi A, Ario R, Pribadi R. 2018. Structure and composition of mangrove vegetation in Sampang Regency, Madura Island, East Java Province. J Mar Res 7 (3): 212-218. DOI: 10.14710/jmr.v7i3.25911.

Sarker SK, Reeve R, Paul NK, Matthiopoulos J. 2019. Modelling spatial biodiversity in the world's largest mangrove ecosystem-The Bangladesh Sundarbans: A baseline for conservation. Divers Distrib 25 (5): 729-742. DOI: 10.1111/ddi.12887.

Shiau YJ, Chiu CY. 2020. Biogeochemical processes of C and N in the soil of mangrove forest ecosystems. Forests 11 (5): 492. DOI: 10.3390/F11050492.

Sobhani P, Danehkar A. 2023. Spatial-temporal changes in mangrove forests for analyzing habitat integrity: A case of hara biosphere Reserve, Iran. Environ Sustain Indic 20: 100293. DOI: 10.1016/j.indic.2023.100293.

Srikanth S, Lum SKY, Chen Z. 2016. Mangrove root: Adaptations and ecological importance. Trees 30: 451-465. DOI: 10.1007/s00468-015-1233-0.

Sugiatmo, Poedjirahajoe E, Pudyatmoko S, Purwanto RH. 2023. Carbon stock at several types of mangrove ecosystems in Bregasmalang, Central Java, Indonesia. Biodiversitas 24: 182-191. DOI: 10.13057/biodiv/d240122

Sutaryo D. 2009. Penghitungan Biomassa Sebuah Pengantar untuk Studi karbon dan Perdagangan Karbon. Wetlands International Programme, Bogor. [Indonesian]

Xu K, Su Y, Liu J, Hu T, Jin S, Ma Q, Zhai Q, Wang R, Zhang J, Li Y, Liu H, Guo Q. 2020. Estimation of degraded grassland aboveground biomass using machine learning methods from terrestrial laser scanning data. Ecol Indic 108: 105747. DOI: 10.1016/j.ecolind.2019.105747.

Zhou X, Hu C, Wang Z. 2023. Distribution of biomass and carbon content in estimation of carbon density for typical forests. Glob Ecol Conserv 48: e02707. DOI: 10.1016/j.gecco.2023.e02707.

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 25-36

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140104

Ethnobotanical study of medicinal plants used by local communities in the Upper Bengawan Solo River, Central Java, Indonesia

FURQON DARMA NURCAHYO[1], HAFIZH MUHAMAD ZEN[1], HANIFA SABILA RAHMA[1], ADITYA TRIYANTO[2,3], AHMAD YASA[4], DARLINA MD. NAIM[5], AHMAD DWI SETYAWAN[1,6,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia
[3]Biodiversity Study Club, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia
[4]Faculty of Medicine, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia
[5]School of Biological Sciences, Universiti Sains Malaysia. 1112, Persiaran Sains, 11800 Gelugor, Pulau Pinang, Malaysia
[6]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuscript received: 18 November 2023. Revision accepted: 8 April 2024.

Abstract. *Nurcahyo FD, Zen HM, Rahma HS, Triyanto A, Yasa A, MD Naim D, Setyawan AD. 2024. Ethnobotanical study of medicinal plants used by local communities in the Upper Bengawan Solo River, Central Java, Indonesia. Intl J Bonorowo Wetlands 14: 25-36.* Medicinal plants are all plants with properties that can cure certain diseases. World Health Organization (WHO) states that more than 80% of the world's population still uses medicinal plants, including the communities living around Bengawan Solo River, Indonesia. This river is the longest river in Java, and it is significant in maintaining biodiversity, including the surrounding fauna and flora, particularly medicinal plants. This study aims to explore the diversity and uses of medicinal plants in three subdistricts along the Upper Bengawan Solo River (Sidodadi, Ngringo and Palur), focusing on documentation and understanding of medicinal plants used by local communities. Ninety informants, including 5 key and 85 general respondents (aged 21-78), were selected using purposive and snowball samplings. Semi-structured interviews and participatory observations gathered ethnobotanical data to be presented descriptively and analyzed quantitatively, including demographics, use values and informant consensus factor. Villagers in the three sub-districts utilize 88 medicinal plant species for various ailments. The majority of medicinal practices rely on traditional methods and oral transmission for knowledge transfer. Leaves (51.1%) and fruits (25%) are the primary plant parts used, processed mainly through boiling (68.5%) and direct consumption (23.9%). Boiling is the most preferred method for combining multiple plants since it is considered the easiest and most cost-effective method. *Zingiber officinale* Roscoe, *Alpinia galanga* (L.) Wild., and *Curcuma longa* L. are the most commonly utilized plants. This study highlights the importance of preserving traditional medicinal plant knowledge along the Bengawan Solo River to inform conservation efforts, support community health, and guide policy for mutual benefits and biodiversity conservation.

Keywords: Informant consensus factor, local knowledge, medicinal plants, use value

INTRODUCTION

The region under ASEAN (the Association of Southeast Asian Nations) is among the areas with the highest biological diversity on Earth. Within the ASEAN region, three countries are among the world's seventeen megadiversity countries, four countries are among the twenty-five biodiversity hotspots, and it has the highest coral reef diversity globally. Numerous endemic species of plants and animals occur in the region due to biogeographic, geological, climatic, and ecological conditions. Indonesia, one of the ten nations constituting ASEAN, is a politically and economically diverse regional entity. Indonesia is the most biologically rich country in the region and ranks second in terms of global biodiversity after Brazil (Keong 2015).

Biodiversity is vital to the welfare of people worldwide because it plays a major role in human development and well-being. One important role of biodiversity is the medicinal uses generated from a large diversity of plant species. Medicinal plants refer to plant species utilized for medicinal purposes in various contexts, such as food, condiments, perfumes, and cosmetics, in both allopathic and traditional medical systems. According to Astutik et al. (2019), medicinal plants are one of the most valuable non-timber forest products since they significantly improve access to cheap healthcare and livelihood stability. A recent research by the World Health Organization (WHO) estimates that over 80% of the world's population still receives basic medical treatment from medicinal plants. Several communities still depend on medicinal plants since they are thought to be able to treat both minor and severe illnesses (Fitrianti and Partasamita 2020).

Ethnobotany is the scientific study of traditional knowledge and customs of people in relation to the medicinal, religious, and other uses of plants, encompassing the relationship between plants, cultural beliefs, and conservation practices in accordance with the knowledge of local communities (Panigrahi et al. 2021). This includes the utilization of medicinal plants for treating various diseases, their classification, and management. The reliance on plant-based medicine underscores the importance of ethnobotany as a discipline examining the intricate relationship between people and plants.

Medicinal ethnobotany is a specialized field within ethnobotany that focuses on the use of plants for healthcare (Cunningham 2001). This field plays a vital role in medical science since natural ingredients have long been used as sources of medicinal drugs, for example, salicylates (willow bark), ergotamine (infected rye), quinine (*Cinchona*), and *Digitalis* (foxglove). Medicinal ethnobotany can be used as a starting point for bioprospecting research on medicinal plants, which are promising for drug discovery and development to be used in biotechnology and pharmaceutical industries (Rintelen et al. 2017). Nonetheless, finding drugs from natural sources is complex and involves molecular, biological, phytochemical, and botanical methods (Sharma et al. 2019).

For ages, tribal and folk societies worldwide have relied on medicinal plants to meet their basic medical needs (Kumar 2020). The conventional therapeutic methodology, rooted in the utilization of botanical resources by indigenous societies, has been consistently upheld and transmitted intergenerationally, flowing from the elder members to the younger ones (Awan et al. 2021). The ethnobotanical knowledge of medicinal plants also exists in the communities living along the Bengawan Solo River, Central Java Province, Indonesia. The Bengawan Solo River Basin is one of Indonesia's largest river basins, characterized by high biodiversity, particularly in medicinal plants. The communities around the Bengawan Solo River use the riverbanks to cultivate medicinal plants with potential in traditional medicine and for environmental conservation efforts (Susilowati and Puspitasari 2023). Further, the traditional market here also facilitates the trade of medicinal plant materials between farmers and users (Ammar et al. 2021).

Despite the abundance of medicinal plant resources in Bengawan Solo River Basin, concerns arise regarding the people's knowledge, specifically regarding its sustainability in cultivation and usage. Therefore, it is necessary to conduct an ethnobotany study to ascertain the knowledge and utilization of plants, especially therapeutic plants. This study aims to gather information on the types of medicinal plants used by the people of three districts along the Bengawan Solo River. We expected the result of this study might be useful for the conservation efforts of traditional medicinal plants, support the development of sustainable policies in natural resource management, and provide guidance for educational programs and outreach to the community regarding the prudent and sustainable use of medicinal plants, thereby fostering environmental stewardship and community well-being.

MATERIALS AND METHODS

Study period and area

The study was conducted from 23 October 2023 to 5 November 2023 in three villages of Central Java, Indonesia, i.e., (i) Sidodadi Village, Masaran Sub-district, Sragen District at 7°28'57.6" S and 110°54'07.9" E; (ii) Ngringo Village, Jaten Sub-district, Karanganyar District at 7°33′24.8″ S and 110°52′23.8″ E; and (iii) Palur Village, Mojolaban Sub-district, Sukoharjo District at 7°34′19.6″ S and 110°51′36.7″E. These three villages were located in the river basin of the Upper Bengawan Solo River (Figure 1), and are typical of rural areas with agriculture and labor as predominant professions (Subroto and Ningrum 2020; pers. comm.).

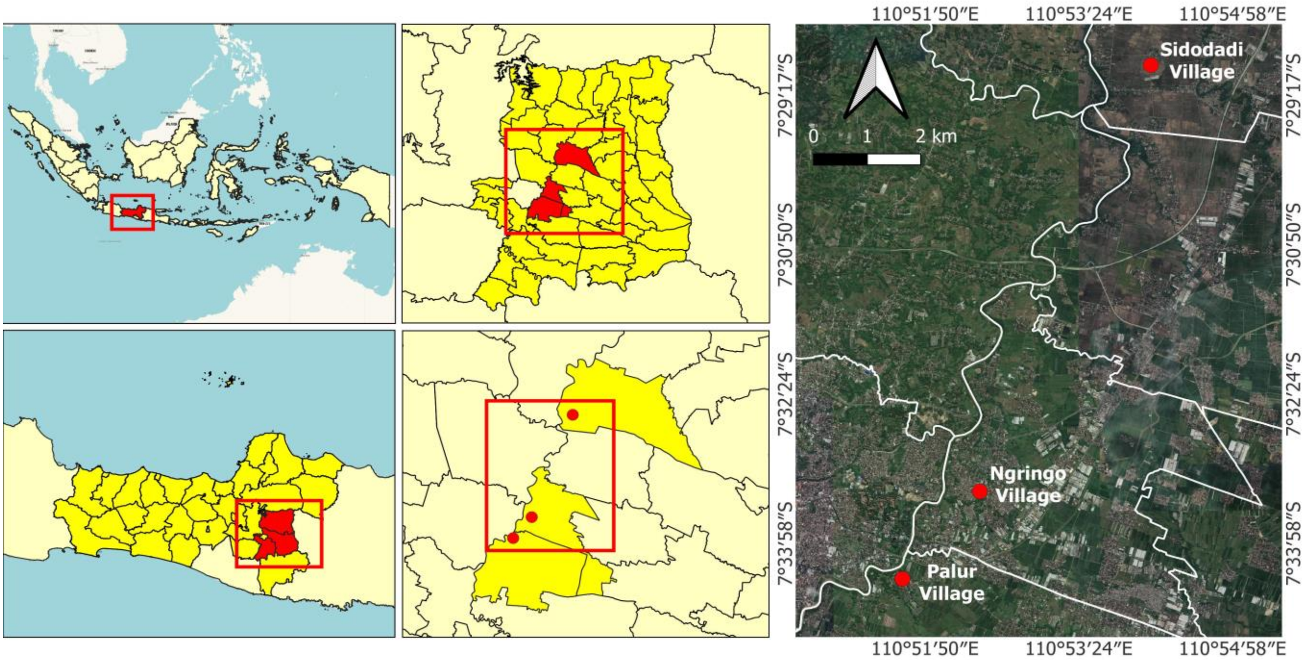


Figure 1. Map of the study area along Bengawan Solo River, Central Java, Indonesia, indicating the sampling sites in Sidodadi Village, Ngringo Village, and Palur Village

Data collection

Information on traditional uses of plants was collected from respondents consisting of 5 key informants and 85 general respondents. The snowball sampling was used to gather deeper information from key informants. Key informants consisted of folk healers (2 people), members of the family welfare education community (PKK) (2 people), and heads of the village (1 person). Key informants are individuals with specialized knowledge or experience related to the research topic. They are selected because of their expertise or experience, which can provide valuable insights into the study. Key informants are typically involved in in-depth interviews or group discussions to gain a deeper understanding of the topic being researched. Meanwhile, general respondents are individuals or groups who provide responses or information in the research. They may need to gain specialized knowledge or experience about the research topic, but they are invited to participate in surveys, interviews, or observations as part of the study. The purpose of general respondents is to provide data that can be analyzed to understand trends or patterns in the population being studied.

Interviews were done to collect information on the diversity and usage of medicinal plants while adhering to established ethnobotanical criteria. During the interview process, recording and taking notes were carried out. Information on the uses and diversity of medicinal plants was obtained from interviews using the in-depth, semi-structured, and participative observation methods, following the existing ethnobotanical guidelines, plant part used, cured diseases, how to process, how to apply, how/source to obtain, information obtained from where and since when consumption methods are presented descriptively in tables and graphs, analyzed in terms of frequency and percentage, and then presented descriptively. The scientific name of each species identified was crosschecked with online databases, including Plant of the World Online (https://powo.science.kew.org/) and GBIF (Global Biodiversity Information Facility) (https://www.gbif .org/)

Data analysis

Data was analyzed qualitatively and quantitatively. Qualitative analysis used descriptive statistics by grouping plants based on their use category (Miles and Huberman 2019). Quantitative analyses were conducted to investigate the importance of each species using two indices: Use Value (UV) and Informant Consensus Factor (ICF).

Use Value (UV)

The relative importance of each plant species known locally for herbal medicine is expressed as Use Value (UV) (Kefifa et al. 2020). UV is calculated using the following formula.

$$UV = \sum \frac{U}{N}$$

Where: The value of a species is UV, while the number of use reports cited by each informant is U, and the total number of informants interviewed for a plant is n.

Informant Consensus Factor (ICF)

ICF was used to see the level of agreement among the respondents (Adam et al. 2020). In term of use of the plant to treat particular disease, Informant Consensus Factor (ICF) was calculated using the following formula.

$$ICF = \frac{[Nur - Nt]}{Nur - 1}$$

Where: Nur is the number of reports of use for a particular disease category, and Nt is the number of taxa used for a disease category by all informants.

RESULTS AND DISCUSSION

Demographic profile of the respondents

A total of 90 informants, consisting of 5 key informants and 85 general respondents, 66 women and 24 men, were interviewed (Table 1). All respondents are of Javanese ethnicity. Based on age, the respondents were divided into 5 categories: <20, 21-30, 31-40, 41-50, 51-60, 61-70, and >70 years. Of the 90 respondents, 16 were elementary school graduates, 18 were junior high school graduates, 38 were high school graduates, and 18 were university graduates. The majority of the respondents from this study were women; this is because women mostly conducted household activities, and they often use traditional ingredients that generally have medicinal properties, such as *Salam* leaves (*Syzygium polyanthum*). Because of this, most female respondents know more about the use and benefits of medicinal plants than male respondents (Razafindraibe et al. 2013).

Diversity of medicinal plants

The villagers in the studied areas in Sidodadi Village, Ngringo Sub-district, and Palur Sub-district utilize 88 species of medicinal plants belonging to 76 genera and 44 families to treat diseases (Table 2, Figure 2). According to the results of the interviews, most of the population still uses medicinal plants as an alternative medicine. Some medicinal plants are cultivated in yards and community gardens or purchased elsewhere. The villagers use various parts of medicinal plants such as rhizomes/roots, leaves, tubers, flowers, and fruits. Compounds found in medicinal plants have antimicrobial and anticancer effects (Kaushik et al. 2020).

Table 1. The demographic structure of the respondents

Parameter	Classification	Frequency	Percentage (%)
Gender	Male	24	27
	Female	66	73
Age	< 20	1	1
	21-30	8	9
	31-40	13	14
	41-50	20	22
	51-60	29	32
	61-70	14	16
	>70	5	6
Education	Elementary School	16	18
	Junior High School	18	20
	Senior High School	38	42
	University	18	20

Table 2. Medicinal plants used by local communities in the Bengawan Solo River basin (Sidodadi, Ngringo, and Palur Villages), Central Java, Indonesia

Scientific name	**Local name**	**Family**	**Growth form**	**Part used**
Allium sativum L.	*Bawang*	Amaryllidaceae	Herbaceous	Tuber, leaves
Aloe vera (L.) Burm.f.	*Lidah Buaya*	Asphodelaceae	Herbaceous	Entire Part
Alpinia galanga (L.) Wild.	*Lengkuas*	Zingiberaceae	Herbaceous	Rhizome
Alternanthera littoralis P.Beauv.	*Krokot Putih*	Amaranthaceae	Herbaceous	Fruit
Andrographis paniculata (Burm.fil.) Nees	*Sambiloto*	Acanthaceae	Herbaceous	Leaves
Annona muricata L.	*Sirsak*	Annonaceae	Tree	Leaves
Annona squamosa L.	*Srikaya*	Annonaceae	Tree	Leaves
Anredera cordifolia (Ten.) Steenis	*Binahong*	Basellaceae	Shrub	Leaves
Apium graveolens L.	*Seledri*	Apiaceae	Herbaceous	Leaves
Artocarpus altilis (Parkinson) Fosberg	*Sukun*	Moraceae	Tree	Fruit
Averrhoa bilimbi L.	*Belimbing Wuluh*	Oxalidaceae	Tree	Fruit
Averrhoa carambola L.	*Belimbing*	Oxalidaceae	Tree	Fruit
Azadirachta indica A.Juss.	*Nimba*	Meliaceae	Tree	Leaves
Biancaea sappan (L.) Tod.	*Kayu Secang*	Fabaceae	Tree	Wood
Boesenbergia rotunda (L.) Mansf.	*Temu Kunci*	Zingiberaceae	Herbaceous	Rhizome, leaves
Carica papaya L.	*Pepaya*	Caricaceae	Herbaceous	Fruit, leaves
Cinnamomum verum J. Presl	*Kayu Manis*	Lauraceae	Tree	Wood
Citrus × *aurantiifolia* (Christm.) Swingle	*Jeruk Nipis*	Rutaceae	Tree	Fruit, leaves
Citrus hystrix DC.	*Jeruk*	Rutaceae	Tree	Fruit, leaves
Citrus × *limon* (L.) Osbeck	*Jeruk Lemon*	Rutaceae	Tree	Fruit, leaves
Clitoria ternatea L.	*Telang*	Fabaceae	Shrub	Flower
Coriandrum sativum L.	*Ketumbar*	Apiaceae	Herbaceous	Seed
Cosmos caudatus Kunth	*Kenikir*	Asteraceae	Herbaceous	Leaves
Cucumis sativus L.	*Timun*	Cucurbitaceae	Shrub	Fruit
Cuminum cyminum L.	*Jinten*	Apiaceae	Herbaceous	Seed
Curcuma aeruginosa Roxb.	*Temuireng*	Zingiberaceae	Herbaceous	Rhizome
Curcuma longa L.	*Kunyit*	Zingiberaceae	Herbaceous	Rhizome
Curcuma xantorhiza Roxb.	*Temulawak*	Zingiberaceae	Herbaceous	Rhizome
Curcuma zedoaria (Christm.) Roscoe	*Kunyit Putih*	Zingiberaceae	Herbaceous	Rhizome
Cymbopogon citratus (DC.) Stapf	*Serai*	Poaceae	Herbaceous	Stem
Dracaena angustifolia (Medik.) Roxb.	*Suji Andong*	Asparagaceae	Shrub	Leaves
Eclipta prostrata (L.) L.	*Urang-Aring*	Asteraceae	Herbaceous	Leaves
Elephantopus scaber L.	*Tapak Liman*	Asteraceae	Herbaceous	Leaves
Eleutherine bulbosa (Mill.) Urb.	*Bawang Dayak*	Iridaceae	Herbaceous	Leaves
Erythrina variegata L.	*Dadap*	Fabaceae	Tree	Leaves
Ficus elastica Roxb.	*Karet Kebo*	Moraceae	Tree	Leaves
Garcinia mangostana L.	*Manggis*	Clusiaceae	Tree	Fruit
Gynura procumbens (Lour.) Merr	*Sambung Nyawa*	Asteraceae	Herbaceous	Leaves
Leuenbergeria bleo (Kunth) Lodé	*Tujuh Bilah*	Cactaceae	Herbaceous	Leaves
Jasminum sambac (L.) Aiton	*Melati*	Oleaceae	Shrub	Flower
Jatropha gossypiifolia L.	*Jarak Tintir*	Euphorbiaceae	Shrub	Leaves
Kaempferia galanga L.	*Kencur*	Zingiberaceae	Herbaceous	Rhizome
Lavandula sp.	*Lavender*	Lamiaceae	Herbaceous	Flower
Leucaena leucocephala (Lam.) de Wit	*Petai Cina*	Fabaceae	Tree	Fruit
Malus domestica (Suckow) Borkh.	*Apel Hijau*	Rosaceae	Tree	Fruit
Mangifera indica L.	*Mangga*	Anacardiaceae	Tree	Leaves
Manihot esculenta Crantz	*Singkong*	Euphorbiaceae	Shrub	Leaves
Manilkara zapota (L.) P.Royen	*Sawo*	Sapotaceae	Tree	Fruit
Mentha ×piperita L.	*Mint*	Lamiaceae	Herbaceous	Leaves
Momordica charantia L.	*Pare*	Cucurbitaceae	Shrub	Fruit
Morinda citrifolia L.	*Mengkudu*	Rubiaceae	Tree	Fruit
Moringa oleifera Lam.	*Kelor*	Moringaceae	Tree	Leaves
Morus alba L.	*Murbei*	Moraceae	Tree	Fruit
Muntingia calabura L.	*Kersen*	Elaeocarpaceae	Tree	Fruit
Musa paradisiaca L.	*Pisang*	Lamiaceae	Herbaceous	Leaves
Ocimum basilicum L.	*Kemangi*	Lamiaceae	Herbaceous	Leaves
Olea europaea L.	*Zaitun*	Oleaceae	Tree	Fruit
Orthosiphon aristatus (Blume) Miq.	*Kumis Kucing*	Lamiaceae	Herbaceous	Leaves

Panax ginseng C.A.Mey.	*Gingseng*	Araliaceae	Herbaceous	Rhizome
Pandanus amaryllifolius Roxb. ex Lindl.	*Pandan*	Pandanaceae	Herbaceous	Leaves
Peperomia pellucida (L.) Kunth	*Sirih Cina*	Piperaceae	Herbaceous	Leaves
Persea americana Mill.	*Alpukat*	Lauraceae	Tree	Leaves
Phaleria macrocarpa (Scheff.) Boerl.	*Mahkota Dewa*	Thymelaeaceae	Tree	Flower
Phyllanthus buxifolius (Blume) Müll.Arg.	*Seligi*	Phyllanthaceae	Shrub	Leaves
Phyllanthus urinaria L.	*Meniran*	Phyllanthaceae	Herbaceous	Leaves
Physalis angulata L.	*Ciplukan*	Solanaceae	Herbaceous	Fruit
Piper betle L.	*Sirih Hijau*	Piperaceae	Herbaceous	Leaves
Piper ornatum N.E.Br.	*Sirih Merah*	Piperaceae	Herbaceous	Leaves
Piper retrofractum Vahl	*Cabe Puyang*	Piperaceae	Herbaceous	Leaves
Platycerium bifurcatum (Cav.) C.Chr.	*Tanduk Rusa*	Polypodiaceae	Herbaceous	Leaves
Portulaca oleracea L.	*Krokot*	Portulacaceae	Herbaceous	Fruit
Psidium guajava L.	*Jambu Biji*	Myrtaceae	Tree	Leaves
Punica granatum L.	*Delima*	Lythraceae	Shrub	Fruit
Ruellia tuberosa L.	*Pletekan*	Lamiaceae	Herbaceous	Leaves
Salacca zalacca (Gaertn.) Voss	*Salak*	Arecaceae	Shrub	Fruit
Sauropus androgynus L.	*Katuk*	Phyllanthaceae	Herbaceous	Leaves
Smallanthus sonchifolius (Poepp. & Endl.) H.Rob.	*Daun Insulin*	Asteraceae	Herbaceous	Leaves
Strobilanthes crispa (L.) Blume	*Keji Beling*	Achantaceae	Herbaceous	Leaves
Swietenia mahagoni (L.) Jacq.	*Mahoni*	Meliaceae	Tree	Fruit
Syzygium polyanthum (Wight) Walp.	*Salam*	Myrtaceae	Tree	Leaves
Tamarindus indica L.	*Asam Jawa*	Fabaceae	Tree	Fruit
Tinospora cordifolia (Willd.) Miers	*Brotowali*	Menispermaceae	Shrub	Leaves
Triphasia trifolia (Burm.fil.) P.Wilson	*Jeruk Kingkit*	Rutaceae	Tree	Fruit
Vitis vinifera L.	*Anggur*	Vitaceae	Tree	Fruit
Zingiber officinale Roscoe	*Jahe*	Zingiberaceae	Herbaceous	Rhizome
Zingiber officinale var. *rubrum* Theilade	*Jahe Merah*	Zingiberaceae	Herbaceous	Rhizome
Zingiber zerumbet (L.) Roscoe ex Sm.	*Lempuyang*	Zingiberaceae	Herbaceous	Rhizome
Ziziphus mauritiana Lam.	*Bidara*	Rhamnaceae	Shrub	Leaves

According to the interviews, the villagers use many plant species as traditional medicine. *Zingiber officinale*, widely known as ginger, is the most commonly used plant. Ginger is easy to care for and grow because it has roots in rhizomes that grow quickly. According to Lestari et al. (2021), ginger can be used to treat cough and hypothermia and improve immunity. Ginger is also a widely used culinary spice that has a long history of usage in herbal remedies and medicine dating back thousands of years (Shahrajabian et al. 2019). In addition to ginger, there are other rhizomes belonging to the Zingiberaceae family that are often used by the community. *Kaempferia galanga*, known as kencur in the local language, is used to treat coughs, ulcers, and hypothermia. In some places, it is also known as fragrant ginger or sand ginger (Wang et al. 2021). *Curcuma longa*, or turmeric, can treat stomachache, acid reflux, dysmenorrhea and cough and warm the body. The plant has limited rhizomatous propagation in its natural habitat, and overexploitation and deforestation have further decreased the plant population (Subositi et al. 2020). *Curcuma xanthorrhiza* or *temulawak* can treat nausea, acid reflux, wound healing, increased immunity, appetite booster, and stomach aches. Numerous active chemicals in these plants have various biological effects (El Alami et al. 2020). *Curcuma zedoaria*, or white turmeric, treats indigestion, colds, and asthma. *Curcuma aeruginosa*, a well-known rhizomatous medicinal plant known as temuireng by local people, is used to treat vaginal discharge, stomachache, and acid reflux (Khumaida et al. 2019). *Alpinia galanga* or galangal relieves arthritis, pain relief, immunity, and indigestion. The *Z. officinale* var. *rubrum* or red ginger treats stomach ache and cough. Furthermore, some research indicates that red ginger possesses antibacterial, immunomodulatory, antihypertensive, antihyperlipidemia, and anti-hyperuricemia properties (Raising et al. 2023). *Zingiber zerumbet* or lempuyang is used in the local language to reduce fever.

Allium sativum or onion is used to treat gastric diseases. The community uses *Eleutherine bulbosa*, or *Bawang Dayak*, to treat infections, cholesterol, and hypertension. *Panax ginseng* or *Ginseng* is consumed to relieve inflammation, headaches and improve immunity. *Annona muricata* (soursop) and *Piper betle* (betel leaf) are plants frequently utilized by communities in various contexts, including traditional medicine. Soursop leaves and betel leaves play a specific role in addressing certain health conditions. Soursop leaves are believed to potentially lower blood pressure in hypertensive patients (Putri 2022), while betel leaves are recognized for their natural antibacterial properties (Afridi et al. 2021). *Aloe vera*, commonly known as *Lidah Buaya*, is widely used by communities to aid in the healing of skin wounds (Sánchez et al. 2020). Papaya (*Carica papaya*), specifically its leaves, is utilized by many people to control blood sugar levels in the body.

Furthermore, the community often uses *Ciplukan* (*Physalis angulata*) to treat asthma (Daltro et al. 2021).

Growth form and plant part used

The people in Sidodadi, Ngringo, and Palur Villages generally use traditional methods and herbal plants for treatment. The knowledge in these three villages is mostly passed down through generations and oral transmission. Medicinal plants with herbaceous growth type dominate with a total of 44, followed by trees with 31, and shrubs with 13 species (Table 2). The diversity in growth types reflects the complexity of the medicinal plant ecosystem. Shrub plants demonstrate high adaptability to various environmental conditions, while tree plants provide long-term benefits. Climber plants require support, while herbaceous plants with lower growth contribute uniquely to the diversity of medicinal plant resources. Growth forms in medicinal plants include various plant shapes and structures that can provide information about the adaptation of these plants (Fiorello 2020). Some common growth forms in medicinal plants involve morphological characteristics such as root, rhizome, leaf, and flower types. Understanding these differences is crucial for managing and conserving natural resources and their optimal utilization in traditional medicinal practices.

In terms of plant parts, the most frequently used part of the plant is the leaves, with 48.94% (Figure 3). The use of leaves as medicine become a profound phenomenon in ethnobotanical knowledge worldwide. Plant leaves are often the main focus of traditional medicine because they are rich in bioactive compounds that provide health benefits. A recent ethnobotanical study conducted by Yeung et al. (2018) provides in-depth insights into using leaves in various traditional healing practices worldwide. Various people use plant leaves to cure various diseases and maintain holistic health. For example, neem or *Azadirachta indica* are used for various medicinal purposes in India (Uzzaman 2020). In Africa, plant leaves such as moringa (*Moringa oleifera*) and *Katuk* (*Sauropus androgynus*) have an important role in traditional medicine (Moyo et al. 2015).

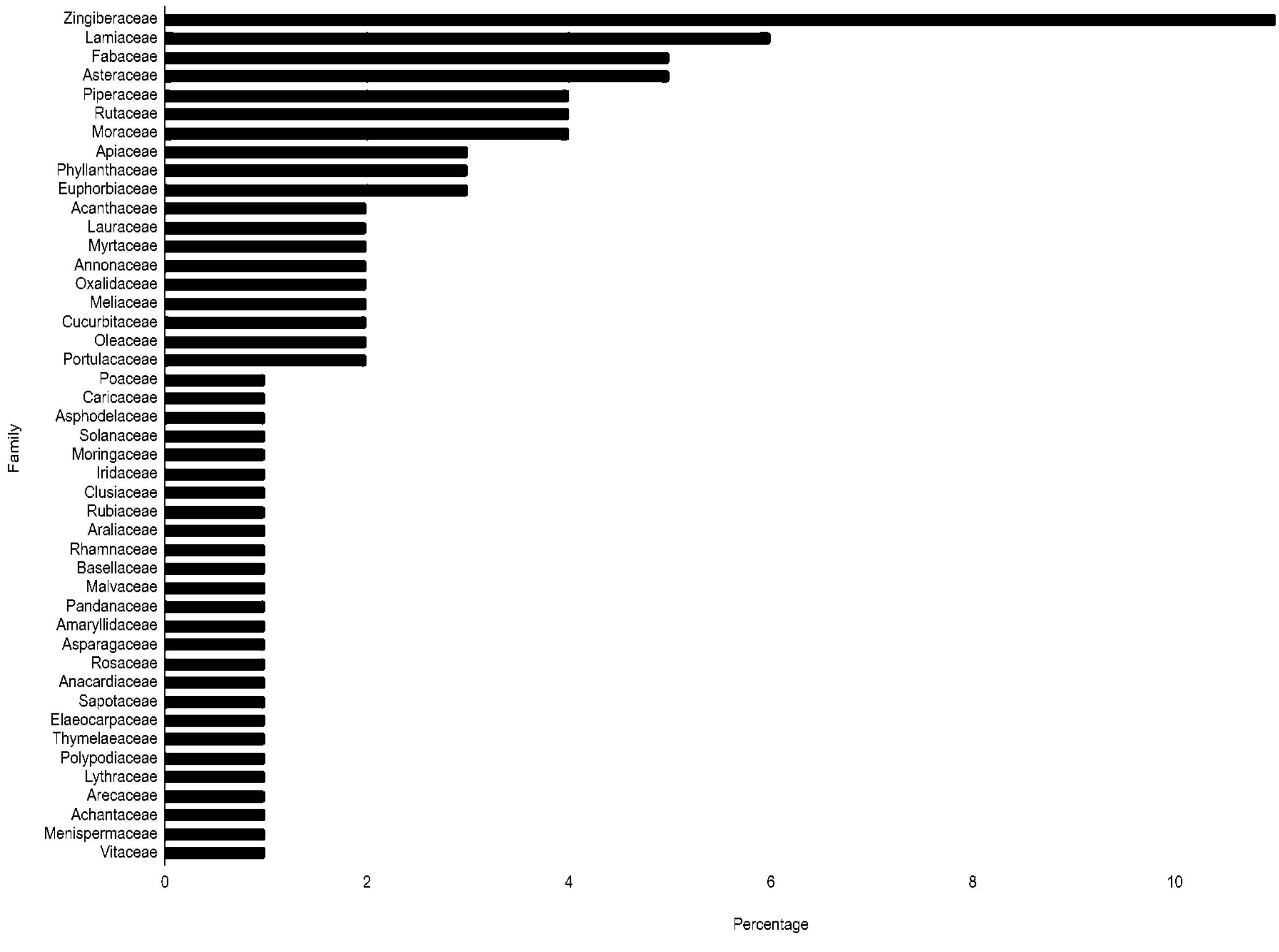


Figure 2. Family of medicinal plants used by the people of Sidodadi Village, Ngringo Village, and Palur Village, Central Java, Indonesia

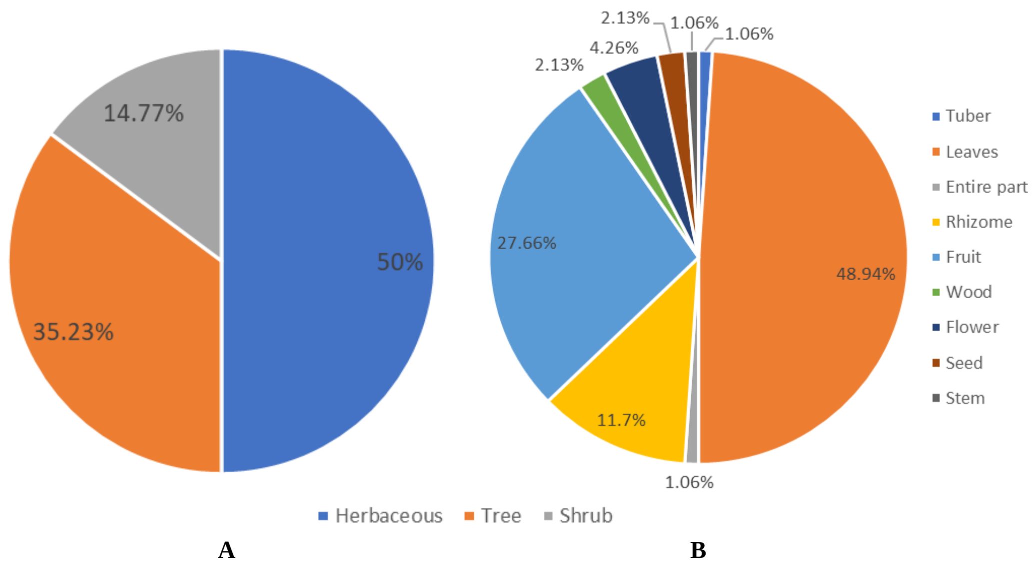


Figure 3. A. Growth form and B. Parts of medicinal plants used by the people of Sidodadi Village, Ngringo Village, and Palur Village, Central Java, Indonesia

The fruit is the second most commonly used part, accounting for 25.6%. Using fruits as part of plants in ethnobotany is closely related to preserving biodiversity, providing food sources, and being used as medicinal worldwide (Suwardi and Navia 2023). Local communities continue to utilize fruit parts of medicinal plants and fulfill the sociocultural needs and people's livelihood (Shai et al. 2020). The medicinal part of plants in the form of fruit is typically extracted to harness its essence. For example, *Citrus* × *aurantiifolia* (family Rutaceae), native to Southeast Asia, is primarily grown in tropical and subtropical climates and is mostly used as a medicine and food additive because of its fragrant aroma (Galovičová et al. 2022). Thus, the use of medicinal fruit plants in the global context of ethnobotany indicates significant potential to provide solutions in health and environmental conservation.

The next most commonly used plant part is the rhizomes at 14.4%, followed by other parts such as flowers at 4.4%, seeds at 2.2%, and entire part of plants at 1.1%. Therefore, using flowers, rhizomes, and seeds in ethnobotany globally reflects the diversity of traditional knowledge within communities regarding using plant natural resources for various purposes, ranging from food to traditional medicine worldwide (Qadir and Raja 2021). For example, the rhizome of *Z. officinale* is used to treat coughs, warm the body, and as body immunity. In the flower part, *Jasminum sambac* is used to treat inflammation (El Shiekh et al. 2021). The stem of *Cymbopogon citratus* is often used to treat diabetes and cholesterol and increase body immunity. The seed of *Coriandrum sativum* is used to treat hypertension.

Preparation and application methods

The processing methods commonly used by the community in the studied area are boiling (68.5%) and direct consumption (23.9%) (Figure 4). Boiling is widely used in the preparation of herbal medicine because this process enhances the extraction of active ingredients from medicinal plants, thereby increasing the efficacy of the medicine (Ssenku et al. 2022). In addition to boiling, many people in the studied area also use the direct consumption method, which requires no processing or tools, making it the simplest way. Plants consumed directly are usually fruits like oranges, green apples, and starfruit, which can be eaten without processing. However, there are also methods like crushing/grinding, as seen in the processing of *dadap* leaves (*Erythrina variegata*) for treating fever, and other methods such as burning, smearing, etc.

Rural communities employ various methods for processing medicinal plants, with boiling being the most common. People experimented with various plants to understand their biological effects. Through these trials, knowledge about specific plants and their application methods for particular disorders has been passed down through generations via oral transmission. Eventually, the information on medicinal plants was scientifically recorded in ethnobotanical field studies (Süntar 2020).

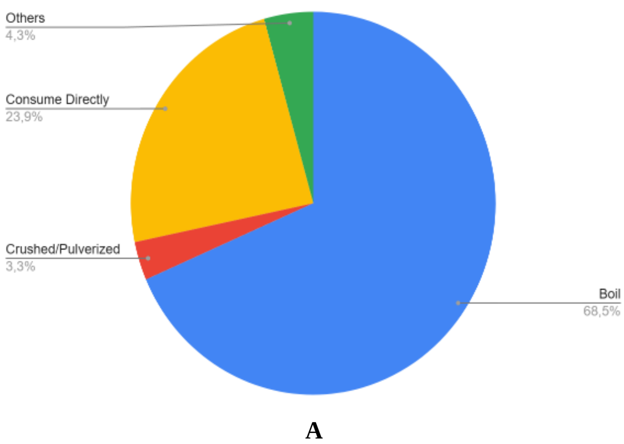
Use Value (UV)

Use Value (UV) is calculated to assess ethnobotanical data by determining the relative importance of plants in the area based on the number of use reports per informant for particular plant species divided by the total number of informants surveyed (Nisa et al. 2022). The Use Value (UV) was calculated as $UV = \sum U/n$ to determine the relative importance of locally known plant species, with high values indicating significance, and further analysis involved a comparative assessment of use values between two regions using a scatterplot and quadrants (Matejić et al. 2020).

Table 3. Preparations, applications, and diseases cured by medicinal plants used by the people of Sidodadi, Ngringo, and Palur Villages, Central Java, Indonesia

Scientific name	Preparation	Application methods	Disease	UV
Allium sativum L.	Direct consumption	Oral	Stomachache	0.1
Aloe vera (L.) Burm.f.	Others	Externally	Diarrhea, antibacterial, inflammation	0.6
Alpinia galanga (L.) Wild.	Boiled	Oral	Joint inflammation, digestive disorders	0.4
Alternanthera littoralis P.Beauv.	Boiled	Oral	Dysentery	0.1
Andrographis paniculata (Burm.fil.) Nees	Boiled	Oral	Inflammation, hypertension, diabetes mellitus	0.4
Annona muricata L.	Boiled	Oral	Stomachache, lung disease, diabetes mellitus, uric acid, diabetes, kidney stones, inflammation, rheumatism	1
Annona squamosa L.	Boiled	Oral	Uric acid, digestive disorders	0.2
Anredera cordifolia (Ten.) Steenis	Pounded/mashed	Oral	Wound, stomachache	0.2
Apium graveolens L.	Boiled	Oral	Kidney stones, hypertension, hepatitis	0.3
Artocarpus altilis (Parkinson) Fosberg	Boiled	Oral	Acid reflux	0.1
Averrhoa bilimbi L.	Direct consumption	Oral	Hemorrhoids, hypertension	0.2
Averrhoa carambola L.	Direct consumption	Oral	Hypertension, digestive disorders	0.2
Azadirachta indica A.Juss.	Boiled	Oral	Stomachache	0.1
Biancaea sappan (L.) Tod.	Boiled	Oral	Itchy skin	0.1
Boesenbergia rotunda (L.) Mansf.	Boiled	Oral	Cough, pharyngitis	0.2
Boesenbergia rotunda (L.) Mansf.	Boiled	Oral	Cancer	0.1
Carica papaya L.	Boiled	Oral	Cancer, meteorism, joint pain, hypertension, symptoms of dengue fever	0.7
Cinnamomum verum J. Presl	Boiled	Oral	Joint inflammation, cholesterol, cough	0.4
Citrus × aurantiifolia (Christm.) Swingle	Direct consumption	Oral	Cough	0.2
Citrus × limon (L.) Osbeck	Direct consumption	Oral	Pharyngitis	0.1
Citrus hystrix DC.	Boiled	Oral	Cough, inflammation	0.4
Clitoria ternatea L.	Others	Externally	Diabetes mellitus	0.1
Coriandrum sativum L.	Boiled	Oral	Hypertension	0.1
Cosmos caudatus Kunth	Boiled	Oral	Hypertension	0.1
Cucumis sativus L.	Direct consumption	Oral	Diabetes mellitus	0.1
Cuminum cyminum L.	Boiled	Oral	Cough	0.1
Curcuma aeruginosa Roxb	Boiled	Oral	Vaginal discharge, stomachache, acid reflux	0.4
Curcuma longa L.	Boiled	Oral	Stomachache, acid reflux, dysmenorrhea, warming, cough	0.6
Curcuma xanthorrhiza Roxb.	Boiled	Oral	Nausea, acid reflux, stomachache	0.7
Curcuma zedoaria (Christm.) Roscoe	Boiled	Oral	Digestive disorders, common cold, asthma	0.4
Cymbopogon citratus (DC.) Stapf	Boiled	Oral	Diabetes mellitus, cholesterol, hypertension, common cold, bloated stomach, digestive disorders	1
Dracaena angustifolia (Medik.) Roxb.	Boiled	Oral	Cancer	0.1
Eclipta prostrata (L.) L.	Boiled	Oral	Ulcer, wound	0.2
Elephantopus scaber L.	Boiled	Oral	Stiffness	0.1
Eleutherine bulbosa (Mill.) Urb.	Direct consumption	Oral	Infection, cholesterol, hypertension	0.3
Erythrina variegata L.	Pounded/mashed	Topical	Fever	0.1
Ficus elastica Roxb.	Boiled	Oral	Itchy skin, skin rash, internal disease	0.2
Garcinia mangostana L.	Boiled	Oral	Diabetes mellitus, uric acid, cholesterol	0.3
Gynura procumbens (Lour.) Merr	Boiled	Oral	Ulcer	0.1
Jasminum sambac (L.) Aiton	Boiled	Oral	Inflammation	0.1
Jatropha gossypifolia L.	Boiled	Oral	Inflammation	0.2
Kaempferia galanga L.	Boiled	Oral	Ulcer, cough, hypothermia	0.3
Lavandula sp. L.	Others	Externally	Headache	0.2
Leucaena leucocephala (Lam.) de Wit	Direct consumption	Oral	Wound	0.2
Leuenbergeria bleo (Kunth) Lodé	Boiled	Oral	Cancer, uric acid	0.2
Malus domestica (Suckow) Borkh.	Direct consumption	Oral	Hepatitis	0.1
Mangifera indica L.	Boiled	Oral	Uric acid	0.1
Manihot esculenta Crantz	Boiled	Oral	Joint inflammation	0.2
Manilkara zapota (L.) P.Royen	Direct consumption	Oral	Diarrhea	0.1
Mentha ×piperita L.	Direct consumption	Oral	Cough	0.1
Momordica charantia L.	Boiled	Oral	Cough, influenza	0.1
Morinda citrifolia L.	Direct consumption	Oral	Hypertension, stomachache, cancer	0.3
Moringa oleifera Lam.	Boiled	Oral	Cancer, mastitis, cholesterol, hypertension	0.4
Morus alba L.	Direct consumption	Oral	Blood sugar, hepatitis	0.2
Muntingia calabura L.	Direct consumption	Oral	Constipation	0.1
Musa paradisiaca L.	Boiled	Oral	Wound	0.1

Ocimum basilicum L.	Boiled	Oral	Inflammation	0.1
Olea europaea L.	Others	Oral	Cholesterol	0.1
Orthosiphon aristatus (Blume) Miq.	Boiled	Oral	Hypertension	0.1
Panax ginseng C.A.Mey.	Boiled	Oral	Inflammation, headache	0.3
Pandanus amaryllifolius Roxb. ex Lindl.	Boiled	Oral	Toothache, cough	0.2
Peperomia pellucida (L.) Kunth	Boiled	Oral	Inflammation	0.3
Persea americana Mill.	Boiled	Oral	Kidney stones	0.1
Phaleria macrocarpa (Scheff.) Boerl.	Boiled	Oral	Cancer, diabetes mellitus	0.1
Phyllanthus buxifolius (Blume) Müll.Arg.	Boiled	Oral	Cough, joint pain, osteoporosis	0.3
Phyllanthus urinaria L.	Boiled	Oral	Stiffness, kidney stones	0.2
Physalis angulata L.	Direct consumption	Oral	Asthma, fever, kidney stones, hypertension	0.5
Piper betle L.	Boiled	Oral	Joint pain, vaginal discharge, cholesterol, cough, inflammation, itchy skin	0.1
Piper ornatum N.E.Br.	Boiled	Oral	Nosebleed, fever, diabetes mellitus, kidney stones	0.4
Piper retrofractum Vahl	Boiled	Oral	Fever	0.2
Platycerium bifurcatum (Cav.) C.Chr.	Direct consumption	Oral	Wound	0.1
Portulaca oleracea L.	Boiled	Oral	Digestive disorders	0.1
Psidium guajava L.	Boiled	Oral	Stomachache, diarrhea, hypertension	0.3
Punica granatum L.	Direct consumption	Oral	Cancer	0.1
Ruellia tuberosa L.	Boiled	Oral	Hypertension	0.1
Salacca zalacca (Gaertn.) Voss	Direct consumption	Oral	Stomachache	0.1
Sauropus androgynus L.	Boiled	Oral	Mastitis	0.1
Smallanthus sonchifolius (Poepp. & Endl.) H.Rob.	Boiled	Oral	Diabetes mellitus	0.1
Strobilanthes crispa (L.) Blume	Boiled	Oral	Stomachache, Kidney stones	0.1
Swietenia mahagoni (L.) Jacq.	Direct consumption	Oral	Diabetes mellitus	0.1
Syzygium polyanthum (Wight) Walp.	Boiled	Oral	Stomachache, cholesterol, hypertension, uric acid	0.4
Tamarindus indica L.	Direct consumption	Oral	Cough, diabetes mellitus, dysmenorrhea	0.3
Tinospora cordifolia (Willd.) Miers	Pounded/mashed	Oral	Fever	0.1
Triphasia trifolia (Burm.fil.) P.Wilson	Direct consumption	Oral	Cough	0.1
Vitis vinivera L.	Direct consumption	Oral	Hypertension	0.1
Zingiber officinale Roscoe	Boiled	Oral	Cough, hypothermia, common cold	0.4
Zingiber officinale var. rubrum Theilade	Boiled	Oral	Stomachache, cough	0.2
Zingiber zerumbet (L.) Roscoe ex Sm.	Boiled	Oral	Fever	0.1
Ziziphus mauritiana Lam.	Boiled	Oral	Fever, diabetes, mellitus, hypertension	0.3



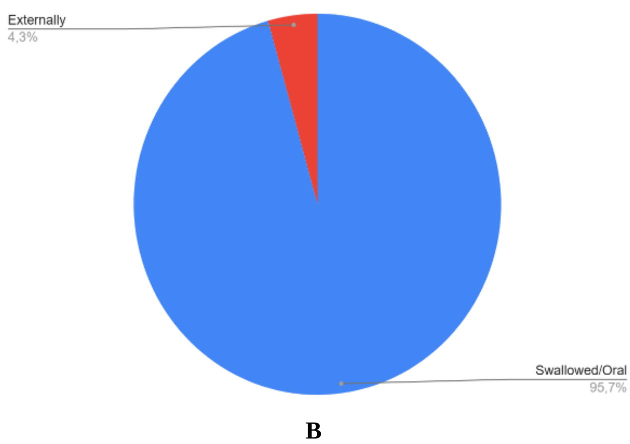


Figure 4. A. Methods of preparation and B. Application of medicinal plants by the people of Sidodadi Village, Ngringo Village, and Palur Village, Central Java, Indonesia

The Use Values (UV) of medicinal plants in the studied area ranged between 0.1 and 1. The average UV value for all plants is 0.228. Higher UV value indicates that the plant is considered more important and is used more frequently based on user reports. In this study, the plants with the highest UV are lemongrass (*A. muricata*; UV = 1) and soursop leaves (*C. citratus*; UV = 1), each with 10 uses reports, followed by betel leaf (*P. betle*; UV = 1) with 9 uses. Other plants with high UV values include papaya (*C. papaya*) and temulawak (*C. xanthorrhiza*) with use value = 0.7, then *lidah buaya* (*A. vera*) and turmeric (*Curcuma longa*) have use value = 0.6, and the last is *ciplukan* (*Physalis angulata*; UV = 0.5) (Figure 5). This suggests that these plants have significant importance in traditional community use. Table 3 shows that most medicinal plants only treat a specific type of disease, which may be influenced by the community's limited understanding of other functions of these plants. UV values can also be interpreted by the number of use reports and the variety of diseases each plant can treat; some plants may have low UV but offer diverse benefits. This study also illustrates that respondents' knowledge about the use of medicinal plants is influenced by factors such as age and accessibility to medicinal plants. Additionally, most recorded plants have more than one use report, indicating the diverse benefits of local medicinal plants.

Informant Consensus Factor (ICF)

The Informant Consensus Factor (ICF) was utilized to gauge consensus among informants regarding the usage of plants for specific ailments, with values ranging from 0 to 1, where value of 1 signifies the highest level of agreement (Caunca and Balinando 2021). Low ICF values, close to 0, indicate random plant selection or a lack of information exchange among informants, while values approaching 1 signify a well-defined selection criterion in the community or information exchange among informants (Muhakr et al. 2024). ICF was used to evaluate the homogeneity in the ethnomedicinal data recorded from traditional health practitioners based on ailments treated and plant species used (Ssenku et al. 2022).

High values of the Informant Consensus Factor (ICF) indicate the effectiveness of a medicinal plant species in addressing specific health conditions. For example, *Psidium guajava* (guava), with an ICF value of 0.94 for diarrhea, suggests that this plant is specifically effective in addressing diarrhea issues (Vivekananda 2023). Meanwhile, the ICF value of 0.92 for *C. longa* indicates the plant's effectiveness in treating dysmenorrhea (Table 4).

Most of the communities in the studied area use two or three parts of plants to prepare medicines to treat single or multiple ailments. Usage categories, namely cysts, low blood pressure (hypotension), and appetite enhancement, have the highest ICF of 1.00. Still, these categories rank the lowest in usage reports (2, 2, 2, and 3, respectively) and the number of species used (1 species for each category). Usage categories with more than 20 usage reports include cough (127 usage reports, 17 species), diarrhea (34 reports, 3 species), and inflammation (21 reports, 15 species) (Table 3). The lowest agreement among informants was observed in kidney disorders, as indicated by the lowest ICF value of 0.14, followed by blood sugar with an ICF of 0.2. Therefore, this study suggests that the level of knowledge shared among the users of medicinal plants for treating particular ailments in the research area is low.

Table 4. Informant Consensus Factor (ICF) for different medicinal plant use categories

Ailment category	Nur	Nt	ICF	Frequently used species
Cyst	2	1	1	*Cinnamomum verum* J. Presl
Internal Disease	2	1	1	*Citrus × limon* (L.) Osbeck
Low Blood Pressure	2	1	1	*Piper retrofractum* Vahl
Appetite	3	1	1	*Curcuma xanthorriza* Roxb.
Diarrhea	34	3	0.94	*Psidium guajava* L.
Dysmenorrhea	15	2	0.92	*Curcuma longa* L.
Nosebleed	12	2	0.91	*Piper ornatum* N.E.Br.
Vaginal Discharge	11	2	0.9	*Piper betle* L.
Hypothermia	41	6	0.88	*Zingiber officinale* Roscoe
Cough	127	17	0.87	*Zingiber officinale* Roscoe

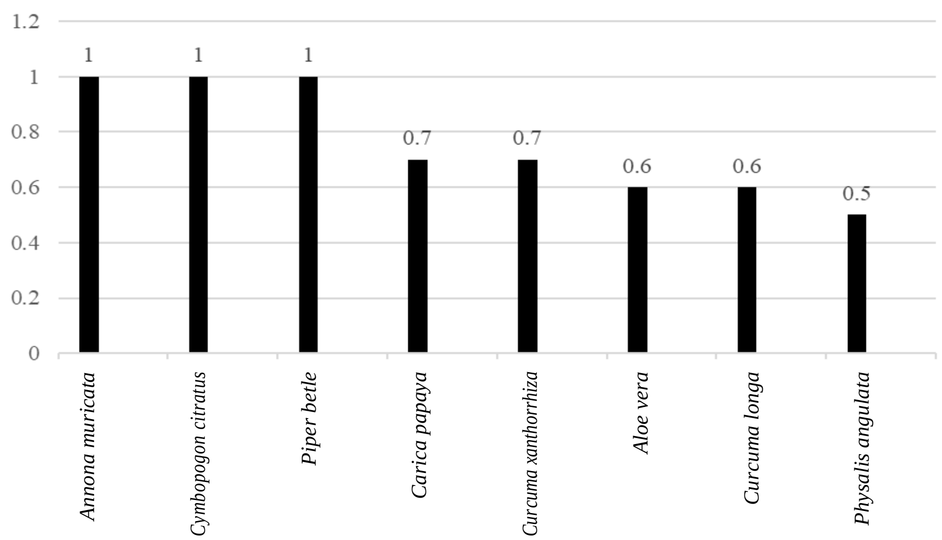


Figure 5. Eight medicinal plants with the highest use values

In conclusion, the local people living along the Bengwan Solo River in Sidodadi, Ngringo, and Palur Villages, Central Java, Indonesia, rely on a diverse array of medicinal plants, indicated by the uses of 88 species from 76 genera and 44 families for treating various diseases. The predominant use of leaves (51.1%) and fruits (25%) as medicinal plant parts reflects the community's traditional knowledge, largely transmitted orally across generations. Boiling (68.5%) is the primary method for plant preparation, with direct consumption (23.9%) being another common approach. The ease, cost-effectiveness, and cleanliness of boiling make it the preferred method. Ginger *(Z. officinale)* is the most frequently used plant, known for treating coughs, providing warmth to the body, and enhancing immunity. Other plants, such as turmeric (C. *longa), kencur* (*K. galanga*), and various citrus fruits, are also widely utilized for their medicinal properties. The community employs these plants to address various health issues, including respiratory problems, digestive disorders, and inflammation. The preparation (boiled, direct consumption, and pounded/mashed), application methods (oral, externally), and diseases treated vary across different plant species. Overall, this study highlights the rich traditional knowledge and reliance on medicinal plants within these villages, emphasizing the need to preserve and further explore the potential of these natural remedies.

ACKNOWLEDGEMENTS

We extend our gratitude to the people who participated in this study as respondents from the villages of Sidodadi, Ngringo, and Palur in Central Java, Indonesia, and to other parties who assisted in preparing this research publication.

REFERENCES

Adam M, Ahmed AA, Yagi A, Yagi S. 2020. Ethnobotanical investigation on medicinal plants used against human ailments in Erkowit and Sinkat areas, Eastern Sudan. Biodiversitas 21 (7): 3255-3262. DOI: 10.13057/biodiv/d210748.

Afridi M, Muhammad IMR, Ahmad T, Hussain A, Akram M, Ghotekar S, Marasini BP. 2021. Ethno-medicinal uses of *Piper betel*—A review. Adv J Chem Sect B 3: 199-208. DOI: 10.22034/ajcb.2021.276229.1079.

Ammar LA, Kurniawati B, Anggorowati D, Cahyaningsih AP, Setyawan AD. 2021. Ethnobotanical study of the medicinal plant by local communities in karst area of Pacitan District, East Java, Indonesia. Intl J Trop Drylands 5 (2): 84-93. DOI: 10.13057/tropdrylands/t050205.

Astutik S, Pretzsch J, Kimengsi JN. 2019. Asian medicinal plants' production and utilization potentials; A review. Sustainability 11 (19): 5483. DOI: 10.3390/su11195483.

Awan AA, Akhtar T, Ahmed MJ, Murtaza G. 2021. Quantitative ethnobotany of medicinal plants uses in the Jhelum valley, Azad Kashmir, Pakistan. Acta Ecol Sin 41 (2): 88-96. DOI: 10.1016/j.chnaes.2020.09.002.

Caunca ES, Balinado LO. 2021. Determination of use-value, informant consensus factor, and fidelity level of medicinal plants used in Cavite, Philippines. Asian J Biol Life Sci 10 (2): 443-453. DOI: 10.5530/ajbls.2021.10.59.

Cunningham AB. 2001. Applied Ethnobotany: People, Wild Plant Use, and Conservation. Earthscan Publications Ltd, Routledge.

Daltro SRT, Santos IP, Barros PL, Moreira DRM, Tomassini TCB, Ribeiro IM, Dos Santos RR, Meira CS, Soares MBP. 2021. In vitro and in vivo immunomodulatory activity of *Physalis angulata* concentrated ethanolic extract. Planta Med 87 (01/02): 160-168. DOI: 10.1055/a-1237-4268.

El Alami A, Fattah A, Chait A. 2020. Medicinal plants used for the prevention purposes during the Covid-19 pandemic in Morocco. J Anal Sci Appl Biotechnol 2 (1): 4-11. DOI: 10.48402/imist.prsm/jasab-v2i1.21056.

El Shiekh RA, Hussein D, Atta AH, Mounier SM, Mousa MR, Abdel-Sattar E. 2021. Anti-inflammatory activity of *Jasminum grandiflorum* L. subsp. *floribundum* (Oleaceae) in inflammatory bowel disease and arthritis models. Biomed Pharmacother 140: 111770. DOI: 10.1016/j.biopha.2021.111770.

Fiorello I, Del Dottore E, Tramacere F, Mazzolai B. 2020. Taking inspiration from climbing plants: methodologies and benchmarks—a review. Bioinspir Biomim 15: 031001. DOI: 10.1088/1748-3190/ab7416.

Fitrianti T, Partasamita R. 2020. Medicinal plants of Cintaratu Village, Pangandaran, West Java. Pros Sem Nas Masy Biodiv Indon 6 (1): 625-634. DOI: 10.13057/psnmbi/m060124. [Indonesian]

Galovičová L, Borotová P, Vukovic NL, Vukic M, Kunová S, Hanus P, Kowalczewski PŁ, Bakay L, Kačániová M. 2022. The potential use of *Citrus aurantifolia* L. essential oils for decay control, quality preservation of agricultural products, and anti-insect activity. Agronomy 12 (3): 735. DOI: 10.3390/agronomy12030735.

Kaushik S, Jangra G, Kundu V, Yadav JP, Kaushik S. 2020. Anti-viral activity of *Zingiber officinale* (Ginger) ingredients against the Chikungunya virus. Virusdisease 31 (3): 270-276. DOI: 10.1007/s13337-020-00584-0.

Kefifa A, Saidi A, Hachem K, Mehalhal O. 2020. An ethnobotanical survey and quantitative study of indigenous medicinal plants used in the Algerian semi-arid region. Phytothérapie 18 (3-4): 204-219. DOI: 10.3166/phyto-2018-0077.

Keong CY. 2015. Sustainable resource management and ecological conservation of mega-biodiversity; The Southeast Asian Big-3 Reality. Intl J Environ Sci Dev 6 (11): 876-882. DOI: 10.7763/ijesd.2015.v6.715.

Khumaida N, Syukur M, Bintang M, Nurcholis W. 2019. Phenolic and flavonoid content in ethanol extract and agro-morphological diversity of *Curcuma aeruginosa* accessions growing in West Java, Indonesia. Biodiversitas 20 (3): 656-663. DOI: 10.13057/biodiv/d200306.

Kumar A. 2020. Phytochemistry, pharmacological activities and uses of traditional medicinal plant *Kaempferia galanga* L. An overview. J Ethnopharmacol 253: 112667. DOI: 10.1016/j.jep.2020.112667.

Lestari D, Koneri R, Maabuat PV. 2021. Keanekaragaman dan pemanfaatan tanaman obat pada pekarangan di Dumoga Utara, Kabupaten Bolaang Mongondow, Sulawesi Utara. Jurnal Bios Logos 11: 82-93. DOI: 10.35799/Jbl.11.2.2021.32017. [Indonesian]

Matejić JS, Stefanović N, Ivković M, Živanović N, Marin PD, Džamić AM. 2020. Traditional uses of autochthonous medicinal and ritual plants and other remedies for health in Eastern and Southeastern Serbia. J Ethnopharmacol 261: 113186. DOI: 10.1016/j.jep.2020.113186.

Miles MB, Huberman AM. 2019. Qualitative Data Analysis: A Sourcebook of New Methods. Sage Publications, Washington DC, USA.

Moyo M, Aremu AO, Van Staden J. 2015. Medicinal plants: An invaluable, dwindling resource in sub-Saharan Africa. J Ethnopharmacol 174: 595-606. DOI: 10.1016/j.jep.2015.04.034.

Muhakr MAYM, Ahmed IM, El hassan GOM, Yagi S. 2024. Ethnobotanical study on medicinal plants in Melit area (North Darfur), Western Sudan. J Ethnobiol Ethnomed 20: 3. DOI: 10.1186/s13002-023-00646-9.

Nisa U, Triyono A, Ardiyanto D, Novianto F, Fitriani U, Jannah WDM, Astana PRW, Zulkarnain Z. 2022. Ethnopharmacological study of medicinal plants indigenous knowledge about low back pain therapy in Sumatra, Indonesia. J Appl Pharm Sci 12 (9): 178-188. DOI: 10.7324/JAPS.2022.120921.

Panigrahi S, Rout S, Sahoo G. 2021. Ethnobotany: A strategy for conservation of plant. Ann Rom Soc Cell Biol 25 (6): 1370-1377.

Putri NR. 2022. Etnomedisin daun sirsak sebagai obat tradisional di Kel Dadok Tunggul Hitam Kec Koto Tangah Padang Sumatera Barat. Universe 3 (2): 114-124. DOI: 10.24036/universe.v3i2.173. [Indonesian]

Qadir SU, Raja V. 2021. Herbal medicine: Old practice and modern perspectives. In: Bhat RA, Hakeem KR, Dervash MA (eds).

Phytomedicine. Academic Press, London, UK. DOI: 10.1016/B978-0-12-824109-7.00001-7.
Raising R, Ayuwardani N, Hermawatiningsih OD, Hariningsih Y, Maritha V, Indrasari T. 2023. Pengelolaan hasil Tanaman Obat Keluarga (TOGA) jamu instan jahe merah (*Zingiber officinale* var. *rubrum*). INDRA: Jurnal Pengabdian Kepada Masyarakat 4 (1): 6-9. DOI: 10.29303/indra.v4i1.176. [Indonesian]
Razafindraibe M, Kuhlman AR, Rabarison H, Rakotoarimanana V, Rajeriarison C, Rakotoarivelo N, Randrianarivony T, Rakotoarivony F, Ludovic R, Randrianasolo A, Bussmann RW. 2013. Medicinal plants used by women from Agnalazaha littoral forest (Southeastern Madagascar). J Ethnobiol Ethnomed 9: 73. DOI: 10.1186/1746-4269-9-73.
Rintelen KV, Arida E, Häuser C. 2017. A review of biodiversity-related issues and challenges in megadiverse Indonesia and other Southeast Asian countries. Res Ideas Outcomes 3: e20860. DOI: 10.3897/rio.3.e20860.
Sánchez M, González-Burgos E, Iglesias I, Gómez-Serranillos MP. 2020. Pharmacological update properties of *Aloe vera* and its major active constituents. Molecules 25 (6): 1324. DOI: 10.3390/molecules25061324.
Shahrajabian MH, Sun W, Cheng Q. 2019. Clinical aspects and health benefits of ginger (*Zingiber officinale*) in both traditional Chinese medicine and modern industry. Acta Agric Scandinavica Sect B 69 (6): 546-556. DOI: 10.1080/09064710.2019.1606930.
Shai KN, Ncama K, Ndhlovu PT, Struwig M, Aremu AO. 2020. An exploratory study on the diverse uses and benefits of locally-sourced fruit species in three villages of Mpumalanga Province, South Africa. Foods 9 (11): 1581. DOI: 10.3390/foods9111581.
Sharma P, Manchanda R, Goswami R, Chawla S. 2019. Biodiversity and therapeutic potential of medicinal plants. In: Shukla V, Kumar N (eds). Environmental Concerns and Sustainable Development: Volume 2. Springer, Singapore. DOI: 10.1007/978-981-13-6358-0_2.
Ssenku JE, Okurut SA, Namuli A, Kudamba A, Tugume P, Matovu P, Wasige G, Kafeero HM, Walusansa A. 2022. Medicinal plant use, conservation, and the associated traditional knowledge in rural communities in Eastern Uganda. Trop Med Health 50: 39. DOI: 10.1186/s41182-022-00428-1.
Subositi D, Kurnianingrum N, Mujahid R, Widiyastuti Y. 2020. *Kaempferia galanga* L. A medicinal plant used by Indonesian Ethnic Groups: Genetic diversity based on Inter-Simple Sequence Repeats (ISSR). Agrivita 42 (1): 45-52. DOI: 10.17503/agrivita.v42i1.1850.
Subroto A, Ningrum V. 2020. The conceptual dynamic model of rural development towards sustainable self-sufficiency. In: Bianchi C, Luna-Reyes LF, Rich E (eds). Enabling Collaborative Governance through Systems Modeling Methods: Public Policy Design and Implementation. Springer Cham, Switzerland. DOI: 10.1007/978-3-030-42970-6_4.
Süntar I. 2020. Importance of ethnopharmacological studies in drug discovery: Role of medicinal plants. Phytochem Rev 19 (5): 1199-1209. DOI: 10.1007/s11101-019-09629-9.
Susilowati, Puspitasari D. 2023. Penggalakan vaksin COVID-19 pada kaum milenial dan penataan lingkungan melalui penanaman TOGA di Dusun Jatiteken, Desa Laban, Sukoharjo. Jurnal Pengabdian Kepada Masyarakat (JPKM) - Aphelion 5 (2): 429-436. [Indonesian]
Suwardi AB, Navia ZI. 2023. Sustainable use and management of wild edible fruit plants: A case study in the Ulu Masen protected forest, West Aceh, Indonesia. J Sustain For 42 (8): 811-830. DOI: 10.1080/10549811.2022.2123355.
Uzzaman S. 2020. Pharmacological activities of neem (*Azadirachta indica*): A review. Intl J Pharmacogn Life Sci 1: 38-41. DOI: 10.33545/27072827.2020.v1.i1a.8.
Vivekananda IBL. 2023. Efektivitas daun jambu biji dalam mengatasi diare. J Sci Mandalika 4 (9): 173-178. DOI: 10.36312/10.36312/vol4iss9pp173-178. [Indonesian]
Wang SY, Zhao H, Xu HT, Han XD, Wu YS, Xu FF, Yang XB, Göransson U, Liu B. 2021. *Kaempferia galanga* L.; Progresses in phytochemistry, pharmacology, toxicology and ethnomedicinal uses. Front Pharmacol 12: 675350. DOI: 10.3389/fphar.2021.675350.
Yeung AWK, Heinrich M, Atanasov AG. 2018. Ethnopharmacology - A bibliometric analysis of a field of research meandering between medicine and food science? Front Pharmacol 9: 215. DOI: 10.3389/fphar.2018.00215.

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 37-48

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140105

Invasive and non-invasive macro aquatic plants in the Upper Bengawan Solo River, Indonesia

CALVIN LEVYANTO PRAMONO[1], DANIEL ABILEON ALYODYA[1], EPRIAN JUNIAR RESTUTI[1], FARAH MEILANI[1], MUCHAMMAD SHOLIQIN[1], ARU DEWANGGA[1], CHEE KONG YAP[2], AHMAD DWI SETYAWAN[1,3,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Department of Biology, Faculty of Science, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia
[3]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia

Manuscript received: 22 December 2023. Revision accepted: 18 May 2024.

Abstract. *Pramono CL, Alyodya DA, Restuti EJ, Meilani F, Sholiqin M, Dewangga A, Yap CK, Setyawan AD. 2024. Invasive and non-invasive macro aquatic plants in the Upper Bengawan Solo River, Indonesia. Intl J Bonorowo Wetlands 14: 37-48.* Macrophytes or aquatic plants are plants that have habitats in water. The uncontrolled growth of macrophytes causes the invasion of alien plant species in the Bengawan Solo River, Indonesia. This study aimed to identify the diversity of invasive and non-invasive macrophytes in the upstream, midstream and downstream of Bengawan Solo River. The methods used were a combination of cruising survey and purposive sampling using line transects. Vegetation data was collected in December 2023 and subject to the analysis of the Shannon-Wiener Species Diversity Index, Simpson Diversity Index, Evenness Index, and Margalef Species Richness Index. The results showed there were 23 macrophyte species with 2,391 individuals spread across three observation stations. There were two types of growth, i.e., free-floating and emergent growth, and they were divided into aquatic and semi-aquatic species. There were 17 invasive plant species, with the most common being *Eichhornia crassipes,* and 6 non-invasive species, with the most common being *Digitaria nuda.* Based on the results of the vegetation analysis, invasive plants had an index of 2.11 (medium), and non-invasive plants had a 0.82 (low). The total Simpson Diversity Index was 0.74 (high), with invasive plants at 0.73 (high) and non-invasive plants at 0.73 (high). The total Evenness Index was 0.69 (high), with invasive plants at 0.74 (high) and non-invasive at 0.46 (medium). The total Margalef Species Richness Index was 1.69 (low), with invasive plants at 1.30 (low) and non-invasive at 0.76 (low). The uncontrolled growth of invasive macrophytes can lead to reduced integrity of the aquatic ecosystem. Thus, invasive alien species must be managed with effective strategies to control their growth.

Keywords: Aquatic, diversity, invasive, plant

INTRODUCTION

Bengawan Solo River is the longest river in Java Island, Indonesia, extending 600 km and encompassing two provinces, namely Central Java and East Java (Lusiana et al. 2022). The Bengawan Solo watershed is divided into three sub-watersheds, namely the upstream, the midstream, and the downstream (Apriana et al. 2017). Bengawan Solo River plays an important role for the surrounding communities as the source of consumed water and agriculture irrigation, especially in Central Java (Ningsih et al. 2020; Hasan et al. 2023). Bengawan Solo River has fairly high anthropogenic pressures in the form of agricultural activities upstream, while in the midstream, there are densely populated areas and industrial activities, and downstream, there are fish pond businesses (Valen et al. 2022). Such activities have negative impacts on aquatic organisms living in the river (Yusron and Jaza 2021).

Macrophytes are aquatic plants that float, sink, and grow on the bottom, surface or submerged in the waters (Nasution et al. 2019). Macrophytes are one of the important elements in aquatic ecosystems (Bucholc et al. 2014) due to their role in both biota and humans (Ali et al. 2020; Swe et al. 2021). Macrophytes serve as food sources of aquatic fauna and a place for fishes to attach their eggs, and their presence increases the complexity and heterogeneity of habitats that greatly affect other aquatic organisms, such as micro-and macro-invertebrates (Budka et al. 2019; Inayah et al. 2023; Thomaz 2023)

Bengawan Solo River contains various species of macrophytes (Le Moal et al. 2019). However, with increasing human pressures, there is uncontrolled growth of macrophytes, causing the widespread occurrence of invasive alien species, including water hyacinths or *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L (Zahro and Nisa 2020). Invasive alien plants are plant species that originate outside the natural habitat of a region and spread rapidly and aggressively, inhibiting the formation and growth of native plants and disrupting existing local ecosystem components, such as soil cover, nutrient cycles, fire patterns, and hydrology (Weidlich et al. 2020). The dominating nature of the habitat is the main characteristic of invasive species (Rahmawati and Rosleine 2023).

In recent years, the water quality in the Bengawan Solo watershed has decreased. This is due to the large amount of industrial and domestic wastes discharged into water bodies, causing the concentration of organic matter to exceed water quality standards (Aboyitungiye et al. 2021). This condition leads to increased nutrient concentrations in the waters, triggering the growth of several macrophytes, particularly invasive alien plants, and eventually affecting plant and animal diversity and composition (Kusumastuti et al. 2021).

Macrophytes can be used as bioindicators of water pollution due to the increase of concentrations of organic matter where some species flourish while some others die because of such conditions (Wang et al. 2021; Amrillah et al. 2023). These organic matters can be sourced from livestock activities, agriculture, fish farming, and household waste in rivers (Lusiana et al. 2022). The increase in organic matter in the water leads to the uncontrolled growth of some macrophytes, especially water hyacinths (Aida et al. 2022). Fitrihidajati and Nurfadlillah (2022) state that several species, including *E. crassipes*, can be used as bioindicators for lead pollution since they can absorb lead dissolved in river water.

The existence of aquatic plants needs to be maintained naturally to preserve ecosystem integrity and species diversity, as in the case of the aquatic garden in the Eka Karya Botanic Garden in Bali (A'tourrohman 2020). Merly et al. (2023) found that the diversity of aquatic plants is useful to maintain the ecosystem integrity of Mayo Swamp with the presence of species such as *Typha angustifolia* L., which is effective in remediating contaminated soil and water. Considering the negative impacts of invasive alien species, it is necessary to assess the diversity of invasive and non-invasive macrophytes. Therefore, this study aims to investigate the diversity of invasive and non-invasive species of macroaquatic plants in the Bengawan Solo River. The results of this study can be used to inform suitable management strategies in the Bengawan Solo River, including the prevention of invasive species.

MATERIALS AND METHODS

Study area and period

The research was conducted in the Upper Bengawan Solo River, Central Java, Indonesia (Figure 1), with several sampling locations established in the upstream (Wonogiri District), midstream (Sukoharjo District and Surakarta City), and downstream (Karanganyar and Sragen Districts), which was determined based on the adjacency of the districts (Adjie and Utomo 2017). This research was conducted on 15-17 December 2023. The upstream in Wonogiri consisted of 2 sampling points. In comparison, the midstream in Sukoharjo and Surakarta and the downstream in Karanganyar and Sragen each consisted of 4 sampling points (Table 1), which were determined based on the accessibility of each location (Kaky et al. 2020) and data reliability and validity (Orr et al. 2021).

Table 1. Distribution of stations, sampling locations and geographical coordinates in the Upper Bengawan Solo River, Central Java, Indonesia

Station	Point ID	Sampling location	Geographical coordinate
Upstream	1	Wonogiri (Pokohkidul)	7°50'00"S 110°55'34"E
	2	Wonogiri (Giritirto)	7°49'31"S 110°55'34"E
Midstream	3	Sukoharjo (Bacem Bridge, Semanggi)	7°36'49.9"S 110°49'10.5"E
	4	Sukoharjo (Colo Dam, Nguter)	7°45'03"S 110°54'01"E
	5	Surakarta (Jurug Bridge, Jebres)	7°34'00"S 110°51'39"E
	6	Surakarta (Sewu Village)	7°34'37"S 110°50'39"E
Downstream	7	Karanganyar (Ringroad Bridge, Dalon)	7°32'46"S 110°52'19"E
	8	Karanganyar (Ngabean, Kebakramat)	7°31'26"S 110°52'27"E
	9	Sragen (Sidokerto, Plupuh)	7°29'22"S 110°53'33"E
	10	Sragen (Pringanom, Masaran)	7°26'48"S 110°54'56"E

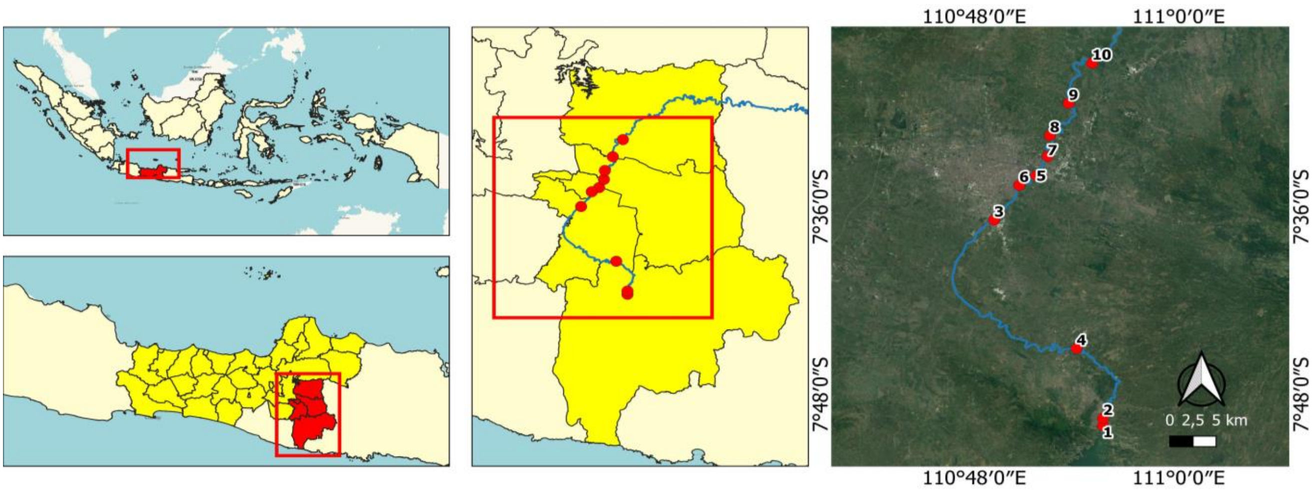


Figure 1. Map of study area showing the sampling points along Upper Bengawan Solo River, Central Java, Indonesia

Data collection procedures

Data was collected using the cruising method and purposive transect line. We explored the river at a deliberately determined length at each location, combined with the establishment of a 500-meter transect line and a sub-transect with a length of 250 m (Nino 2019). Along the transect line, a rope was stretched from the edge of the land toward the river, with a length of 5 m (Yunita et al. 2023). Along this line, we documented aquatic plants. The research tools and materials included plant nets, tally sheets and smartphones. Species were identified using online databases, including gbif.org and Inaturalist and the book "Guide Book to Invasive Alien Plant Species in Indonesia," published by the Ministry of Environment and Forestry (2015).

Data analysis

The vegetation data obtained was classified based on growth type, habitat (aquatic/semi-aquatic), number of individual species, invasive/non-invasive, and the use of these aquatic plants. Vegetation analysis was done to calculate the Shannon-Wiener Species Diversity Index, Simpson Dominance index, Evenness Index, and Margalef Species Richness Index (Sutrisna et al. 2018).

Shannon–Wiener diversity index (Shannon and Weaver 1949)

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N}\right) \ln\left(\frac{ni}{N}\right)$$

Where:
H' : Shannon-Wiener Species Diversity Index
Pi : ni/N
ni : Number of species i
N : Total number of individuals
S : The sum of all individuals

The Shannon-Wiener Species Diversity Index was classified as low (H'<1), medium (1<H'<3) and high (H'>3).

Simpson Dominance Index (Thukral 2017)

$$E = \sum \left(\frac{ni}{N}\right)^2$$

Where:
C : Species Dominance Index
Ni : Number of individuals of the i-th species on each plot
N : Number of individuals of the i-th species on all plots

The category for species dominance is low (C<0.1), medium (0.5<C<0.75) and high (0.75<C<1).

Evenness Index (Redowan 2015)

$$E = \frac{H'}{LnS}$$

Where:
E : Evenness Index
H' : Shannon Wiener Species Diversity Index
S : Number of all species

The category for evenness is low (E<0.3), medium (0.3<E<0.6) and high (E>0.6).

Margalef Species Richness Index (Margalef 1958)

$$R = \frac{S-1}{Ln\ N}$$

Where:
R : Margalef Species Richness Index
S : Number of all species
N : Number of individuals of the i-th species on all plots

The category for Margalef species richness was low (R<3.5), medium (3.5<R<5.0) and high (R>5.0).

RESULTS AND DISCUSSION

Macrophyte species diversity in Bengawan Solo River

Table 2 shows 23 species of macrophytes documented in Bengawan Solo River with 2,391 individuals spread across 3 observation stations. This species number is higher than the species found in water bodies in Kyiv, Ukraine, with only 3 species. The river in Kyiv is a large river that crosses several countries in Europe (Prokopuk et al. 2023). There were only two growth types of macrophytes in the studied area: free-floating (19 species) and emergent (4 species). Free-floating is a plant that is not attached to the bottom of sediment, or it has leaves that float in the water while its roots are submerged (Lesiv et al. 2020). Water movement influences the free-floating type of growth due to wind blows so that it can easily move from one place to another (Sudipta et al. 2020). In addition, free-floating species can grow in all types of water bodies and are not affected by water depth (Hussner et al. 2021).

Meanwhile, emergent growth type is usually found in submerged soil where groundwater is around 0.5 m below the ground surface. The characteristic of this plant is that its shoots and leaves are above the water, with its roots remaining below the surface (Yuliasni et al. 2023). Emergent growth types were often found at research stations except at the downstream stations such as Karanganyar (ring road bridge) and Sragen. This is because at several research stations, such as upstream, middle, and downstream (Ngabean), several parts of the riverbank are slightly submerged in water. According to Yang et al. (2020), factors that influence emergent plant growth are water levels and competitive interactions between species.

No submerged type was found in the Bengawan Solo River. This is a type of aquatic plant that grows underwater with roots in mud. This type is rarely found because several factors influence its growth, such as the water's depth and color, which is quite murky, so the amount of light entering it and the low gas saturation does not support their living (Lesiv et al. 2020). According to Hussner et al. (2021), the type of submerged growth is influenced by water depth factors because it is related to light requirements. In addition, the submerged growth type is not found in all study sites.

Distribution of aquatic and semi-aquatic species in Bengawan Solo River

Based on their habitat, macrophytes are divided into aquatic and semi-aquatic species (Ali et al. 2020). Table 2 shows that there were 10 species of aquatic plants across 10 observation locations. Aquatic plant species such as *E. crassipes* were found in Wonogiri to Karanganyar. This species was also found in Sragen, but the number was lower than that in Surakarta City. Bengawan Solo River is close to residential areas and subjected to domestic waste, which can lead to eutrophication (Arifianto et al. 2021). Aquatic plant species such as *Limnophyton obtusifolium* (L.). Furthermore, *Ipomoea aquatica* Forssk., *Portulaca oleracea* L., and *Azolla pinnata* R.Br. are found in Sukoharjo and Surakarta; *I. aquatica* was found at Pokohkidul and Giritirto stations, Wonogiri. In comparison, at the downstream station, not too many species of aquatic plants were found; aquatic species were found in downstream locations, such as *E. crassipes, P. stratiotes,* and *A. pinnata*. The distribution of aquatic species at the downstream station was lower than at the upstream and midstream stations, which is due to the large number of industries in the Karanganyar and Sragen areas that do not manage industrial liquid waste properly and are discharged into the Bengawan Solo River (Mustikasari 2019; Hidayad 2020). In addition, the rainy season enlarges water currents, so many aquatic plants are carried away by rainwater at downstream stations (Thiara et al. 2022).

Naturally, semi-aquatic plants can partially live in water (Inelova et al. 2023). Based on Table 2, the number of semi-aquatic plants found was 13 species across 7 observation locations. Semi-aquatic species were not found in Ngabean Karanganyar, Sidokerto, and Proanganom Sragen. This is because many anthropogenic activities around the Bengawan Solo River produce much waste, making semi-aquatic plants rarely found at the downstream stations (Prajoko 2018). In addition, the downstream area of Bengawan Solo River does not have river boundaries, making it difficult to find semi-aquatic species. At the midstream station, semi-aquatic plants were quite diverse, including *Mimosa pudica* L., *Eclipta prostrata* (L.) L., and *Cyperus alternifolius* L. This is due to relatively few anthropogenic activities (Ramadhani 2016). At the upstream station, the distribution of semi-aquatic plant species was also still diverse, including *M. pudica*, *Digitaria nuda* Schumach., *Alternanthera sessilis* (L.) DC., *E. prostrata, Grangea maderaspatana* (L.) Poir. and several other species.

Invasive and non-invasive macrophytes in the Bengawan Solo River

In this study, several invasive alien plants were found along the Bengawan Solo River. A total of 17 invasive alien plant species were identified from the 23 plants documented, and each station had at least one species of invasive alien plant. Invasive alien plant species found along the Bengawan Solo River are caused by several factors, one of which is anthropogenic factors (Li et al. 2022). These anthropogenic factors will significantly influence ecosystem structure and function; for example, river water contaminated with heavy metals will alter water quality, affecting the relationship between species composition and ecological processes (Tokhtar et al. 2020).

At the upstream station, 9 species were found. Invasive alien plants that dominated this station were *I. aquatica* because the flow speed significantly influences the growth rate of this species, where high current speeds will reduce the capability of this plant to absorb nitrates and phosphates (Melani et al. 2020). The *E. crassipes* were also found at the upstream station because the water is contaminated by waste, resulting in eutrophication, especially phosphorus (P) and nitrogen (N) (Maulidyna et al. 2021). The presence of *E. crassipes* reduces dissolved oxygen and blocks sunlight from entering the water, disturbing aquatic ecosystems. The *Pontederia vaginalis* Burm.f. is one of the most invasive plants in the world because this species is perennial and multiplies rapidly in rivers in tropical and subtropical regions (Chen et al. 2017). The *P. vaginalis* is able to cover several hectares of open water because it has a fast reproduction rate and complex root structure (Ghoussein et al. 2023). The *M. pudica* were found on the river banks, reducing the light to penetrate the soil surface so that the plants below *M. pudica* outcompete (Kato-Noguchi 2023). The *L. obtusifolium* was not abundant in the river and is not considered invasive. However, these plants can spread aggressively and affect aquatic ecosystems (Ali and Elhajaz 2021). The *L. flava* is considered invasive because it usually appears when flooded and inhabits shallow swamps. However, this plant can be used for animal feed to control its spread (Chandran and Ramasamy 2015). The *P. oleracea* is also known as one of the most invasive plants worldwide. It can spread very quickly and form dense populations, and it is usually located on river banks with many landfills (Anđelković et al. 2022). The *E. prostrata* is an invasive plant that can grow and multiply rapidly due to the high nutrient content in riverside soils (Liao et al. 2023). The *C. alternifolius* can multiply rapidly in wetlands and form dense stands that can potentially disrupt aquatic ecosystems in the Bengawan Solo River (Verloove 2014).

There were 14 invasive alien plant species found at the midstream station. The highest number of invasive alien species was *E. crassipes*, with 131 individuals. At this station, the water was contaminated by livestock waste and batik dye waste (Hanum et al. 2022). One of the impacts of *E. crassipes* is the reduction of dissolved oxygen and blocking sunlight from entering the water, which ultimately causes aquatic ecosystems to be disturbed (Maulidyna et al. 2021). A large number of *Lemna minor* L. were also found at this station. The calmer water flow is also a factor at this station, where livestock waste is discharged by the surrounding community into the river, resulting in a relatively high nutrient content that triggers excessive growth (Ceschin et al. 2021) and disrupts aquatic ecosystems (Mariani et al. 2020). The *P. stratiotes* can multiply vegetatively rapidly, adversely affecting the environment and biodiversity because of their ability to form a dense layer that blocks the watercourse, hindering fishing and boat transportation and impeding the flow of water in irrigation and flood control canals (Galal et al. 2019).

Table 2. List of macrophytes in Bengawan Solo River, Central Java, Indonesia

Station	Location	Species	Family	Number of Individuals	Growth Type	Habitat Type	Invasiveness
Upstream	Wonogiri (Pokohkidul)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	7	Free-floating	Aquatic	Invasive
		Pontederia vaginalis Burm.f.	Pontederiaceae	95	Emergent	Semi-aquatic	Invasive
		Limnocharis flava (L.) Buchenau	Limnocharitaceae	25	Emergent	Aquatic	Invasive
		Mimosa pudica L.	Fabaceae	89	Emergent	Semi-aquatic	Invasive
		Ipomoea aquatica Forssk.	Convolvulaceae	110	Emergent	Aquatic	Invasive
		Digitaria nuda Schumach	Poaceae	5	Emergent	Semi-aquatic	Non-invasive
		Limnophyton obtusifolium (L.) Miq.	Alismataceae	30	Emergent	Aquatic	Invasive
		Portulaca oleracea L.	Portulacaceae	1	Emergent	Aquatic	Invasive
		Eclipta prostrata (L.) L.	Asteraceae	14	Emergent	Semi-aquatic	Invasive
		Gomphrena celosioides Mart.	Amaranthaceae	5	Emergent	Semi-aquatic	Non-invasive
	Wonogiri (Giritirto)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	5	Free-floating	Aquatic	Invasive
		Ipomoea aquatica Forssk.	Convolvulaceae	4	Emergent	Aquatic	Invasive
		Grangea maderaspatana (L.) Poir	Asteraceae	6	Emergent	Semi-aquatic	Non-invasive
		Mimosa pudica L.	Fabaceae	21	Emergent	Semi-aquatic	Invasive
		Cyperus alternifolius L.	Cyperaceae	5	Emergent	Semi-aquatic	Invasive
Midstream	Sukoharjo (Bacem Bridge, Semanggi)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	325	Free-floating	Aquatic	Invasive
		Lemna minor L.	Lemnaceae	234	Free-floating	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	85	Free-floating	Aquatic	Invasive
		Mimosa pudica L.	Fabaceae	3	Emergent	Semi-aquatic	Invasive
	Sukoharjo (Colo Dam, Nguter)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	4	Free-floating	Aquatic	Invasive
		Ipomoea aquatica Forssk.	Convolvulaceae	8	Emergent	Aquatic	Invasive
		Alternanthera philoxeroides (Mart.) Griseb	Amaranthaceae	3	Emergent	Aquatic	Non-invasive
		Digitaria nuda Schumach	Poaceae	6	Emergent	Semi-aquatic	Non-invasive
		Eclipta prostrata (L.) L.	Asteraceae	1	Emergent	Semi-aquatic	Invasive
		Limnophyton obtusifolium (L.) Miq.	Alismataceae	7	Emergent	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	15	Free-floating	Aquatic	Invasive
		Impatiens glandulifera Royle	Balsaminaceae	1	Emergent	Semi-aquatic	Invasive
		Portulaca oleracea L.	Portulacaceae	5	Emergent	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	35	Free-floating	Aquatic	Invasive
		Mimosa pudica L.	Fabaceae	3	Emergent	Semi-aquatic	Invasive
		Tridax procumbens L.	Asteraceae	12	Emergent	Semi-aquatic	Invasive

	Surakarta (Jurug Bridge, Jebres)	*Grangea maderaspatana* (L.) Poir	Asteraceae	2	Emergent	Semi-aquatic	Non-invasive
		Eichhornia crassipes (Mart.) Solms	Pontederiaceae	127	Free-floating	Aquatic	Invasive
		Ludwigia adscendens (L.) H.Hara	Onagraceae	86	Emergent	Aquatic	Invasive
		Achyranthes aspera L.	Amaranthaceae	1	Emergent	Semi-aquatic	Non-invasive
		Murdania spirata (L.) G.Brückn.	Commelinaceae	1	Emergent	Semi-aquatic	Non-invasive
		*Limnocharis flava (*L.) Buchenau	Limnocharitaceae	15	Emergent	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	29	Free-floating	Aquatic	Invasive
		Mimosa pudica L.	Fabaceae	5	Emergent	Semi-aquatic	Invasive
		Cyperus alternifolius L.	Cyperaceae	8	Emergent	Semi-aquatic	Invasive
		Alternanthera sessilis (L.) DC.	Amaranthaceae	3	Emergent	Semi-aquatic	Invasive
	Surakarta (Sewu Village)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	190	Free-floating	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	15	Free-floating	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	35	Free-floating	Aquatic	Invasive
		Lemna minor L.	Lemnaceae	46	Free-floating	Aquatic	Invasive
		Mimosa pudica L.	Fabaceae	3	Emergent	Semi-aquatic	Invasive
Downstream	Karanganyar (Ringroad Bridge, Dalon)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	154	Free-floating	Aquatic	Invasive
		Hippobroma longiflora (L.) G.Don	Campanulaceae	14	Emergent	Semi-aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	36	Free-floating	Aquatic	Invasive
		Alternanthera sessilis (L.) DC.	Amaranthaceae	16	Emergent	Semi-aquatic	Non-invasive
	Karanganyar (Ngabean, Kebakramat)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	90	Free-floating	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	16	Free-floating	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	9	Free-floating	Aquatic	Invasive
	Sragen (Sidokerto, Plupuh)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	178	Free-floating	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	6	Free-floating	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	40	Free-floating	Aquatic	Invasive
	Sragen (Pringanom, Masaran)	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	56	Free-floating	Aquatic	Invasive
		Azolla pinnata R.Br.	Salviniaceae	25	Free-floating	Aquatic	Invasive
		Pistia stratiotes L.	Araceae	16	Free-floating	Aquatic	Invasive

The *E. prostrata* grows in a humid environment where there is no soil deposit at the midstream and downstream and only water. *Impatiens glandulifera* Royle was only found at this station. This plant usually lives on river banks and is able to displace native vegetation due to its rapid growth and abundant seed production, reducing the richness and diversity of species in aquatic ecosystems by 11-30% (Coakley and Petti 2021). *Tridax procumbens* L. is an invasive plant that can thrive in various habitats due to its ability to tolerate various temperatures and solar radiation (Panda and Behera 2019). This plant can adapt to various types of soil and can spread seeds easily so that they can thrive on river banks (Mecina et al. 2016). *Ludwigia adscendens* (L.) H.Hara can develop rapidly and form a solid layer on the water's surface, blocking light and oxygen. This plant can also release secondary metabolites into the underlying ecosystem, limiting the growth of native plants (Thiébaut et al. 2018). The *A. sessilis* grows quickly in disturbed areas and wetland habitats. It can reproduce in various conditions and has fast growth so that this plant can outcompete native vegetation in aquatic ecosystems (Shen et al. 2021).

At the downstream stations, there were 4 species of invasive alien plants (Table 2). At this station, the river body was contaminated by industries that discharged their waste into the river (Sulistiono et al. 2023). Waste that often contains nutrients and is discharged into river water will feed invasive alien plants, increasing the population of invasive alien plants and damaging aquatic ecosystems (Prabakaran et al. 2019). At this station, there were more than 324 individuals of *E. crassipes* because the river was contaminated by sewage, which allowed it to grow and develop quickly. In addition, many small plants, such as *A. pinnata*, were also found. Because of the slow water flow, this plant can thrive at this station. Excessive growth of *A. pinnata* will result in disturbed ecosystems due to decreased oxygen levels in the water (Bhujel and Rizal 2022). *Hippobroma longiflora* (L.) G.Don was also found at this station due to excessive nutrient levels caused by waste disposal, which accelerates the growth of this plant (Mosyaftiani et al. 2019).

Ecological indices of macrophytes

Shannon-Wiener Species Diversity Index

Table 3 shows that the Shannon-Wiener Species Diversity Index of invasive plant species found at the three research stations was 2.11, or in the medium category. If differentiated based on the station, the upstream had an index of 1.90, the midstream of 2.34, and the downstream with 2.09. In contrast, the diversity index for non-invasive species was only 0.82 (low), with the index upstream being 1.09, midstream was 1.38, and no non-invasive species were found downstream. When the invasive and non-invasive species combined, the Shannon Wiener diversity index of the three stations was 2.17 (moderate), with the index at the upstream being 2.03 (medium), the midstream was 2.38 and downstream was 2.09. The higher diversity index in the midstream is due to fewer industrial and agricultural activities compared to the upstream and downstream areas (Valen et al. 2022). Many factors cause the diversity to be moderate, including weather, water flow, temperature, water discharge, nutrients water and environmental factors (Gao et al. 2022).

The diversity of aquatic plants is one of the indicators of the sustainability of river ecosystems (Biggs et al. 2017). Ceschin et al. (2021) stated that aquatic plants provide abiotic, biotic, and cultural elements in aquatic ecosystems. The diversity index is influenced by the number of species and the number of individuals from each species (Bezaredie et al. 2023). The presence of invasive alien species is an indicator of the suppression of local species in their habitat (Thiemer et al. 2023). Table 4 shows that the Shannon Wiener diversity index for macro aquatic plant species in the Bengawan Solo River is in the moderate category. The moderate diversity in the Bengawan Solo River area is likely influenced by weather (Siddha and Sahu 2022). The reduction in water discharge in the upstream area due to the prolonged dry season causes the water to recede; therefore, the species and number of individuals found were small. In addition, fairly fast current conditions are a factor that causes the diversity of floating-type plant species to be carried faster by the current toward the midstream area (O'Hare et al. 2018). This is almost the same as the condition of Chinese waters, which explains that the condition of macroaquatic plants is influenced by the speed of currents that hit aquatic plants (Zhou et al. 2023).

The low diversity of aquatic plant species downstream is due to high currents and minimal discharge (Gholami et al. 2020). However, in certain seasons, water plants will spread rapidly if stagnant water conditions occur, there is no heavy rain, and the main gate of the dam upstream is not opened, then water plants of certain types, such as *E. crassipes*, *P. stratiotes*, *A. pinnata,* and *L. minor* will be found along the water of Bengawan Solo River. The same study by Numbere et al. (2019) in Nigeria revealed that invasive aquatic plants will find it easier to develop diversity in stagnant and stable water conditions. Invasive species grow and develop very fast and easily dominate and cover the water surface (Weidlich et al. 2020). Stefanidis et al. (2021) explained that the heterogeneity and distribution of aquatic plants influence the diversity of aquatic plants. Furthermore, Zhang et al. (2017) revealed that the stability of aquatic plants in China is influenced by climate change, eutrophication, explosion of invasive species, reclamation, and anthropogenic activities. The activities of households and large-scale industries are also one of the causes of the entry of pollutants into the water, disrupting the continuous diversity. As in South Africa, many aquatic plants are reduced due to pollutants and contamination by industry activities, affecting water quality and species (Edokpayi et al. 2017). The condition of Bengawan Solo River being used for industrial waste has an impact on the diversity of aquatic plants, therefore increasing the dominance of invasive plants.

Simpson Diversity Index

The Simpson Diversity Index of invasive aquatic plants at the tree stations reached 0.73 or moderate (Table 3), where the index upstream was 0.78 (high), midstream was

0.69, and downstream was 0.44 (low). On the other hand, the Simpson Diversity Index of non-invasive aquatic plants at the upstream and midstream was 0.71 and 0.76 or in the high category, and no non-invasive species were found downstream. Table 4 shows that the total Simpson Diversity Index was 0.74 (medium).

The Simpson Diversity Index determines how large a number of species are in a location. Table 3 shows the high Simpson diversity levels obtained from invasive and non-invasive plant species studied. This indicates that the dominance of less varied species will provide high diversity. In comparison, the increased variety of species will provide a low chance of dominance. Based on Table 4, the value of the Simpson Diversity Index is almost close to 1. So, with this value, it can be stated that species of aquatic plants occur at each location in the Bengawan Solo River. The most dominant species were *E. crassipes* and *P. stratiotes.* These plants are very abundant, especially in stations located in Sukoharjo, Surakarta, Karanganyar, and Sragen. The water in Sukoharjo had typical stagnant waters with fairly small currents in the Semanggi area; therefore, a large number of *E. crassipes* and *P. stratiotes* were found in this area. These species have good growth potential if they are in slow water flow (El-Shahawy 2017), swamps, wetlands (Younas et al. 2022), shallow ponds (Kitunda 2017), puddles (Gezie et al. 2018), and large/small rivers that are quite light (Mishra and Maiti 2017). However, some species often coexist with *E. crassipes* and *P. stratiotes,* such as *A. pinnata* and *L. minor*, which have the same habitat and type of roots that float freely on the water's surface. Both species can rapidly cover the water surface if not disturbed by strong water currents.

The species of aquatic plants that dominate the Bengawan Solo River are recognized as very invasive and have high adaptability to a broad range of conditions. Good adaptability is an advantage of invasive plants in reproduction (Van Boheemen et al. 2019). Although the water of the Bengawan Solo River has been contaminated, these aquatic plants are still able to survive (Rizqiyah and Nurina 2021). Special actions are needed to control the dominance of invasive aquatic plant species so that the ecosystem remains stable (Caudill et al. 2019). Controlling the dominance of invasive species is considered important because this phenomenon also occurs in many aquatic ecosystems in South Africa (Hill et al. 2020).

Evenness Index

Based on Table 3, the evenness of invasive aquatic plants in the Bengawan Solo River reached 0.74, which is included in the high category. The upstream and midstream had an index of 0.86 and 0.86 (high), while the downstream had 1.30 (very high). On the other hand, the evenness of non-invasive species had an index of 0.46 (moderate), with an upstream index of 1.00 and a midstream of 0.86. Both are in the high category, and no non-invasive species was found downstream. Table 4 shows the Evenness Index of aquatic plants, which is 0.69 (high), where the upstream had an index of 1.33, the midstream had 1.95, and the downstream had 0.62 (low).

Environmental factors influence the distribution of each species. This resulted in different species distribution for each research station (Tables 3 and 4). The high level of evenness of aquatic plant species in the Bengawan Solo River is caused by the presence of invasive species. One of the causes of high evenness is the dominance of adaptive species in several water areas (Huang et al. 2020). In addition, current speed is also crucial in distributing species from upstream to downstream (McElrone et al. 2013). Currents have become an easy way to free-float aquatic plants such as *E. crassipes*, *P. stratiotes*, *A. pinnata*, and *L. minor* (Datta et al. 2021). On the other hand, aquatic plants attached to the bottom of the soil will spread to other areas through seeds or water-carrying flowers (Rodríguez-Garlito et al. 2022). Therefore, the evenness of aquatic plants in Bengawan Solo River is dominated by free-floating species such as *E. crassipes.*

Table 3. Ecological indices of all macrophytes in Bengawan Solo River, Central Java, Indonesia

Station	Shannon-Wiener Species Diversity Index	Evenness Index	Simpson Diversity	Species Richness (Margaleft)
Upstream	2.03	0.82	0.80	1.82
Middle	2.38	0.79	0.69	2.65
Downstream	2.09	1.30	0.44	0.62
Total	2.17	0.69	0.74	1.69

Table 4. Ecological indices of macrophytes differentiated based on the type of invasiveness in Bengawan Solo River, Central Java, Indonesia

Invasiveness	Station	Shannon-Wiener Species Diversity Index	Evenness Index	Simpson Diversity	Species Richness (Margaleft)
Invasive	Upstream	1.90	0.86	0.78	1.33
	Midstream	2.34	0.86	0.69	1.95
	Downstream	2.09	1.30	0.44	0.62
	Total	2.11	0.74	0.73	1.30
Non-invasive	Upstream	1.09	1.00	0.71	0.72
	Midstream	1.38	0.86	0.76	1.56
	Downstream	-	-	-	-
	Total	0.82	0.46	0.73	0.76

This result is similar to other studies in the Greater Letaba River (Thamaga and Dube 2019), South China (Wu and Ding 2020), Ethiopia (Getnet et al. 2021), and Argentina (Poi et al. 2020). Another factor that can help the dispersal of plant species to other places is animals and humans (Catford and Jansson 2014).

Margalef Species Richness Index

The Margalef index of invasive plants was 1.30 (low), whereas the upstream index was 1.33, the midstream index was 1.95, and the downstream index was 0.62. The index for non-invasive plants was only 0.76, while the upstream had 0.72, the midstream had 1.56, and no non-invasive species were found downstream. Table 4 shows the Margalef index of aquatic plants upstream was 1.82 (moderate), midstream was 2.65 (medium), and downstream was 0.62 (very low), resulting in the combined index for upstream to downstream stations of 1.69 (low).

Although the level of evenness of macrophytes in the Bengawan Solo River was high, Margalef species richness was in the low category. This is because only 23 species were found. Species richness indicates that the greater the number of species found in an area, the richer it is. Poor water and soil quality are also factors that lead to the low number of species (Zhang et al. 2019). The presence of invasive alien species and environmental changes also cause fewer other aquatic plant species to grow and thrive (Hejda et al. 2021). The changing and unstable environment leads to the transformation of local aquatic plant species to decrease (Huang et al. 2020). That way, there is a need for stability, prevention, and control in the Bengawan Solo River against invasive alien aquatic plants and water pollutants to maintain the richness of aquatic plant species.

Controlling invasive alien plants in Bengawan Solo River

Invasive alien species documented in this study need to be managed with certain strategies. Those strategies are focused on the most eminent impacts of invasive plants using different management options adapted to the surrounding environmental conditions (Hess et al. 2019). Identifying areas in the river affected and regularly monitoring invasive plant growth will help determine locations that require necessary measures (Mikulyuk et al. 2020). Location points that require rehabilitation will be taken by two methods: biological techniques, such as using natural enemies and native species, and manual techniques, such as uprooting and removing invasive plants (Sitepu 2020; Weidlich et al. 2020). The government should also play a role by emphasizing and funding universities and organizations to study invasive aquatic plant control (Anifowose and Fagorite 2020). Therefore, controlling invasive alien plants in the Bengawan Solo River can be done based on short-term and long-term scales. Short-term control activities that can be carried out are to identify and recognize invasive types to control and prevent alien species from entering the river. In addition, short-term control can also be done by quickly controlling the population by intensifying the shrubs and weeds pruning in the river area (Sitepu 2020). Long-term control in Bengawan Solo River can be done by conducting an Invasive Plant Risk Assessment (ISPRA). Invasive Plant Risk Assessment is a process to evaluate the invasive potential of a plant species in a particular area, which aims to assess how much risk the plant becomes invasive that is able to spread quickly and disrupt local ecosystems (Bradley et al. 2018).

In conclusion, this study revealed that in Bengawan Solo River, there were 23 species of macrophytes with a total of 2,391 individuals spread across three observation stations. The most common invasive species was *E. crassipes*, and non-invasive is *D. nuda*. The *E. crassipes* was found almost along the Bengawan Solo River since the plant can multiply quickly and easily adapt to changes in extreme conditions such as water currents and nutrient availability. The diversity index of invasive and non-invasive aquatic plant species in the Bengawan Solo River was very low due to the presence of invasive alien species, which suppress local species in their habitat. The Simpson index of invasive and non-invasive plants was quite high, suggesting the dominance of less varied species. The Evenness Index was high due to the presence of several invasive species, while the Margalef Species Richness Index was low.

REFERENCES

Aboyitungiye JB, Suryanto, Gravitiani E. 2021. River pollution and human health risks: Assessment in the locality areas proximity of Bengawan Solo river, Surakarta, Indonesia. Indones J Environ Manag Sustain 5: 13-20. DOI: 10.26554/ijems.2021.5.1.13-20.

Adjie S, Utomo AD. 2017. The catch of several types of fishing equipment in the Bengawan Solo River. BAWAL 3 (1): 33-44. DOI: 10.15578/bawal.3.1.2010.33-44.

Aida SN, Ridho MR, Saleh E, Utomo AD. 2022. Distribution of phytoplankton based on the water quality of Bengawan Solo River, Central Java. Aquacult Aquar Conserv Legis 15 (2): 641-651.

Ali S, Abbas Z, Rizwan M, Zaheer IE, Yavaş İ, Ünay A, Abdel-DAIM MM, Bin-Jumah M, Hasanuzzaman M, Kalderis D. 2020. Application of floating aquatic plants in phytoremediation of heavy metals polluted water: A review. Sustainability 12: 1927. DOI: 10.3390/su12051927.

Amrillah AM, Kilawati Y, Rizqa V. 2023. Species composition and relative abundance of phytoplankton in Ranu Klakah, Lumajang, East Java. J Fish Mar Res 7 (3): 27-31.

Anđelković A, Popović S, Živković M, Cvijanović D, Novković M, Marisavljević D, Pavlović D, Radulović S. 2022. Catchment area, environmental variables and habitat type as predictors of the distribution and abundance of *Portulaca oleracea* L. in the riparian areas of Serbia. Acta Agric Serb 27 (53): 9-15. DOI: 10.5937/AASer2253009A.

Anifowose FA, Fagorite VI. 2020. Assessment of current status of invasive aquatic plants in Louisiana. Open Access Libr J 7: 1-10. DOI: 10.4236/oalib.1106429.

Apriana N, Fariyanti A, Burhanuddin B. 2017. Preferensi risiko petani padi di daerah aliran sungai Bengawan Solo, Kabupaten Bojonegoro, Provinsi Jawa Timur. Jurnal Manajemen & Agribisnis 14 (2): 165-165. DOI: 10.17358/jma.14.2.165. [Indonesian]

Arifianto A, Mufti E, Marhendra APW, Kurniawan N. 2021. Minnow trap color effectiveness test using cat food bait as aquatic sampling gear on diurnal fish in Gajah Mungkur Reservoir, Cental Java, Indonesia. J Exp Life Sci 11: 15-20. DOI: 10.21776/ub.jels.2021.011.01.04.

A'tourrohman M. 2020. Inventory and ethnobotanical study of aquatic plants in the Eka Karya Bali Botanical Garden Aquatic Park. BIOSEL 9 (1): 1-10. DOI: 10.33477/bs.v9i1.1312.

Bezaredie D, Tadesse Z, Tadesse Z. 2023. Effects of *Prosopis juliflora* on plant diversity on rangeland in Shilabo District, Somali Regional State, Ethiopia. Heliyon 9 (3): e14049. DOI: 10.1016/j.heliyon.2023.e14049.

Bhujel A, Rizal G. 2022. Exploring use of *Azolla* as the potential livestock feed resources: A review. Bhutan J Anim Sci: 40-47.

Biggs J, Von Fumetti S, Kelly-Quinn M. 2017. The importance of small waterbodies for biodiversity and ecosystem services: Implications for policy makers. Hydrobiologia 793: 3-39. DOI: 10.1007/s10750-016-3007-0.

Bradley BA, Allen JM, O'Neill MW, Wallace RD, Bargeron CT, Richburg JA, Stinson K. 2018. Invasive species risk assessments need more consistent spatial abundance data. Ecosphere 9 (7): e02302. DOI: 10.1002/ecs2.2302.

Bucholc K, Szymczak-Żyła M, Lubecki L, Zamojska A, Hapter P, Tjernström E, Kowalewska G. 2014. Nutrient content in macrophyta collected from Southern Baltic Sea beaches in relation to eutrophication and biogas production. Sci Total Environ 473: 298-307. DOI: 10.1016/j.scitotenv.2013.12.044.

Budka A, Łacka A, Szoszkiewicz K. 2019. The use of rarefaction and extrapolation as methods of estimating the effects of river eutrophication on macrophyte diversity. Biodivers Conserv 28: 385-400. DOI: 10.1007/s10531-018-1662-3.

Catford JA, Jansson R. 2014. Drowned, buried and carried away: Effects of plant traits on the distribution of native and alien species in riparian ecosystems. New Phytol 204 (1): 19-36. DOI: 10.1111/nph.12951.

Caudill J, Jones AR, Anderson L, Madsen JD, Gilbert P, Shuler S, Heilman MA. 2019. Aquatic plant community restoration following the long-term management of invasive *Egeria densa* with fluridone treatments. Manag Biol Invasions 10 (3): 473-485. DOI: 10.3391/mbi.2019.10.3.05.

Ceschin S, Bellini A, Scalici M. 2021. Aquatic plants and ecotoxicological assessment in freshwater ecosystems: A review. Environ Sci Pollut Res 28: 4975-4988. DOI: 10.1007/s11356-020-11496-3.

Chandran SS, Ramasamy EV. 2015. Utilization of *Limnocharis flava* an invasive aquatic weed from Kuttanad wetland ecosystem, Kerala, India as a potential feedstock for livestock. Online J Anim Feed Res 5 (1): 22-27.

Chen Y, Sun C, Zhan A. 2017. Biological invasions in aquatic ecosystems in China. Aquat Ecosyst Health Manag 20 (4): 402-412. DOI: 10.1080/14634988.2017.1403268.

Coakley S, Petti C. 2021. Impacts of the invasive *Impatiens glandulifera*: Lessons learned from one of Europe's top invasive species. Biology 10 (7): 619. DOI: 10.3390/biology10070619.

Datta A, Maharaj S, Prabhu GN, Bhowmik D, Marino A, Akbari V, Rupavatharam S, Sujeetha JARP, Anantrao GG, Poduvattil VK, Kumar S, Kleczkowski A. 2021. Monitoring the spread of water hyacinth (*Pontederia crassipes*): Challenges and future developments. Front Ecol Evol 9: 631338. DOI: 10.3389/fevo.2021.631338.

Edokpayi JN, Odiyo JO, Durowoju OS. 2017. Impact of wastewater on surface water quality in developing countries: A case study of South Africa. In: Tutu H (eds). Water Quality. Intech Open, London. DOI: 10.5772/66561.

El-Shahawy TAEG. 2017. Eco-genetic study on water hyacinth, *Eichhornia crassipes* (Mart.) Solms, the world's most invasive aquatic plant. Agric Eng Intl CIGR J 2017: 69-79.

Fitrihidajati H, Nurfadlillah AS. 2022. Biodiversity and Pb heavy metal levels of floating aquatic plants in the Brantas River Mojokerto as bioindicators of lead pollution. LenteraBio 11 (1): 63-70. DOI: 10.26740/lenterabio.v11n1.p63-70.

Galal TM, Dakhil MA, Hassan LM, Eid EM. 2019. Population dynamics of *Pistia stratiotes* L. Rend Lincei Sci Fis Nat 30: 367-378. DOI: 10.1007/s12210-019-00800-0.

Gao Y, Jia J, Lu Y, Sun K, Wang J, Wang S. 2022. Carbon transportation, transformation, and sedimentation processes at the land-river-estuary continuum. Fundam Res [In Press]. DOI: 10.1016/j.fmre.2022.07.007.

Getnet H, Kifle D, Fetahi T. 2021. Impact of water hyacinth (*Eichhornia crassipes*) on water quality and phytoplankton community structure in the littoral region of Koka Reservoir, Ethiopia. Intl J Fish Aquat Stud 9: 266-276.

Gezie A, Assefa WW, Getnet B, Anteneh W, Dejen E, Mereta ST. 2018. Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana Watershed, Northwest Ethiopia. Biol Invasions 20: 2517-2534. DOI: 10.1007/s10530-018-1717-0.

Gholami V, Khalili A, Sahour H, Khaleghi MR, Tehrani EN. 2020. Assessment of environmental water requirement for rivers of the Miankaleh wetland drainage basin. Appl Water Sci 10: 233. DOI: 10.1007/s13201-020-01319-8.

Ghoussein Y, Abou Hamdan H, Fadel A, Coudreuse J, Nicolas H, Faour G, Haury J. 2023. Biology and ecology of *Pontederia crassipes* in a Mediterranean river in Lebanon. Aquat Bot 188: 103681. DOI: 10.1016/j.aquabot.2023.103681.

Hanum U, Ramadhan MF, Armando MF, Sholiqin M, Rachmawati S. 2022. Analisis kualitas air dan strategi pengendalian pencemaran air di Sungai Pepe Bagian Hilir, Surakarta. Prosiding Sains dan Teknologi 1 (1): 376-386. [Indonesian]

Hasan V, Andraini NE, Isroni W, Sari LA, Nafisyah AL, Dewi NN, Putri DNA, Prasasti TAB, Ramadhani AA, Daniel K, South J, Vieira LO, Ottoni FP, Maftuch, Faqih AR, Wirabuana PYAP, Tamam MB, Valen FS. 2023. Fish diversity of the Bengawan Solo River estuary, East Java, Indonesia. Biodiversitas 24: 2207-2216. DOI: 10.13057/biodiv/d240433.

Hejda M, Sádlo J, Kutlvašr J, Petřík P, Vítková M, Vojík M, Pyšek P, Pergl J. 2021. Impact of invasive and native dominants on species richness and diversity of plant communities. Preslia 93 (3): 181-201. DOI: 10.23855/preslia.2021.181.

Hess MC, Mesléard F, Buisson E. 2019. Priority effects: Emerging principles for invasive plant species management. Ecol Eng 127: 48-57. DOI: 10.1016/j.ecoleng.2018.11.011.

Hidayad RSN. 2020. Perancangan Pusat Wisata Batik dengan Pendekatan *Green Architecture* di Desa Pilang Kabupaten Sragen. [Skripsi]. Universitas 'Aisyiyah Yogyakarta, Yogyakarta. [Indonesian]

Hill MP, Coetzee JA, Martin GD, Smith R, Strange EF. 2020. Invasive alien aquatic plants in South African freshwater ecosystems. In: van Wilgen BW, Measey J, Richardson DM, Wilson JR, Zengeya TA (eds). Biological Invasions in South Africa. Springer, Cham. DOI: 10.1007/978-3-030-32394-3.

Huang X, Xu X, Guan B, Liu S, Xie H, Li Q, Li K. 2020. Transformation of aquatic plant diversity in an environmentally sensitive area, the Lake Taihu drainage basin. Front Plant Sci 11: 513788. DOI: 10.3389/fpls.2020.513788.

Hussner A, Heidbüchel P, Coetzee J, Gross EM. 2021. From introduction to nuisance growth: A review of traits of alien aquatic plants which contribute to their invasiveness. Hydrobiologia 848: 2119-2151. DOI: 10.1007/s10750-020-04463-z.

Inayah ZN, Musa M, Arfiati D, Pratiwi RK. 2023. Community structure of plankton in Whiteleg Shrimp, *Litopenaeus vannamei* (Boone, 1931), pond ecosystem. Biodiversitas 24: 4008-4016. DOI: 10.13057/biodiv/d240738.

Inelova Z, Zayadan B, Zaparina Y, Aitzhan M, Boros E. 2023. Perspectives for the application of aquatic and semi-aquatic plants in biomonitoring of freshwater, saline and soda aquatic ecosystems. Pak J Bot 55 (3): 1099-1115. DOI: 10.30848/PJB2023-3(33).

Kaky E, Nolan V, Alatawi A, Gilbert F. 2020. A comparison between Ensemble and MaxEnt species distribution modelling approaches for conservation: A case study with Egyptian medicinal plants. Ecol Inf 60: 101150. DOI: 10.1016/j.ecoinf.2020.101150.

Kato-Noguchi H. 2023. Invasive mechanisms of one of the world's worst alien plant species *Mimosa pigra* and its management. Plants 12 (10): 1960. DOI: 10.3390/plants12101960.

Kitunda JM. 2017. A History of the Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present. Lexington Books, Maryland. DOI: 10.1017/s0021853718000816.

Kusumastuti ASW, Bisri BM, Solichin C. 2021. Water quality monitoring and evaluation in the Bengawan Solo River region. IOP Conf Ser Earth Environ Sci 641 (1): 012024. DOI: 10.1088/1755-1315/641/1/012024.

Le Moal M, Gascuel-Odoux C, Ménesguen A, Souchon Y, Étrillard C, Levain A, Moatar F, Pannard A, Souchu P, Lefebvre A, Pinay G. 2019. Eutrophication: A new wine in an old bottle? Sci Total Environ 651: 1-11. DOI: 10.1016/j.scitotenv.2018.09.139.

Lesiv MS, Polishchuk AI, Antonyak HL. 2020. Aquatic macrophytes: Ecological features and functions. Stud Biol 14 (2): 79-94. DOI: 10.30970/sbi.1402.619.

Li J, Leng Z, Wu Y, Du Y, Dai Z, Biswas A, Zheng X, Li G, Mahmoud EK, Jia H, Du D. 2022. Interactions between invasive plants and heavy metal stresses: A review. J Plant Ecol 15 (3): 429-436. DOI: 10.1093/jpe/rtab100.

Liao PQ, Chiu YC, Mejia HM, Tan CM, Chen YK, Yang JY. 2023. First report of '*Candidatus Phytoplasma aurantifolia*' associated with the invasive weed *Eclipta prostrata* in Taiwan. Plant Dis 107 (2): 550. DOI: 10.1094/PDIS-03-22-0504-PDN.

Lusiana ED, Mahmudi M, Hutahaean SM, Darmawan A, Buwono NR, Arsad S, Musa M. 2022. A multivariate technique to develop hybrid water quality index of the Bengawan Solo River, Indonesia. J Ecol Eng 23 (2): 123-131. DOI: 10.12911/22998993/144420.

Margalef R. 1958. Information theory in ecology. Syst Gen 3: 36-71.

Mariani M, Beck KK, Fletcher MS, Schneider L, Aquino-López MA, Gadd PS, Zawadzki A. 2020. The impacts of intensive mining on terrestrial and aquatic ecosystems: A case of sediment pollution and calcium decline in cool temperate Tasmania, Australia. Environ Pollut 265: 1-13. DOI: 10.1016/j.envpol.2020.114695.

Maulidyna A, Alicia F, Agustin HN, Dewi IR, Nurhidayah I, Dewangga A, Kusumaningrum L, Nugroho GD, Jumari, Setyawan AD. 2021. Review: Economic impacts of the invasive species water hyacinth (*Eichhornia crassipes*): Case study of Rawapening Lake, Central Java, Indonesia. Intl J Bonorowo Wetlands 11: 18-31. DOI: 10.13057/bonorowo/w110103.

McElrone AJ, Choat B, Gambetta GA, Brodersen CR. 2013. Water uptake and transport in vascular plants. Nat Edu Knowl 4 (5): 6.

Mecina GF, Santos VHM, Andrade AR, Dokkedal AL, Saldanha LL, Silva LP, Silva RMG. 2016. Phytotoxicity of *Tridax procumbens* L. South Afr J Bot 102: 130-136. DOI: 10.1016/j.sajb.2015.05.032.

Melani WR, Apriadi T, Lestari F, Saputra YO, Hasan A, Mawaddah MAR, Fatmayanti N. 2020. Keanekaragaman makrofita dan fitoplankton di Waduk Gesek, Pulau Bintan, Kepulauan Riau. Limnotek 27 (1): 1-12. DOI: 10.14203/limnotek.v27i1.260. [Indonesian]

Merly SL, Pangaribu RD, Ndawi BM. 2023. Community structure of aquatic plants in Mayo Swamp, Kurik District, South Papua Province. Agricola 13 (2): 110-121. DOI: 10.35724/ag.v13i2.5598.

Mikulyuk A, Kujawa E, Nault ME, Van Egeren S, Wagner KI, Barton M, Hauxwell J, Zanden MJV. 2020. Is the cure worse than the disease? Comparing the ecological effects of an invasive aquatic plant and the herbicide treatments used to control it. Facets 5 (1): 353-366. DOI: 10.1139/facets-2020-0002.

Ministry of Environment and Forestry. 2015. Guide Book to Invasive Alien Plant Species in Indonesia. Research, Development and Innovation Agency, Bogor. [Indonesian]

Mishra S, Maiti A. 2017. The efficiency of *Eichhornia crassipes* in the removal of organic and inorganic pollutants from wastewater: A review. Environ Sci Pollut Res 24: 7921-7937. DOI: 10.1007/s11356-016-8357-7.

Mosyaftiani A, Kaswanto K, Arifin HS. 2019. Ground vegetation diversity on different type of riverbank along ciliwung river in Bogor City, West Java. HAYATI J Biosci 26 (1): 35-35. DOI: 10.4308/hjb.26.1.35.

Mustikasari A. 2019. Teknik Pengolahan Airtanah Kawasan Industri Tekstil di Desa Purwosuman dan Desa Patihan, Kecamatan Sidoharjo, Kabupaten Sragen, Provinsi Jawa Tengah. [Thesis]. Universitas Pembangunan Nasional Veteran Yogyakarta, Yogyakarta. [Indonesian]

Nasution AS, Windarti W, Efawani E. 2019. Identification of macrophytes in the swamp area of Sawah Village, Kampar Regency, Riau Province. Asian J Aquat Sci 2 (2): 95-106. DOI: 10.31258/ajoas.2.2.95-106.

Ningsih SD, Khotimah K, Risnanti F, Nugrahanti DA, Ahmad RD, Maulana RM. 2020. Potensi beban pencemaran limbah sektor pertanian, perkebunan dan peternakan terhadap DAS Bengawan Solo di Kabupaten Boyolali. La Geografia 18 (1): 52-70. DOI: 10.35580/lageografia.v19i1.14412. [Indonesian]

Nino MM. 2019. Keanekaragaman Kupu-kupu (Lepidoptera) di sekitar pinggiran Sungai Maslete Kabupaten Timor Tengah Utara. Bio-Edu 4 (2): 50-58. DOI: 10.32938/jbe.v4i2.386. [Indonesian]

Numbere AO. 2019. Impact of invasive Nypa Palm (*Nypa fruticans*) on mangroves in coastal areas of the Niger Delta Region, Nigeria. In: Makowski C, Finkl CW (eds). Impacts of Invasive Species on Coastal Environments: Coasts in Crisis. Springer, Cham. DOI: 10.1007/978-3-319-91382-7_13.

O'Hare MT, Aguiar FC, Asaeda T, Bakker ES, Chambers PA, Clayton JS, Elger A, Ferreira TM, Gross EM, Gunn IDM, Gurnell AM, Hellsten S, Hofstra DE, Li W, Mohr S, Puijalon S, Szoszkiewicz K, Willby NJ, Wood KA. 2018. Plants in aquatic ecosystems: Current trends and future directions. Hydrobiologia 812: 1-11. DOI: 10.1007/s10750-017-3190-7.

Orr MC, Hughes AC, Chesters D, Pickering J, Zhu CD, Ascher JS. 2021. Global patterns and drivers of bee distribution. Curr Biol 31 (3): 451-458. DOI: 10.1016/j.cub.2020.10.053.

Panda RM, Behera MD. 2019. Assessing harmony in distribution patterns of plant invasions: A case study of two invasive alien species in India. Biodivers Conserv 28: 2245-2258. DOI: 10.1007/s42965-020-00135-0.

Poi AS, Neiff JJ, Casco SL, Gallardo, LI. 2020. Macroinvertebrates of *Eichhornia crassipes* (Pontederiaceae) roots in the alluvial floodplain of large tropical rivers (Argentina). Rev Biol Trop 68: 104-115. DOI: 10.15517/rbt.v68is2.44342.

Prabakaran K, Li J, Anandkumar A, Leng Z, Zou CB, Du D. 2019. Managing environmental contamination through phytoremediation by invasive plants: A review. Ecol Eng 138: 28-37. DOI: 10.1016/j.ecoleng.2019.07.002.

Prajoko S. 2018. Water feasibility study of Bengawan Solo River for irrigation: The need for technology to solve rice field pollution in Sragen, Indonesia. Intl J Appl Biol 2 (1): 12-21. DOI: 10.20956/ijab.v2i1.3971.

Prokopuk MS, Zub LM, Bereznichenko YG. 2023. Tropical invaders *Egeria densa* Planch., *Pistia stratiotes* L., and *Eichhornia crassipes* (Mart.) Solms in aquatic ecosystems of Kyiv. Hydrobiol J 59 (1): 41-56. DOI: 10.1615/HydrobJ.v59.i1.40.

Rahmawati R, Rosleine D. 2023. Spatial distribution of invasive plants in Bandung, West Java, Indonesia. Biotropia 30 (2): 171-182. DOI: 10.11598/btb.2023.30.2.1780.

Ramadhani E, Anna AN, Cholil M. 2016. Analisis Pencemaran Kualitas Air Sungai Bengawan Solo Akibat Limbah Industri di Kecamatan Kebakkramat Kabupaten Karanganyar [Thesis]. Universitas Muhammadiyah Surakarta, Surakarta. [Indonesian]

Redowan M. 2015. Spatial pattern of tree diversity and evenness across forest types in Majella National Park, Italy. For Ecosyst 2: 24. DOI: 10.1186/s40663-015-0048-1.

Rizqiyah Z, Nurina VL. 2021. Identifikasi Jenis dan Kelimpahan Miroplastik pada Ikan di hilir Bengawan Solo. Environ Pollut J 1 (2): 167-174. DOI: 10.58954/epj.v1i2.17. [Indonesian]

Rodríguez-Garlito EC, Paz-Gallardo A, Plaza A. 2022. Monitoring the spatiotemporal distribution of invasive aquatic plants in the Guadiana River, Spain. IEEE J Sel Top Appl Earth Observ Remote Sens 16: 228-241. DOI: 10.1109/JSTARS.2022.322520.

Shannon CE, Weaver W. 1949. The Mathematical Theory of Communication. Illinois University Press, Urbana.

Shen S, Guo WF, Wang W, Li XQ. 2021. Effects of above-and below-ground herbivore interactions on interspecific relationship between the invasive plant *Alternanthera philoxeroides* and its native congener *Alternanthera sessilis*. J Appl Ecol 32: 2975-2981. DOI: 10.13287/j.1001-9332.202108.038.

Siddha S, Sahu P. 2022. Impact of climate change on the river ecosystem. In: Madhav S, Kanhaiya S, Srivastav A, Singh V, Singh P (eds). Ecological Significance of River Ecosystems. Elsevier, Amsterdam. DOI: 10.1016/b978-0-323-85045-2.00014-5.

Sitepu BS. 2020. Keragaman dan Pengendalian Tumbuhan Invasif di KHDTK Samboja, Kalimantan Timur. Jurnal Sylva Lestari 8: 351-365. DOI: 10.23960/jsl38351-365. [Indonesian]

Stefanidis K, Oikonomou A, Papastergiadou E. 2021. Responses of different facets of aquatic plant diversity along environmental gradients in Mediterranean Streams: Results from rivers of Greece. J Environ Manag 296: 113307. DOI: 10.1016/j.jenvman.2021.113307.

Sudipta IGM, Arthana IW, Suryaningtyas W. 2020. Kerapatan dan persebaran tumbuhan air di Danau Buyan Kabupaten Buleleng, Provinsi Bali. J Mar Aquat Sci 6: 67-77. DOI: 10.24843/jmas.2020.v06.i01.p09. [Indonesian]

Sulistiono E, Syakbanah NL, Wicaksono RR, Aniriani GW, Hanif M, Prasidya DA, Rizky S. 2023. Sosialisasi Kualitas Air di Daerah Aliran Sungai Bengawan Solo Desa Taji Kecamatan Maduran Kabupaten Lamongan. BERNAS Jurnal Pengabdian Kepada Masyarakat 4 (4): 3485-3490. [Indonesian]

Sutrisna T, Umar MR, Suhadiyah S, Santosa S. 2018. Keanekaragaman dan komposisi vegetasi pohon pada kawasan Air Terjun Takapala dan Lanna di Kabupaten Gowa Sulawesi Selatan. Biome 3: 12-18. DOI: 10.20956/bioma.v3i1.4258. [Indonesian]

Swe T, Lombardo P, Ballot A, Thrane JE, Sample J, Eriksen TE, Mjelde M. 2021. The importance of aquatic macrophytes in a eutrophic

tropical shallow lake. Limnologica 90: 125910. DOI: 10.1016/j.limno.2021.125910.
Thamaga KH, Dube T. 2019. Understanding seasonal dynamics of invasive water hyacinth (*Eichhornia crassipes*) in the Greater Letaba river system using Sentinel-2 satellite data. GISci Remote Sens 56: 1355-1377. DOI: 10.1080/15481603.2019.1646988.
Thiara TSU, Asra R, Adriadi A. 2022. Keanekaragaman dan kelimpahan perifiton pada vegetasi tumbuhan di Rawa Bento sebagai bioindikator kualitas air. Biospecies 15: 1-10. DOI: 10.22437/biospecies.v15i2.14924. [Indonesian]
Thiébaut G, Thouvenot L, Rodríguez-Pérez H. 2018. Allelopathic effect of the invasive *Ludwigia hexapetala* on growth of three macrophyte species. Front Plant Sci 9: 1835. DOI: 10.3389/fpls.2018.01835.
Thiemer K, Immerzeel B, Schneider S, Sebola K, Coetzee J, Baldo M, Thiebaut G, Hilt S, Köhler J, Harpenslager SF, Vermaat JE. 2023. Drivers of perceived nuisance growth by aquatic plants. Environ Manag 71 (5): 1024-1036. DOI: 10.1007/s00267-022-01781-x.
Thomaz BC. 2023. Ecosystem services provided by freshwater macrophytes. Hydrobiologia 850: 2757-2777. DOI: 10.1007/s10750-021-04739-y.
Thukral AK. 2017. A review on measurement of alpha diversity in biology. Agric Resour J 54: 1-10. DOI: 10.5958/2395-146X.2017.00001.1.
Tokhtar VK, Vinogradova YK, Zelenkova VN, Kurskoy AY. 2020. Can invasive plant species "differentiate" colonized ecotopes? Eur J Biosci 14: 2285-2292. DOI: 10.22281/2686-9713-2019-3-39-44.
Valen FS, Hasan V, Ottoni FP, Nafisyah AL, Erwinda M, Annisa AN, Adis MA. 2022. First country record of the bearded gudgeon *Pogoneleotris heterolepis* (Günther, 1869) (Teleostei: Eleotridae) from Indonesia. IOP Conf Ser Earth Environ Sci 1036: 012074. DOI: 10.1088/1755-1315/1036/1/012074.
Van Boheemen LA, Atwater DZ, Hodgins K A. 2019. Rapid and repeated local adaptation to climate in an invasive plant. New Phytol 222: 614-627. DOI: 10.1111/nph.15564.
Verloove F. 2014. A conspectus of *Cyperus* sl (Cyperaceae) in Europe (incl. Azores, Madeira and Canary Islands), with emphasis on non-native naturalized species. Webbia 69 (2): 179-223. DOI: 10.1080/00837792.2014.975013.
Wang H, Molinos JG, Heino J, Zhang H, Zhang P, Xu J. 2021. Eutrophication causes invertebrate biodiversity loss and decreases cross-taxon congruence across anthropogenically-disturbed lakes. Environ Intl 153: 106494. DOI: 10.1016/j.envint.2021.106494.
Weidlich EW, Flórido FG, Sorrini TB, Brancalion PHS. 2020. Controlling invasive plant species in ecological restoration: A global review. J Appl Ecol 57: 1806-1817. DOI: 10.1111/1365-2664.13656.
Wu H, Ding J. 2020. Abiotic and biotic determinants of plant diversity in aquatic communities invaded by water hyacinth [*Eichhornia crassipes* (Mart.) Solms]. Front Plant Sci 11: 01306. DOI: 10.3389/fpls.2020.01306.
Yang Z, Davy AJ, Liu X, Yuan S, Wang H. 2020. Responses of an emergent macrophyte, *Zizania latifolia*, to water-level changes in lakes with contrasting hydrological management. Ecol Eng 151: 105814. DOI: 10.1016/j.ecoleng.2020.105814.
Younas A, Kumar L, Deitch MJ, Qureshi SS, Shafiq J, Naqvi SA, Kumar A, Amjad AQ, Nizamuddin S. 2022. Treatment of industrial wastewater in a floating treatment wetland: A case study of Sialkot Tannery. Sustainability 14: 12854. DOI: 10.3390/su141912854.
Yuliasni R, Kurniawan SB, Marlena B, Hidayat MR, Kadier A, Ma PC, Imron MF. 2023. Recent progress of phytoremediation-based technologies for industrial wastewater treatment. J Ecol Eng 24 (2): 208-220. DOI: 10.12911/22998993/156621.
Yunita LH, Harjuni F, Wulanda Y, Heltria S, Gelis ERE. 2023. Keragaman jenis dan kerapatan tumbuhan air di Sungai Mandau Kabupaten Siak Provinsi Riau. Jurnal Pendidikan MIPA 13 (2): 329-334. DOI: 10.37630/jpm.v13i2.933. [Indonesian]
Yusron M, Jaza MA. 2021. Analisis jenis dan kelimpahan mikroplastik serta pencemaran logam berat pada Hulu Sungai Bengawan Solo. Environ Pollut J 1: 41-48. DOI: 10.58954/epj.v1i1.6. [Indonesian]
Zahro NM, Nisa VC. 2020. Fitoremediasi Eceng Gondok (*Eichhornia crassipes*) pada limbah domestik dan timbal di hilir Sungai Bengawan Solo Gresik sebagai solusi ketersediaan air bersih sekarang dan masa depan. J Chem Edu 4: 73-83. DOI: 10.20527/jcae.v4i2.691. [Indonesian]
Zhang Q, Liu YP, Luo FL, Dong BC, Yu FH. 2019. Does species richness affect the growth and water quality of submerged macrophyte assemblages? Aquat Bot 153: 51-57. DOI: 10.1016/j.aquabot.2018.11.006.
Zhang Y, Jeppesen E, Liu X, Qin B, Shi K, Zhou Y, Thomaz SM, Deng J. 2017. Global loss of aquatic vegetation in lakes. Earth-Sci Rev 173: 259-265. DOI: 10.1016/j.earscirev.2017.08.013.
Zhou YD, Qian H, Xiao KY, Wang QF, Yan X. 2023. Geographic patterns and environmental correlates of taxonomic and phylogenetic diversity of aquatic plants in China. J Syst Evol 61: 979-989. DOI: 10.1111/jse.12939.

INTL J BONOROWO WETLANDS
Volume 14, Number 1, June 2024
Pages: 49-56

P-ISSN: 2775-8052
E-ISSN: 2775-8044
DOI: 10.13057/bonorowo/w140106

Modeling the future distributions of *Centropus bengalensis* (Lesser coucal) in Muara Gembong Wetlands, West Java, Indonesia, related to CMIP5 climate change scenarios

ANDRIO A. WIBOWO[1,♥], VITA MEYLANI[2], NISSA AZZAHRA PRATIWI[2], DIVA NADHYA FEBRIANI[2], NASYA NURUL SURYAWATI[2]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Gd. E FMIPA, Kampus UI Depok, Pondok Cina, Beji, Depok 16424, West Java, Indonesia. Tel.: +62-21-727 0163, +62-21-7884-9009, Fax.: +62-21-7884-9010, ♥email: awbio2021@gmail.com
[2]Program of Biology Education, Faculty of Teaching and Education Science, Universitas Siliwangi. Jl. Siliwangi No. 24, Kahuripan, Tasikmalaya 46115, West Java, Indonesia

Manuscript received: 15 April 2024. Revision accepted: 29 May 2024.

Abstract. *Wibowo AA, Meylani V, Pratiwi NA, Febriani DN, Suryawati NN. 2024. Modeling the future distributions of* Centropus bengalensis *(Lesser coucal) in Muara Gembong Wetlands, West Java, Indonesia, related to CMIP5 climate change scenarios. Intl J Bonorowo Wetlands 14: 49-56.* Wetlands and their water birds have been threatened recently due to climate change. In West Java, Muara Gembong is a threatened wetland along with Lesser coucal (*Centropus bengalensis*, Gmelin 1788). This study aimed to model and forecast the distribution of Lesser coucal in the remaining wetland habitats to support species conservation. The novelty of this study is that it uses future Species Distribution Modeling (SDM) based on climate change scenarios. Modeling was performed based on SDM using R platforms incorporating 19 bioclimatic variables. The climate change scenarios used trajectories based on the 5th Coupled Model Intercomparison Project (CMIP) using RCP 2.6 and RCP 8.5 trajectories for 2050 and 2070. A multicollinearity test was performed, and the coucal occurrences were recorded at five sampling points. The results show climate change scenarios will significantly alter the suitable habitats for coucal, and the Area Under the Curve (AUC) is 0.75. The distribution of the species is mostly affected by isothermality (Bio 3), temperature annual range (Bio 7), and precipitation seasonality (Bio 15). In the low emission scenario, or RCP 2.6, from 2050 to 2070, it is predicted that the suitable habitats for coucals will be increased and expanded to the east and the north in coastal areas. Habitats classified in 2050 as less suitable will become moderately suitable in 2070 under the RCP 2.6 scenario. This condition is contrary to the high emission scenario under RCP 8.5. In this scenario, the habitats with high suitability only increased slightly. At the same time, and opposite to the low emission scenario, the RCP 8.5 scenario will cause moderately suitable habitats to become less suitable or have low suitability. This study provides empirical evidence of how a climate change scenario with high emissions can impact the water birds living in the wetlands.

Keywords: Climate change, coucal, RCP, SDM, wetlands

Abbreviations: CMIP: 5th Coupled Model Intercomparison Project, RCP: Representative Concentration Pathways, SDM: Species Distribution Modeling

INTRODUCTION

Currently, two coucal species exist in the wetland ecosystems: greater coucal (*Centropus sinensis* Stephens, 1815) and Lesser coucal (*Centropus bengalensis*, Gmelin 1788). The diet of *Centropus* is mainly insects, which makes this species important in controlling insect populations so as not to become pests in ecosystems. The difference lies in size and some morphological characteristics; first, compared to the greater coucal, the Lesser coucal has a slightly smaller body size and a shorter bill than the greater coucal. Pale shaft streaks on the head and back feathers differentiate the lesser from the greater coucal. Compared to the greater coucal, which has a crimson red iris, the Lesser coucal has a darker brown iris than the greater coucal. Regarding behavior characteristics and environmental requirements, the Lesser coucal has similar characteristics. The Lesser coucals require the undergrowth in marshy or grassy areas adjoining forests to live in singles or pairs, and for the climate presents to prefer mainly the lowland climate ecosystems. Coucals build a dome-shaped nest made of grass blades on a low tree, where this species hatches from 2 to 4 eggs inside the nests.

The species has a wide distribution from the west, including the Indian subcontinent, and extends to the east across Southeast Asia. Species in Southeast Asia have smaller sizes. It is widely distributed in Indonesia, from inland to coastal habitats. Despite inland or coastal habitats, the preferred habitats were wetlands. On Sumatra Island, *C. bengalensis* is common in Sugihan wetlands, South Sumatra (Setiawan et al. 2020). Still in Sumatra, *C. bengalensis* is commonly found in inland forests and plantations; this includes Lampung in rubber plantations (Tohir et al. 2020). Lorenza (2023) reported the presence of *C. bengalensis* in the inland secondary forest in Jambi Province, Sumatra, far from wetlands and coastal areas. The presence of grass and shrubs has supported the presence of *C. bengalensis* in this secondary forest. In urban Tangerang City, *C. bengalensis* is observed in Situ Cihuni, a wetland in the form of a lake in the middle of the city (Ekowati 2019). In this habitat, *C. bengalensis* appeared in almost 80% of those Situ Cihuni areas.

The species distribution model is significant, as evidenced by current research. As a result, a wide range of methods have been developed to replicate the spatial distribution of species. Species Distribution Modeling (SDM) based on machine learning is one technique widely used to estimate potential species spatial distributions. This model has been used to estimate the probable distributions of animals (Stephenson et al. 2022), crops (Dong et al. 2023), ticks (Pérez et al. 2023), and vegetation. There are many techniques for assessing an SDM's habitat suitability. The Generalized Additive Model (GAM), Bioclim, Domain, MaxEnt (Maximum Entropy), GLM, and Biomapper are some techniques. Each machine-learning technique is unique and has advantages and disadvantages therein. Marcer et al. (2013) claim that SDM is one of the most effective and widely used strategies for modeling the habitat suitability of certain species. SDM is performed in R environments, and R has advantages for developing SDM algorithms.

Currently, SDM has been used in avifauna studies, mainly in modeling the suitable habitats of bird species. In Sanjiangyuan National Park, Zhang et al. (2019) have successfully modeled suitable habitats for three raptor species. In their study, using SDM, it was predicted that the suitable habitats of raptors ranged from 60 to 90%. For water birds, Tian et al. (2023) have found suitable habitats for the anatid Baer's Pochard (*Aythya baeri* Radde, 1863). In Indonesia, SDM has been used to model the suitable habitats of the Javan hawk-eagle (*Nisaetus bartelsi* Stresemann, 1924) (Aryanti et al. 2021), indicating that highly suitable habitats accounted for 30%. Despite growing research on SDM on avifauna species, studies of SDM on particular shorebirds are still limited. Besides that, studies on how those avifaunal species respond to climate change are still lacking.

Muara Gembong is a remaining wetland on the coasts of West Jawa, Indonesia that is threatened due to the land use conversion from mangrove forests and wetlands to fish ponds and settlements. This wetland contains diverse shorebirds, accounting for 43 species (Fathani 2020), including *C. bengalensis* (Lesser coucal). According to the IUCN Red List, lesser coral is classified as the least concern (LC), as can be accessed from https://www.iucnredlist.org/species/22684254/93021566. The rapid conversion of remaining wetlands (Maulani et al. 2021), threatening the wetlands of Muara Gembong, will also threaten the presence of Lesser coucals. Those threats will become more imminent when combined with climate change phenomenon. Then, this study aims to model and forecast the distribution of Lesser coucals in the remaining wetland habitats to support this species' conservation. The novelty of this study is that it uses future distribution modeling based on climate change scenarios.

MATERIALS AND METHODS

The research was conducted on Muara Gembong's wetlands in West Java Province, Indonesia. Based on Species Distribution Modeling (SDM), the study methodology followed methods developed by Semu et al. (2021), including species occurrence, environmental variables, and model evaluations.

Study area

The study areas included 5 sampling locations (Figure 1) in Muara Gembong's wetlands, West Java Province, with geocoordinates of 106.96°-107.44° east longitude and 5.96°-6.20° south latitude. This wetland covers Bekasi Districts in the west and Karawang Districts in the east. The sea bordered the northern parts of the wetlands, and paddy fields and settlements bordered the southern parts. The wetlands are combinations of water vegetated with mangroves and fish ponds.

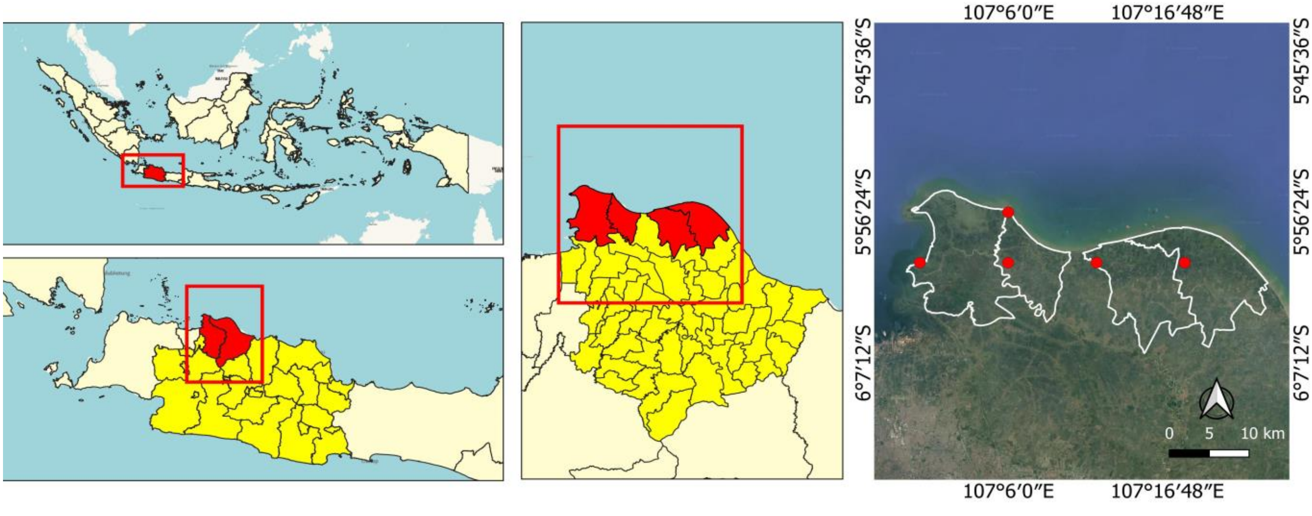


Figure 1. A map of the study area shows five sampling points of occurrences located in Muara Gembong's wetlands, West Java Province, Indonesia

Procedures

Coucal occurrence surveys

The coucal survey in the wetlands of Muara Gembong was conducted for two months, from January to February 2024, with 3 replications for each sampling point. The survey techniques used included visual encounter surveys and multiple surveys through random visits. The survey was conducted during various periods of the day using direct observations supported by binoculars and unaided eyes. Based on the coucal activities, the survey was conducted at 05.30-7.00 am and continued at 04.00-06.15 pm. Coucal was identified using a bird identification book and field guide (MacKinnon and Phillipps 1993). The presence of coucal is then tabulated into a Geographical Information System (GIS) to be mapped into Muara Gembong basemap layers.

Coucal bioclimatic variables

This study includes a range of bioclimatic variables (Table 1), in line with Dong et al. (2023) and Arshad et al. (2022). Bioclimatic variables (Bio 1-19) from the global climate database WordClim (www.worldclim.org, the new version 2.0) (Khanum et al. 2013; Rana et al. 2017) were accessed in January and February 2024 (Hijmans et al. 2005). In recent years, including in Southeast Asia, bioclimatic variables have been extensively utilized in habitat suitability modeling.

Those bioclimatic variables were chosen based on the selection and evaluation of bioclimatic variables that had a significant impact, aiming to create an accurate and comprehensive habitat suitability model. Jackknife analysis was used to evaluate the contribution of each bioclimatic variable to the final model. The model did not evaluate a few bioclimatic variables from the Jackknife analysis since their percentage contribution equaled 0 and had no effect. The bioclimatic variables are thought to have a low average contribution if the values are less than 6% or a low permutation if the values are less than 6%, according to Wei et al. (2018). The contribution percentage and permutation are two important indicators representing the comprehensive quantification of the bioclimatic variable's contribution and significance to the SDM model.

Multicollinearity test

A multicollinearity test was conducted using Pearson's correlation tests (Préau et al. 2018) on 19 bioclimatic variables, ranging from Bio 1 to Bio 19 (Table 1), to prevent collinearity between the variables and develop a model that performs better with fewer variables. Variables that were highly cross-correlated and had r^2 values larger than 0.8 were removed, while variables with r^2 values less than 0.8 were kept for further analysis concerning particular distribution modeling. A variable's predictive ability is deemed unstable and erroneous when multicollinearity occurs because of its strong association with other variables in the model (As'ary et al. 2023). The chosen bioclimatic variables to be employed were Bio 3, 4, 7, 13, and 15 based on the results of the multicollinearity test.

Coucal habitat suitability analysis

The R application version 3.6.3 (Mao et al. 2022) machine learning SDM methods were used in this study to create predicted suitability maps of *C. bengalensis* over Muara Gembong Wetlands. Many R applications, including sp, dismo (Khan et al. 2022), maptools, rgdal (Bivand 2022), and raster packages (Lemenkova 2020), are needed to create the suitability maps. The SDM uses received inputs from 19 bioclimatic variables (Bio 1-19). The receiver operating curve (AUC) area was utilized to assess the performance model, and a Jackknife Test was employed to ascertain the impact and contribution of each bioclimatic variable on the *C. bengalensis* habitat suitability model (Promnikorn et al. 2019). AUC values vary from 0 (least appropriateness) to 1, where a value of more than 0.5 indicates that the final model is extremely good and informative, and a value of less than 0.5 suggests that the final model represents uninformative data.

The prediction map generated by the SDM models was put into GIS for presentation and additional study, according to Hijmans et al. (2005). On the SDM model map, habitat suitability levels are divided into five categories, according to Wei et al. (2018): 0 for unsuitable, 1 for having low suitability, 2 for moderate suitability, 3 for high suitability, and 4 for very high suitability.

CMIP5 future scenario

Two scenarios were used in this investigation. The first scenario is the situation as it is in 2024 or the current distribution, and the second is a future scenario based on the RCP 2.6 and RCP 8.5 estimates from the 5th Coupled Model Intercomparison Project (CMIP) for the year 2070. The future scenario is based on the Fifth Assessment Report (AR5) (IPCC 2008) of the Intergovernmental Panel on Climate Change (IPCC) using downscaled global climate model data from CMIP5. The IPCC's 2014 AR5 applied multiple Representative Concentration Pathways (RCPs) for the CMIP5, representing trajectories of greenhouse gas concentrations rather than emissions. This has replaced the forecasts from the Special Report on Emissions Scenarios (SRES) issued in 2000 (Vuuren et al. 2009). These routes in climate modeling and study describe four potential future climates, all of which are thought to be feasible depending on the quantity of greenhouse gases released shortly. The four RCPs—RPP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5—are called after potential ranges of Radiative Forcing values in the year 2100 in comparison to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively), according to Weyant et al. (2009). Therefore, to simulate the habitat suitability distributions of *C. bengalensis* by the years 2050 and 2070, this study chose the RCP 2.6 models representing low emission scenarios followed by RCP 8.5 models representing high emission scenarios.

Table 1. Bioclimatic variables were used in this study (Ulak and Paudel 2021)

Variables	Sources	Format	Unit
Annual mean temperature (Bio 1)	www.worldclim.org	Image data in Raster	°C
Mean diurnal range (Bio 2) (mean of monthly (max temp - min temp))	www.worldclim.org	Image data in Raster	°C
Isothermality (Bio 3)*	www.worldclim.org	Image data in Raster	%
Temperature seasonality (Bio 4)*	www.worldclim.org	Image data in Raster	°C
Max temperature of the warmest month (Bio 5)	www.worldclim.org	Image data in Raster	°C
Min temperature of the coldest month (Bio 6)	www.worldclim.org	Image data in Raster	°C
Temperature annual range (Bio 7)*	www.worldclim.org	Image data in Raster	°C
Mean temperature of the wettest quarter (Bio 8)	www.worldclim.org	Image data in Raster	°C
Mean temperature of the driest quarter (Bio 9)	www.worldclim.org	Image data in Raster	°C
Mean temperature of warmest quarter (Bio 10)	www.worldclim.org	Image data in Raster	°C
Mean temperature of coldest quarter (Bio 11)	www.worldclim.org	Image data in Raster	°C
Annual precipitation (Bio 12)	www.worldclim.org	Image data in Raster	mm
Precipitation of wettest month (Bio 13)*	www.worldclim.org	Image data in Raster	mm
Precipitation of driest month (Bio 14)	www.worldclim.org	Image data in Raster	mm
Precipitation seasonality (Bio 15)*	www.worldclim.org	Image data in Raster	dimensionless
Precipitation of wettest quarter (Bio 16)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest quarter (Bio 17)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest quarter (Bio 18)	www.worldclim.org	Image data in Raster	mm
Precipitation of coldest quarter (Bio 19)	www.worldclim.org	Image data in Raster	mm

Note: *: selected variables based on multicollinearity test

RESULTS AND DISCUSSION

Coucal occurrences

According to the collected occurrence data and survey, coucals are mainly found (Figure 1) in the middle and towards the coasts of Muara Gembong. They are expanded from the western in the Bekasi and to the eastern in Karawang. Near the coastal areas, coucals were observed in the wetlands mixed with mangroves and fishponds. In the middle parts, coucals were observed in the wetlands mixed with fishponds and settlements.

Coucal bioclimatic variables

There were selected bioclimatic variables according to the multicollinearity test. Those selected bioclimatic variables include Bio 3 (isothermality), Bio 4 (temperature seasonality), Bio 7 (temperature annual range), Bio 13 (precipitation of the wettest month), and Bio 15 (precipitation seasonality). According to percentage contributions 3 (Figure 2), Bio 3 has the highest contributions, accounting for 47.24%, followed by Bio 7 and Bio 15, with values of 21.78% and 16.53%, respectively, indicating the contributions of temperature and precipitation bioclimatic variables in determining the suitable habitats for coucal in Muara Gembong. For Bio 3 (Figure 3), the most suitable habitats for coucal were characterized by isothermality (Bio 3) (47.24%) with values of 80-85. For the temperature annual range (Bio 7) (21.78%), the suitable habitats had differences in annual temperature with ranges of 11.0-11.3°C and 70-75 for precipitation seasonality (Bio 15) (16.53%). The highest suitability occurred when air temperature seasonality (Bio 4) (13.91%) ranged from 420 to 450 and precipitation of the wettest month (Bio 13) (0.52%) ranged from 38.5 to 40.0 mm.

Coucal current potential distributions

Figure 4 shows the current potential distributions of coucal in the Muara Gembong's wetlands with an Area Under the Curve (AUC) value of 0.75 (Figure 5), indicating the model performance of SDM is good. Based on the SDM analysis, the potential habitats are available in the western in the Bekasi District and Karawang in the eastern. The potential habitats were concentrated on the coast and rarely observed in the middle regions. This habitat follows the availability of the wetlands that remain in the coastal area of Muara Gembong. The current potential habitat sizes for coucal based on the suitability levels are high > low > very high suitability levels, with values of 425 km^2 for both high and low suitability levels and 100 km^2 for very high suitability levels (Figure 6). The suitable habitats with very high suitability levels were available in the Karawang Districts, and most of the suitable habitats with high suitability levels were located in the Bekasi District, which expanded to southwestern Jakarta in the west of Bekasi. Those areas are considered suitable for coucals since they have a suitable climate.

Coucal future potential distributions

Climate change will impact the potential habitats for coucal, which is apparent in the suitable habitats' size and locations (Figure 7). Under RCP 2.6, areas considered suitable will decrease compared to current habitats. This includes reducing the suitable habitats classified as highly suitable under the current scenario that will be reduced under RCP 2.6 in 2050. However, in 2070, the highly suitable habitats will be estimated to increase to the extent stated, similar to the current conditions. Under RCP 2.6 in 2070, habitat classified as very suitable, especially in Bekasi District, will be expanded to the southern, increasing from 50 km^2 in 2050 to 350 km^2 in 2070. At the same time, in Karawang District, habitats classified as very suitable will be expanded to the northern to include coastal habitats. Besides that, under RCP 2.6 in 2070, a habitat classified as less suitable or having low suitability in 2050, particularly Karawang District, will be changed to moderately suitable (Figure 7).

Under RCP 8.5 (25 km^2) in the year 2050, the areas classified as very highly suitable are reduced in comparison to similar suitable habitats under RCP 2.6 (50 km^2) in 2050 (Figure 7). In 2070, the suitable habitats classified as very-high suitable will be slightly increased; those very high suitable habitats will be increased to the eastern in Karawang. Compared to the year 2050, under RCP 8.5, very highly suitable habitats will only be available in Karawang in 2070. Under RCP 8.5, habitats previously classified as moderate in 2050 will disappear in 2070 and be replaced by low-suitability habitats (Figure 5).

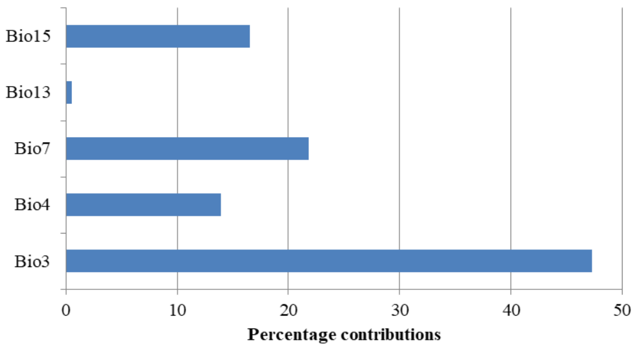


Figure 2. Percentage contribution averages of selected bioclimatic variables (Bio 3, Bio 4, Bio 7, Bio 13, Bio 15) representing different climatic scenarios

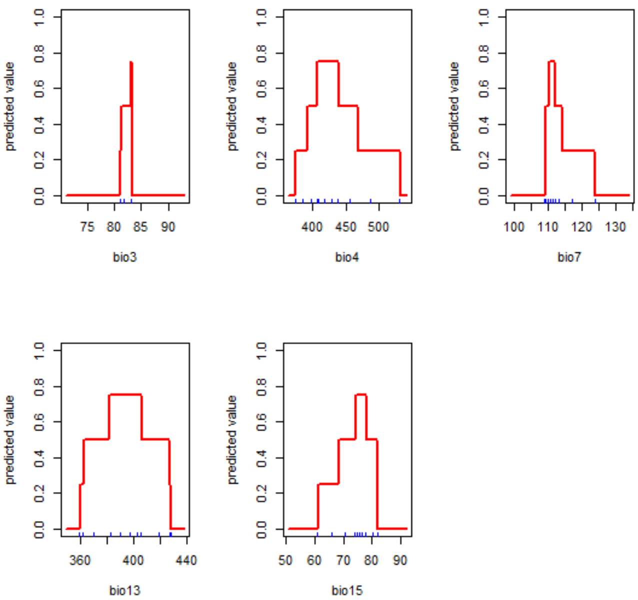


Figure 3. Response curves of selected bioclimatic variables (Bio 3, Bio 4, Bio 7, Bio 13, Bio 15)

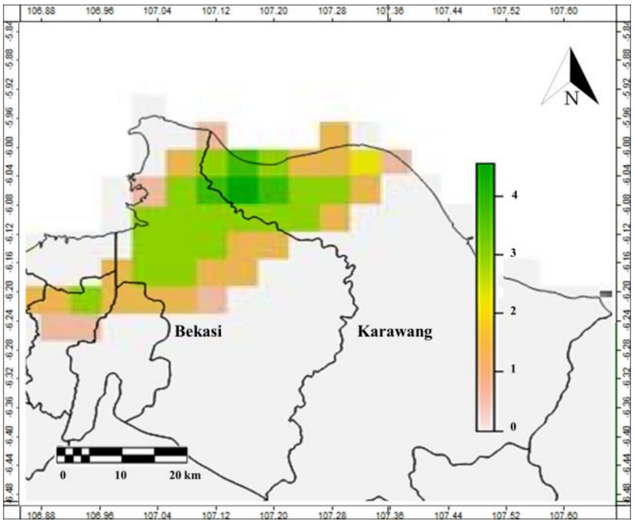


Figure 4. A map of the study area shows the current potential distribution of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia (Suitability level 0: unsuitable, 1: low suitability, 2: moderate suitability, 3: high suitability, 4: very high suitability)

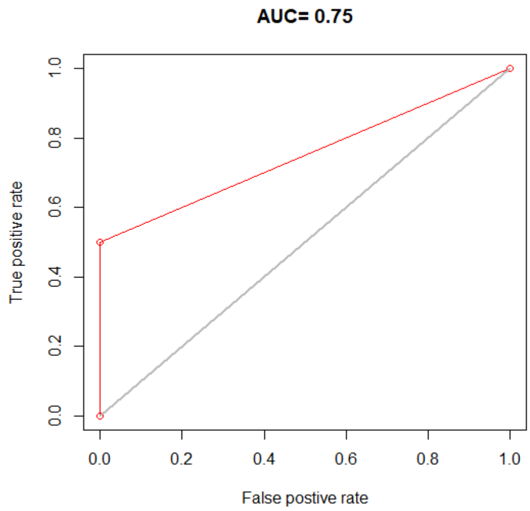


Figure 5. Area Under the Curve (AUC) of the model

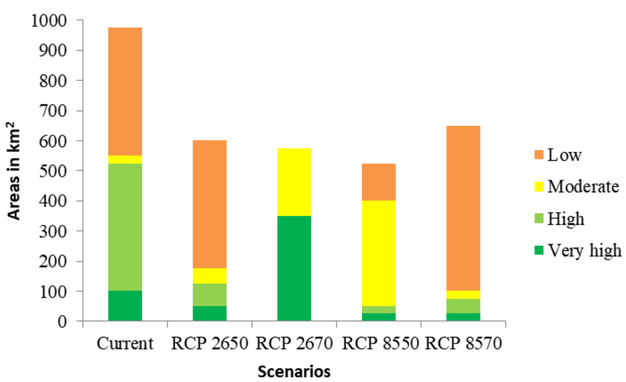


Figure 6. Compositions of areas in km^2 based on current and future potential distributions of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia, based on RCP 2.6 and RCP 8.5 scenarios for 2050 and 2070

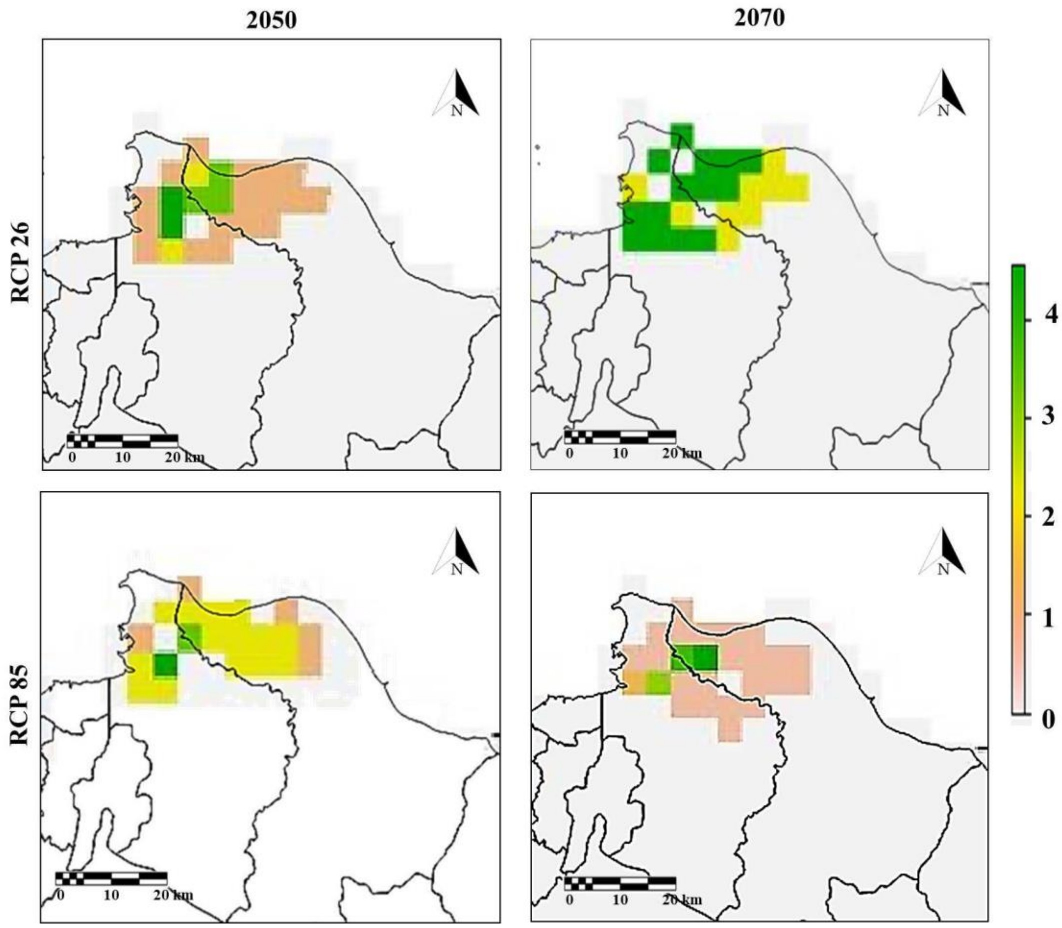


Figure 7. A map of the study area shows the future potential distribution of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia, based on RCP 2.6 and RCP 8.5 scenarios for 2050 and 2070 (Suitability level 0: unsuitable, 1: low suitability, 2: moderate suitability, 3: high suitability, 4: very high suitability)

Discussion

This is the first study that successfully modeled and forecasted future distributions of particular avifauna species, in this case, Lesser coucal species, in particular wetland habitats in Southeast Asia, specifically West Java. Therefore, using SDM methods, this study completed similar previous studies (Moreno et al. 2011, Montenegro et al. 2017). This study confirms that climate change will reduce the suitable habitats for coucals; the high emission scenario of climate change will cause a loss of almost half of its suitable habitats. The loss of significant habitats experienced by avifauna species due to climate change, as found in this study, agrees with current studies. Şekercioğlu et al. (2012) estimated that an avifauna species would lose 25% to 56% of its suitable habitats under low-emission scenarios. At the same time, under the high emissions scenarios, an avifauna species will lose even from 27% to 74% of its suitable habitats, confirming habitat reduction increases due to climate change. This situation is also observed in the Muara Gembong, where under RCP 8.5, a previously classified moderate habitat can become less suitable or have low suitability levels.

This study revealed the suitable habitats for coucals will shift. In 2070, the suitable habitats will shift eastward under RCP 2.6, and under RCP 8.5, the suitable habitats will shift slightly eastward in 2070. The shifting of suitable habitats is an impact of climate change. In their study, Wang et al. (2024) observed that the avifauna suitable habitats shifted southeast in 2050 in the Central Urban Area of Chongqing Municipality. The shifting of suitable habitats varied depending on the characteristics of study areas that were unique and varied among geographical locations.

This study shows most bioclimatic variables influencing climate suitability are dominated by temperature and precipitation-related bioclimatic variables. Those variables include Bio 7, Bio 13, and Bio 15. This finding agrees with previous studies observing that particular Bio 7, Bio 13, and Bio 15 are determinant bioclimatic variables. Temperature-related bioclimatic variables were considered the most important variables that could potentially impact species metabolisms; the other variable is temperature, which affects animal reproductive systems and growth. Under the high emission scenario 2070 indicating temperature rises, some areas previously suitable for climate change became less suitable. Therefore, under the climate change scenario, those areas are becoming warmer, indicating a temperature increase that may not suit climate change. Warming temperatures are associated with slower growth and smaller bird hatchlings (Weeks et al. 2022). The warmer temperatures can inhibit the increases in some avifauna body parts required for movements and flights, including lengths of tarsus, feathers, and head and body sizes (Sauve et al. 2021).

Temperature can also affect breeding regarding the breeding timing of avifauna species, causing habitat to become unsuitable. Climate change, characterized by increased temperature, will lead an avifauna to lay its eggs earlier (Li et al. 2022), and this becomes an unsuitable condition if the food is unavailable for hatchlings. As a result, the bird hatchling does not have the necessary food supply and will starve to death.

Climate change, followed by temperature rise, will affect the presence of avifauna species, including insects that are the coucal's main diet. Coucals are known as insectivores and feed on insects and caterpillars, and a habitat will become suitable if an insect is available in that habitat. According to previous studies, temperature rise due to climate change will cause a delay in the feeding activities of caterpillars (Chenon and Susanto 2006) and lead to a decline in their abundance. This explains why some areas in Muara Gembong become less suitable under the high emission scenario. This probably affects the coucal prey, particularly caterpillar availability and abundance in these areas, which may be reduced following climate change and temperature rises.

Moreover, the indirect causes, besides bioclimatic variables, were also responsible for explaining the suitable coastal habitat reductions in the wetlands of Muara Gembong under high-emission scenarios. Climate changes will be followed by sea level rises, and this is predicted to happen in the coastal areas of West Java, including in Muara Gembong. It is estimated that the sea level rises on Java coasts (Kismawardhani et al. 2018) accounted for 10.6 mm/year, and this, combined with the land subsidence, accounted for 5.37 cm/year, as reported by Andari et al. (2023) will treat coucal habitats in the wetlands. Climate change, followed by sea level rise and land subsidence, will cause flooding and inundation of dryland parts of wetlands that are inhabited by coucals. As a result, inundation caused by sea level rise and climate change (Rosencranz et al. 2018) will cause a coastal loss of areas of the wetlands, including habitats for coucals foraging and nesting.

This study has successfully modeled the future distribution of Lesser coucals under climate change scenarios in the Muara Gembong Wetlands. The low-emission scenario will provide an opportunity for coucals to strive. This condition is different under high-emission scenarios. Therefore, under RCP 8.5 and in the future, habitats classified as moderate will disappear in 2070 and be replaced by low-suitability habitats. This study contributes to the landscape ecology of *C. bengalensis* by informing us that the coastal habitats of this species may change and shift in the future, and conservation initiatives should be aware of these alterations.

ACKNOWLEDGMENTS

We are deeply indebted to the students and community of Muara Gembong, Indonesia which has supported this study.

REFERENCES

Andari L, Sugianto DN, Wirasatriya A, Ginanjar S. 2023. Identification of sea level rise and land subsidence based on sentinel 1 data in the coastal city of Pekalongan, Central Java, Indonesia. Jurnal Kelautan Tropis 26 (2): 329-339. DOI: 10.14710/jkt.v26i2.18324.

Arshad F, Waheed M, Fatima K, Harun N, Iqbal M, Fatima K, Umbreen S. 2022. Predicting the suitable current and future potential distribution of the native endangered tree *Tecomella undulata* (sm.) seem. in Pakistan. Sustainability 14: 7215. DOI: 10.3390/su1412721.

Aryanti NA, Susilo TSSD, Ningtyas AN, Rahmadana, M. 2021. Spatial modeling of Javan Hawk-Eagle (*Nisaetus bartelsi*) habitat suitability in Bromo Tengger Semeru National Park. Jurnal Sylva Lestari 9 (1): 179-189. DOI: 10.23960/jsl19179-189.

As'ary M, Setiawan Y, Rinaldi D. 2023. Analysis of changes in habitat suitability of the Javan Leopard, 2000-2020. Diversity 15: 529. DOI: 10.3390/d15040529.

Bivand R. 2022. R packages for analyzing spatial data: A comparative case study with areal data. Geogr Anal 54 (3): 488-518. DOI: 10.1111/gean.12319.

Chenon RD, Susanto A. 2006. Ecological observations on diurnal birds in indonesian oil palm plantations. J Oil Palm Res April 2006: 122-143.

Dong H, Zhang N, Shen S, Zhu S, Fan S, Lu Y. 2023. Effects of climate change on the spatial distribution of the threatened species *Rhododendron purdomii* in Qinling-Daba Mountains of Central China: Implications for conservation. Sustainability 15 (4): 3181. DOI: 10.3390/su15043181.

Ekowati A. 2019. Pemanfaatan Situ Cihuni sebagai Habitat Berbagai Jenis Burung. [Thesis]. Fakultas Sains dan Teknologi Universitas Islam Negeri Syarif Hidayatullah Jakarta, Jakarta. [Indonesian]

Fathani MH. 2020. Bird Communities in Wetland Ecosystems of Muara Gembong, Bekasi. [Thesis]. Departemen Konservasi Sumber Daya Hutan dan Ekowisata Fakultas Kehutanan Dan Lingkungan Institun Petanian Bogor, Bogor. [Indonesian]

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. Intl J Climatol 25: 1965-1978. DOI: 10.1002/joc.1276.

IPCC. 2008. Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. IPCC Expert Meeting Report, Noordwijkerhout, The Netherlands.

Khan AM, Li Q, Saqib Z, Khan N, Habib T, Khalid N, Majeed M, Tariq A. 2022. Maxent modelling and impact of climate change on habitat suitability variations of economically important Chilgoza pine (*Pinus gerardiana* wall.) in South Asia. Forests 13: 715. DOI: 10.3390/f13050715.

Khanum R, Mumtaz A, Kumar S. 2013. Predicting impacts of climate change on medicinal asclepiads of Pakistan using Maxent modeling. Acta Oecol 49: 23-31. DOI: 10.1016/J.ACTAO.2013.02.007.

Kismawardhani RA, Wirastriya A, Berlianty D. 2018. Sea level rise in The Java Sea based on altimetry satellites data over 1993-2015. IOP Conf Ser: Earth Environ Sci 165: 012006. DOI: 10.1088/1755-1315/165/1/012006.

Lemenkova P. 2020. Using R packages 'Tmap', 'Raster' and 'Ggmap' for cartographic visualization: An example of DEM-based terrain modelling of Italy, Apennine Peninsula. Zbornik radova - Geografski fakultet Univerziteta u Beogradu 68: 99-116. DOI: 10.5937/zrgfub2068099L.

Li X, Liu Y, Zhu Y. 2022. The effects of climate change on birds and approaches to response. IOP Conf Ser: Earth Environ Sci 1011: 012054. DOI: 10.1088/1755-1315/1011/1/012054.

Lorenza A. 2023. Keanekaragaman Jenis Burung di Taman Hutan Raya Bukit Sari Provinsi Jambi. [Thesis]. Program Studi Kehutanan Fakultas Pertanian Universitas Jambi, Jambi. [Indonesian]

MacKinnon JR, Phillipps K. 1993. A Field Guide to the Birds of Borneo, Sumatra, Java, and Bali, the Greater Sunda Islands. Oxford University Press, UK. DOI: 10.1093/oso/9780198540359.001.0001.

Mao M, Chen S, Qian Z, Xu Y. 2022. Using Maxent to predict the potential distribution of the little fire ant (*Wasmannia auropunctata*) in China. Insects 13: 1008. DOI: 10.3390/insects13111008.

Marcer A, Sáez L, Molowny-Horas R, Pons X, Pino J. 2013. Using species distribution modelling to disentangle realised versus potential distributions for rare species conservation. Biol Conserv 166: 221-230. DOI: 10.1016/j.biocon.2013.07.001.

Maulani A, Taufiq-SPJ N, Pratikto I. 2021. Perubahan lahan mangrove di Pesisir Muara Gembong, Bekasi, Jawa Barat. J Mar Res 10 (1): 55-63. DOI: 10.14710/jmr.v10i1.28396. [Indonesian]

Montenegro M, Solitario LA, Manglar SF, Guinto DD. 2017. Niche modelling of endangered philippine birds using GARP and MAXENT. 7th Intl Conf Cloud Comput Data Sci Eng Conflu 2017: 547-551. DOI: 10.1109/CONFLUENCE.2017.7943211.

Moreno R, Zamora R, Martínez JRM. 2011. Predictive modeling of microhabitats for endemic birds in South Chilean temperate forests using Maximum entropy (MaxEnt). Ecol Inf 6 (6): 364-370. DOI: 10.1016/j.ecoinf.2011.07.003.

Pérez MS, Feria Arroyo TP, Venegas Barrera CS, Sosa-Gutiérrez C, Torres J, Brown KA, Gordillo Pérez G. 2023. Predicting the impact of climate change on the distribution of *Rhipicephalus sanguineus* in the Americas. Sustainability 15: 4557. DOI: 10.3390/su15054557.

Préau C, Trochet A, Bertrand R, Isselin-Nondedeu F. 2018. Modeling potential distributions of three European amphibian species comparing ENFA and MaxEnt. Herpetol Conserv Biol 13 (1): 91-104.

Promnikorn K, Jutamanee K, Kraichak E. 2019. Maxent model for predicting potential distribution of *Vitex glabrata* R.Br. in Thailand. Agric Nat Resour 53: 44-48.

Rana SK, Rana HK, Ghimire SK, Shrestha KK, Ranjitkar S. 2017. Predicting the impact of climate change on the distribution of two threatened Himalayan medicinal plants of liliaceae in Nepal. J Mt Sci 14 (3): 558-570. DOI: 10.1007/s11629-015-3822-1.

Rosencranz JA, Thorne KM, Buffington KJ, Takekawa JY, Hechinger RF, Stewart TE, Ambrose RF, MacDonald GM, Holmgren MA, Crooks JA, Patton RT, Lafferty KD. 2018. Sea-level rise, habitat loss, and potential extirpation of a salt marsh specialist bird in urbanized landscapes. Ecol Evol 8 (16): 8115-8125. DOI: 10.1002/ece3.4196.

Sauve D, Friesen VL, Charmantier A. 2021. The effects of weather on avian growth and implications for adaptation to climate change. Front Ecol Evol 9: 569741. DOI: 10.3389/fevo.2021.569741.

Şekercioğlu ÇH, Primack RB, Wormworth J. 2012. The effects of climate change on tropical birds. Biol Conserv 148: 1-18. DOI: 10.1016/j.biocon.2011.10.019.

Semu AA, Bekele T, Lulekal E, Cariñanos P, Nemomissa S. 2021. Projected impact of climate change on habitat suitability of a vulnerable endemic *Vachellia negrii* (Pic.Serm.) Kyal. & Boatwr (Fabaceae) in Ethiopia. Sustainability 13: 11275. DOI: 10.3390/su132011275.

Setiawan A, Iqbal M, Pormansyah, Priscillia B, Setiawan D, Yustian I. 2020. The importance of Sugihan wetlands (South Sumatra province) for birds habitat. AIP Conf Proc 2260: 020003. DOI: 10.1063/5.0015684.

Stephenson K, Wilson B, Taylor M, McLaren K, Veen R, Kunna J, Campbell J. 2022. Modelling climate change impacts on tropical dry forest fauna. Sustainability 14 (8): 4760. DOI: 10.3390/su14084760.

Tian Z, Huo D, Yi K, Que J, Lu Z, Hou J. 2023. Evaluation of suitable habitats for birds based on MaxEnt and Google Earth Engine—A case study of Baer's Pochard *(Aythya baeri*) in Baiyangdian, China. Remote Sens 16: 64. DOI: 10.3390/rs16010064.

Tohir RK, Sitanggang FI, Sutiawan R. 2020. The diversity, distribution and feeding guild of mammals and birds in Institut Teknologi Sumatera (ITERA) landscape. IOP Conf Ser: Earth Environ Sci 537: 012014. DOI: 10.1088/1755-1315/537/1/012014.

Ulak S, Paudel P. 2021. Maxent modelling for habitat suitability of vulnerable tree *Dalbergia latifolia* in Nepal. Silva Fennica 55 (4): 10441. DOI: 10.14214/sf.10441.

Vuuren DPV, Edmonds J, Kainuma M, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque JF, Masui T, Meinshausen M, Nakicenovic N, Smith SJ, Rose SK. 2009. The representative concentration pathways: an overview. Clim Change 109: 5-31. DOI: 10.1007/s10584-011-0148-z.

Wang F, Yuan X, Sun Y, Liu Y. 2024. Species distribution modeling based on MaxEnt to inform biodiversity conservation in the Central Urban Area of Chongqing Municipality. Ecol Indic 158: 111491. DOI: 10.1016/j.ecolind.2023.111491.

Weeks BC, Klemz M, Wada H, Darling R, Dias T, O'Brien B K, Probst CM, Zhang M, Zimova M. 2022. Temperature, size and developmental plasticity in birds. Biol Lett 18 (12): 0357. DOI: 10.1098/rsbl.2022.0357.

Wei B, Wang R, Hou K, Wang X, Wu W. 2018. Predicting the current and future cultivation regions of *Carthamus tinctorius* using Maxent model under climate change in China. Glob Ecol Conserv 16: e00477. DOI: 10.1016/j.gecco.2018.e00477.

Weyant J, Azar C, Kainuma M, Kejun J, Nakicenovic N, Shukla PR, La Rovere E, Yohe G. 2009. Report of 2.6 Versus 2.9 Watts/m^2 RCPP Evaluation Panel. IPCC Secretariat, Geneva.

Zhang J, Jiang F, Li G, Qin W, Li S, Gao H, Cai Z, Lin G, Zhang T. 2019. Maxent modeling for predicting the spatial distribution of three raptors in the Sanjiangyuan National Park, China. Ecol Evol 9 (11): 6643-6654. DOI: 10.1002/ece3.5243.