第 48 卷 第 8 期
2021 年 8 月

湖南大学学报（自然科学版）
Journal of Hunan University（Natural Sciences）

Vol. 48. No. 8.
August 2021

Open Access Article

Integrated Estuary Ecosystem Assessment for Conservation and Sustainable Development in Gunung Anyar Estuary Area, East Java, Indonesia

Rudianto Rudianto[1], Dietriech G. Bengen[2], Very Dermawan[3], Dwi Setijawati[4], Rarasrum Dyah Kasitowati[5]

[1] Head of Research Group of Integrated Coastal Ecosystems Restoration and Sustainable Development (ICESSMENT), Marine Science Department, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia

[2] Department of Marine Sciences and Technology, IPB University, Bogor, West Java, 16680, Indonesia

[3] Head of Water Resources Engineering Study Program, Faculty of Engineering, Brawijaya University, Malang, Indonesia

[4] Agricultural Product Technology Study Program, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia

[5] Marine Science Department, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia

Abstract: Estuaries are the main coastal ecosystems that provide food and environmental benefits for human beings. They play a critical role in maintaining a healthy ecosystem by providing pollution filtration and habitats for nesting, breeding, and feeding many species. However, estuaries in developing countries face severe threats from economic development and human activities. Water pollution, declining mangrove forests, limited carbon sequestration, and stock, reduced mudskippers, and increased plastic discharge. All these factors reduce the capacity of estuaries areas to support human wellbeing sustainably. This research conducts an integrated assessment of various environmental variables that influence the existence of estuaries in Surabaya. The researchers used the Analytical Hierarchy Process (AHP) and the Partial Least Squares (PLS) regression as the basis for policy formulation. The results indicate the need to optimize the use of estuaries for mangrove forest park areas. It is necessary to conduct an integrated ecological assessment involving many ecological variables. For this reason, research related to ecological variables becomes a reference for formulating an integrated estuary management policy. Therefore, the scientific novelty is to find out the conservation estuary based on integrated ecological assessment.

Keywords: integrated assessment, water pollution, carbon, mangroves, gastropods, micro-plastics.

印度尼西亞東爪哇 古農安雅爾河口地區保護和可持續發展綜合河口生態系統評估

摘要: 河口是主要的沿海生態系統，為人類提供食物和環境效益。它們通過為許多物種提供污染過濾和棲息地，為許多物種提供築巢、繁殖和餵養的棲息地，在維持健康的生態系統方面發揮著關鍵作用。然而，發展中國家的河口面臨著經濟發展和人類活動的嚴重威脅。結果是水污染、紅樹林減少、碳固存和儲存有限、彈塗魚數量減少以及塑料排放增加。所有這些因素都降低了河口地區可持續支持人類福祉的能力。本研究旨在對影響泗水市河口存在的各種環境變量進行綜合評估。研究人員使用層次分析法 和偏最小二乘法 回歸作為政策制定的基礎。結果表明，優化河口對紅樹林公園區域的利用，需要進行涉及多個生態變量的綜合生態評價。因此，與生態變量相關的研究成為製定河口綜合管理政策的參考。因此，在綜合生態評價的基礎上找出保護河口是科學創新。

關鍵詞： 綜合評估, 水污染; 碳; 紅樹林, 腹足動物, 微塑料。

Received: May 27, 2021 / Revised: June 6, 2021 / Accepted: July 23, 2021 / Published: August 30, 2021

About the authors: Rudianto Rudianto, Head of Research Group of Integrated Coastal Ecosystems Restoration and Sustainable Development (ICESSMENT), Marine Science Department, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia; Dietriech G. Bengen, Department of Marine Sciences and Technology, IPB University, Bogor, Indonesia; Very Dermawan, Head of Water Resources Engineering Study Program, Faculty of Engineering, Brawijaya University, Malang, Indonesia; Dwi Setijawati, Agricultural Product Technology Study Program, Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, Indonesia; Rarasrum Dyah Kasitowati, Marine Science Department, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia

1. Introduction

Estuaries are transitional water areas between land and sea, where there is a mixture of water from the land and saltwater from the sea. These transition zones are dynamic ecosystems with high productivity and high nutritional and organic content. Estuaries play an essential role in the biogeochemical cycle. They maintain the balance between estuary service capacity and efforts to dilute pollutants [1, 2]. Thus, it is necessary to maintain organic matters and dissolve inorganic nutrients directly from domestic and industrial waste.

Urban growth in coastal cities influences the quality of estuary waters, both in terms of the quality of the marine environment and the habitat of animals and plant biota. The most serious and rapidly worsening impact during the urbanization stage is the increasing concentration of inorganic nutrients and dissolved organic matter affecting the coastal marine system. Many watersheds in developing countries, especially in big cities, are experiencing rapid urbanization. The increase is swift due to domestic exhaust [3, 4, 5, 6]. Therefore, it is important to achieve efficiency in environmental protection and ecosystem sustainability simultaneously. Efforts are needed to manage and protect water from pollution for community welfare and ecologically sustainable development [7, 8].

Water management is critical. Considering that the impact on the health and welfare of the community is significant, the sustainable management of estuary areas is needed [9, 10]. The literature review shows that estuary service assessments are more focused on management actions [11]. The widely performed studies are hydrological actions (134 publications, 47% of all publications reviewed), followed by habitat actions (87 publications, 30%), morphological actions (84 publications, 29%), and water-related measures and measures of sediment quality (30 publications, 10%). Health status evaluation of marine ecosystems requires an integrated approach based on science [12]. It needs to combine knowledge of ecosystem functions and services to produce management decisions to improve the health of estuary ecosystems. Water management plays a vital role in supporting and providing ecosystem services in estuary areas.

The purpose of this study is to assess the integration of estuary ecosystem conditions related to the problem of water pollution due to plastic waste, heavy metal pollution, and the presence of gastropods in mangrove and mudskipper ecosystems. This study also covers the calculation of the environmental carrying capacity for marine eco-tourism. The study relates this assessment to the conservation effort to support a healthy ecosystem, which is an integral part of the sustainable development of coastal areas.

Estuary issues, especially those in urban areas, are currently experiencing an endless process of pollution. Estuaries are biologically productive areas compared to rivers and areas bordering the sea in normal conditions [13]. Estuaries are the most important marine ecosystem globally in terms of both biological production and human activities. An estuary is an environment where physical-chemical conditions fluctuate, and biological processes must overcome these fluctuations [14]. It is because the nutrient concentration is higher, which stimulates primary production. Human activities in estuaries are mainly related to domestic and agricultural waste discharge, especially the disposal of soil sediments into rivers. In addition, there has been a rapid expansion of industrial estates, including the expansion of medium and large-scale housing developments. In addition, increasing the population in large and medium cities means that land is required for various activities. It disrupts the natural balance of estuaries, including changes in the water mass at the coastline. The study on surface water quality in urban estuaries in northern New Jersey [15] shows that the anthropogenic aspects of waste have been the primary source of pollution in the Hackensack River over the past 15 years. Therefore, it is necessary to prevent the entry of combined effluent streams into the estuary by conducting wastewater treatment to improve estuary water quality.

The anthropogenic process does not only cause pollution, but it is also due to the eutrophication process, which causes anoxia and hypoxia on estuaries. One of the specific symptoms commonly found in the estuary region is eutrophication, causing the declination of biotas such as fish, mudskippers, and gastropods. Eutrophication is a fundamental problem in many estuaries. Such problems are closely related to terrestrial and endogenous inputs. Terrestrial inputs come in any materials transported by rainfall, industrial and agricultural activities originating from the estuary, and domestic waste. Endogenous inputs come from aquatic plants, plankton, and microbes. Problems that arise include the increasing chlorophyll and the high production of organic materials, mainly algae plants in the estuary. The latter problem arises due to an increase in the number of nutrients discharged into water bodies. The resultant emergence of algae production is swift, as an increase in the number of nutrients discharged into water bodies results in anoxia and hypoxia and dangerous and toxic algae blooms [16, 17, 18]. The occurrence of eutrophication — which results in unhealthy conditions and leads to the dying condition — is caused by many stressors. The main stress comes from anthropogenic pressure that changes natural ecosystems to irrational use: damaging them with various waste discharges. Urban growth in coastal cities causes actual changes in the quality of the marine environment, which affects animals and plants. Pressure on the estuary continues and ignores the substantial role of ecosystems in the estuary. Humans usually assume that the estuary ecosystem will recover without considering restoring itself to normal [19, 20].

This study uses an estuary ecological approach to determine how to deal with the increasingly severe damage of the estuary environment. The restoration of coastal ecosystems, especially in the estuary region, will benefit biodiversity conservation, including utilizing estuary areas like fishing and marine eco-tourism areas and utilizing sustainable estuaries.

At this time, ecological restoration activities are ignored in Indonesia. Thus, intensive coastal damage continues. Coastal ecosystems provide many benefits, especially for tourism services [21]. Besides that, activities that are important for climate change adaptation are currently extreme. In addition, coastal ecosystems can protect from storms and rising sea levels, prevent the erosion of coastlines, regulate coastal water quality, provide habitat for commercial fisheries and endangered marine species, and ensure food security for many coastal communities. Restoration requires much effort because various disturbances have pushed the ecosystem beyond its ability to recover spontaneously [22]. Mangrove restoration or rehabilitation objectives often include conservation, coastal protection, timber production forests, or mixed forests for high sustainable yields. However, previous experience shows that restoration applied to sustainable development requires restoration activities in the ecological landscape [23, 24]. External influences can affect the performance of estuary ecosystems in restoration, even when the changes caused by restoration affect the surrounding area.

Restoration opportunities abound in various coastal ecosystems near the coast or the estuary region [25]. In each coastal ecosystem at various scales, many opportunities are associated with estuaries, including marshes and tides, rivers and tides; river deltas; deep-sea swamps, coral reef areas, seagrass beds, and mangrove forests. The restoration of coastal ecosystems, especially in the estuary region, will provide benefits for biodiversity conservation. The benefits include human efforts to utilize estuary areas as fishing activity and marine eco-tourism areas.

2. Materials and Methods

2.1. Description of the Study Area

Surabaya is the second-largest city in Indonesia, with a total area of 326.36 km^2. The population of the city reached 2.89 million in 2019 [26]. Of the total population, 49.41 percent were male, and 50.59 percent were female. Population growth in 2019 was 0.37 percent, with the average population growth rate of Surabaya City from 2013 to 2019 was recorded at 0.45 percent per year [26]. The population density of the City of Surabaya is 9,497 people per km^2. Surabaya is generally a lowland area with an altitude between 3–6 meters above sea level, except for areas in the south with an altitude between 25–50 meters above sea level. The average rainfall in Surabaya City in 2019 ranged from 108.08 mm to 158.63 mm.

Surabaya City already has a Regional Spatial Plan in Regional Regulation No. 12 of 2014 concerning the Spatial Plan for Surabaya in 2014–2034. Based on the Regional Medium Terms Program Plan [27] PJMD of the city of Surabaya, Gununganyar District is included as the third priority on the list of Areas for Arrangement and Improvement of the Quality of Housing and Settlements in the City of Surabaya, especially in the east coast area of Surabaya in Gunung Anyar District. The Gununganyar area is a natural protected area in mangrove vegetation located on the east coast of Surabaya City. The Pamurbaya mangrove area plays an essential role in maintaining the balance of the coastal ecosystem and serves as a natural barrier from abrasion and seawater intrusion.

The growth of the city and its population has led to an increase in the development and use of motorized vehicles, which has triggered environmental pollution, including the high production of municipal waste and air and water pollution. Thus, environmental pollution control, solid waste management, and Green Open Space management optimization are significant efforts to improve the quality of the environment. Based on the statistical data of Surabaya City, the volume of waste production is based on the assumption of waste generated by each person per day. The volume of waste produced in Surabaya City increased in 2011 to 9,677.83 m^3/day, and in 2015, it was 9,475.21 m^3/day.

As a metropolitan city, Surabaya has an estuary that has become a foundation for the community as a source of livelihood, a buffer for tidal flooding, and a habitat for biodiversities such as salt marsh grass and algae phytoplankton, worms, shellfish, crabs, and fish. Thus, the estuary plays an important role in maintaining environmental balance. Estuaries in the city of Surabaya are the Porong River estuary, Wonokromo, Kali Mas, the Wonorejo estuary, and the Gunung Anyar estuaries. The condition of the estuaries in Surabaya is facing problems due to pressure from the city's increasing population, including changes in land use, increased water pollution, intensive sedimentation and erosion, and increased plastic waste. The Gunung Anyar estuary is an interesting phenomenon. This estuary has a mangrove forest that is still quite dense, but this estuary is threatened by the increasing number of changes in its use of land use and pollution that is more intensive.

This study established a conceptual model of an estuary city. The specific problem, which needs to be analyzed, is how the estuary ecosystem responds to the input that enters the estuary waters, such as plastics and heavy metal waste. The existence of gastropods strongly related to mangrove forests, including mudskippers, needs to be identified due to the contamination of estuary waters and the capability of mangrove forests to absorb and store carbon. Estuary pollution caused by anthropogenic aspects is also investigated to gain knowledge about the process of eutrophication and to determine to what extent it affects the fertility of the waters. Therefore, the environment's capacity for eco-tourism becomes a strategic point for policy input for the local government in Surabaya.

Gunung Anyar Mangrove Tourism is a mangrove tourism area on the east coast of Java. Gunung Anyar Mangrove Tourism has been developed since 2016 as an alternative type of mangrove tourism in Surabaya. Based on the Surabaya City Regulation No. 12 of 2014 concerning the Surabaya City Spatial Plan, Gunung Anyar Mangrove Tourism is one of Surabaya's coastal zones that must be undertaken to manage sustainable coastal zones. As an estuary area located in an urban area, this region receives a burden from industrial and domestic wastes. Thus, water pollution containing heavy metals occurs. This estuary waters pollution will affect the existence of mangrove forests, including the existence of gastropods. Field observations show that there are many types of plastic waste in the estuary waters of Gunung Anyar. Therefore, there is a close relationship between estuarine waters pollution and plastic waste that decomposes into micro-plastics. The impact caused by pollution is that the mudskipper stays mainly in the mud. Besides that, pollution affects the capacity of mangroves as carbon sequestration. The burden of pollution received by estuaries will affect the ability and capacity of land use for eco-tourism. The population of Surabaya increases 2.5% per year, and land use around the estuary changes intensively.

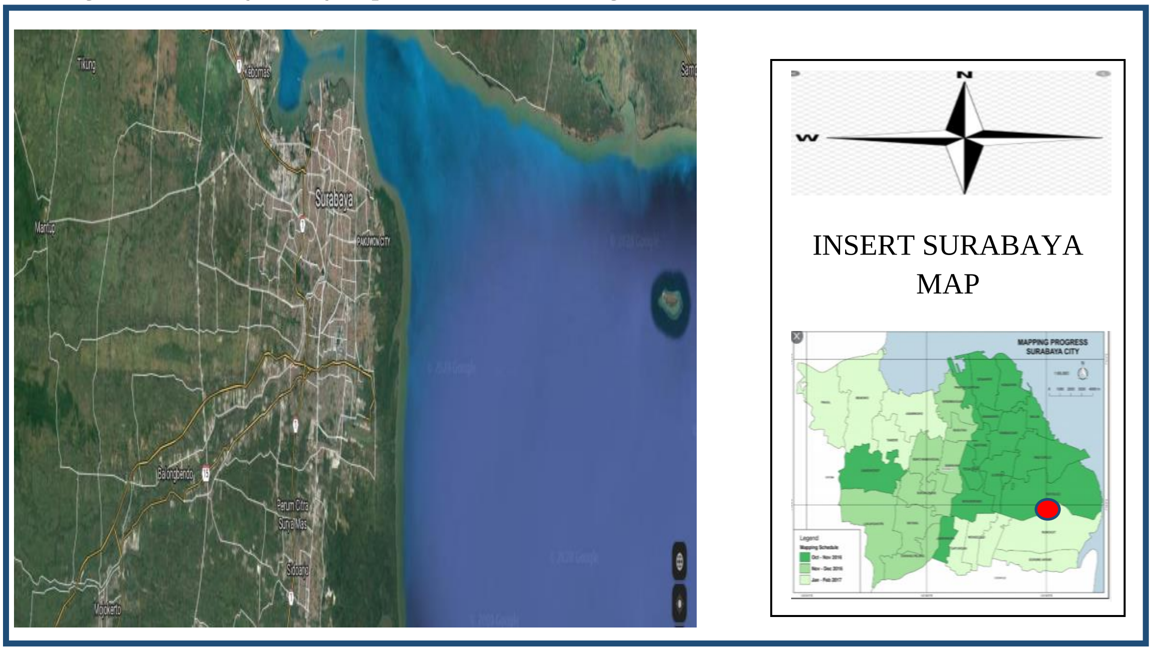

Fig. 1 Map of Gunung Anyar estuary

2.2. Data

It was necessary to conduct an integrated analysis of the estuary ecosystem by interviewing privately and openly with respondents, as shown in Table 1. The interviews covered topics related to water pollution due to heavy metals, mangrove density and gastropods, water pollution and micro-plastics, the carrying capacity of the environment and suitability of the land as a mangrove estuary eco-tourism area, the density of mangrove and mudskipper fish density, and carbon stock and carbon absorption in mangroves.

Table 1 List of respondents

No	Respondents	Number of Respondents
1.	Local People	15
2.	Local Government of Surabaya	10
3.	Local Industries	10
4.	Tourism Awareness Group	5

2.3. Analysis Methods

The Analytical Hierarchy Process (AHP) and the Partial Least Squares (PLS) regression assessed the Integrated Estuary Ecosystem. The Analytical Hierarchy Process is a method for solving an unstructured, complex situation into several components in a hierarchical arrangement by giving a subjective value about the relative importance of each variable and determining which variable has the highest priority to influence the outcome of the situation. Thus, the AHP analysis tested each variable to identify the main factor in explaining each variable with the highest coefficient. The main tool, AHP, aims to obtain a functional hierarchy with human perception as the main input. With hierarchy, a complex and unstructured problem is solved into groups and organized into a hierarchy.

In addition to AHP, a statistical analysis based on Partial Least Squares (PLS) was carried out. In PLS, there are two models: (1) the structural model (inner model) that connects latent variables, and (2) the outer model, which is a measurement model that links indicators with latent variables. The PLS analysis is tested to determine the influence between six variables: (1) Water Pollution (WP), (2) Carbon Stock Variables and Carbon Absorption (CSAM), (3) Water Pollution and Micro-plastics (WPM), (4) Mangrove Density and Gastropod Density (MDG), (5) Density of Mangroves and Mudskippers (DMG), and (6) Carrying Capacity of the Environment and Suitability of the Land (CCES). The conceptual model of PLS is described in Figure 2.

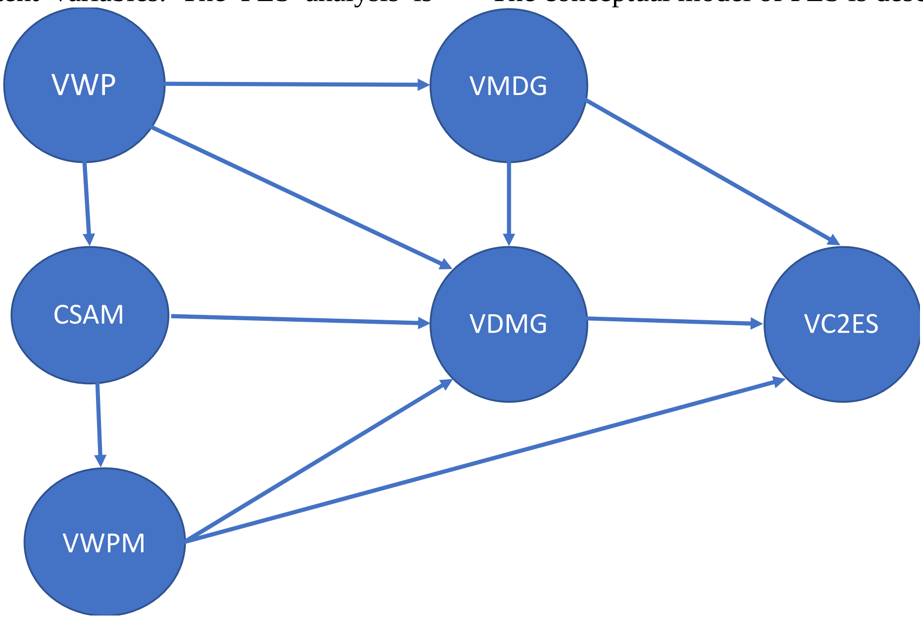

Figure 2 Conceptual model of PLS

Legend:

Acronym for Variable	Description
VWP:	Water pollution (heavy metals)
VMDG:	Mangrove density and gastropod density
VWPM:	Water pollution and micro-plastics
VC2ES:	Carrying capacity of the environment and suitability of the land as a mangrove estuary eco-tourism area
VDMG:	The density of mangroves and mudskippers fish
CSAM:	Carbon stock variables and carbon absorption in mangroves

For each variable expressed in Figure 2, sub-variables are related to each main variable as listed in Table 2.

Table 2 Sub variables of the model

No	Symbols	Remarks
I.	VWP	Variable of water pollution
1.	VWP 1	Average concentration of heavy metals (Cu) in water 0.026 + 0.015 mg/L
2.	VWP 2	The average concentration of heavy metals (Cu) in sediments is 22,147 + 0.835 mg/L
3.	VWP 3	The average concentration of heavy metals (Cu) at the concentration of mangrove roots 4.607 + 0.829 mg/kg
4.	VWP 4	The average concentration of heavy metals (Cu) in the concentration of mangrove leaves is 2,742 +1,502 mg/kg.
5.	VWP 5	Average absorption value of 0.497–0.793 (TF or translocation factor <1) for *Avicennia marina*
II	VMDG	Variable of mangrove density and gastropod density
1.	VDMG 1	The diversity index score for medium categorized mangroves was 1.03–1.56
2.	VDMG 2	Diversity index (E) values categorized as high population uniformity 0.64–0.83
3.	VDMG 3	The dominance index value states that no species dominates 0.28–0.45
4.	VDMG 4	The average density of mangroves at tree level including varying densities, i.e., high, medium, rare, low density
5.	VDMG 5	Relationship of mangroves with gastropod density, which has a strong relationship
III	VWPM	Variable of water pollution and micro-plastics
1.	VWPM 1	Types of micro-plastics in water samples are very high, namely: fiber.
2.	VWPM 2	Micro-plastic types in sediment samples are very high, namely: fiber.
3.	VWPM 3	Micro-plastic types in blackfish samples found 8.88 + 2.22 fiber types.
4.	VWPM 4	Results of micro-plastic abundance in water samples 3532.33 + 521.27 particles/m3
5.	VWPM 5	Results of micro-plastic abundance in sediment samples 758.56 + 34.33 particles/kg
6.	VWPM 6	Results of micro-plastic abundance in samples of blackfish 8.88 + 2.22 particles/gram
IV	VC2ES	Variable of the carrying capacity of the environment and suitability of the land as a mangrove estuary eco-tourism area
1.	VC2ES 1	Land suitability for mangrove tourism has a corresponding Tourism Conformity Index.
2.	VC2ES 2	The carrying capacity of mangrove areas can accommodate 56 people/day for photography activities.

3.	VC2ES 3	The carrying capacity for tracking activities can accommodate 20 people/day.
4.	VC2ES 4	Carrying capacity for boating (as many as 48 people)
5.	VC2ES 5	Carrying capacity for bird watching (16 people/day)
V	VDMG	Variable of the density of mangroves and mudskippers fish.
1.	VDMG 1	Average mangrove density values vary from high and medium density.
2.	VDMG 2	There are four mangrove species: *Avicennia marina*, *Avicennia alba*, *Rhizophora mucronate*, and *Sonneratia alba*.
3.	VDMG 3	Mudskippers fish density values range from 3.6 individual/m2 to 9.2 individual/m2
4.	VDMG 4	The carrying capacity for boating as many as 48 people
5.	VDMG 5	Mangrove density affects mudskipper density by 86%
6.	VDMG 6	A correlation value of 0.92 means that there is a relationship between the density of mangroves and mudskippers with a very strong category
V1	CSAM	Carbon stock variables and carbon absorption in mangroves
1.	CSAM 1	*Sonneratia alba* mangroves can absorb and store high carbon with an absorption value of 301.34 tons of CO2 Ha-1 and a carbon storage rate of 82.18 tons of C CO2 Ha-1.
2.	CSAM 2	*Sonneratia alba* mangroves can absorb and store high carbon with an absorption value of 201.34 tons of CO2 Ha-1 and a carbon storage rate of 62.12 tons of C CO2 Ha-1.
3.	CSAM 3	*Avicennia marina* mangroves can absorb 134.70 tons of CO2 Ha-1 and store carbon at the rate of 36.74 C CO2 Ha-1.
4.	CSAM 4	*Rhizophora mucronata* mangroves have an absorption value of 110.56 tons CO2 Ha-1 and a carbon storage rate of 30.15 tons C Ha-1.
5.	CSAM 5	The total carbon stock in the mangrove surface's sediment, litter, and root sections is 1721.18 tons C Ha-1.
6.	CSAM 6	The total estimated mangrove carbon stock has an area of 40 hectares of 68,847 tons C.

2.4. Data Measurement

The integrated assessment of the estuaries ecosystem requires biological and bio-chemical data related to pollution, mangrove density, micro-plastics, and the relationship between mangrove density and eco-tourism and gastropods and mudskippers. The data were collected from various mangrove areas in the location of the study (five stations). The mangrove areas contained various mangrove species and were used for eco-tourism such as bird watching, photography activities, boating, and fishing.

Water pollution was measured by the concentration of heavy metals indicated by bio-concentration factors and translocation factors. Calculation of the bio-concentration factor (BCF) is used to determine the accumulation of metals in mangroves. Meanwhile, the translocation factor (TF) compares heavy metal concentrations on leaves and roots [28]. It is indicated that the *Avicennia marina* mangrove has the highest average density with a value of 425 individuals/ha. The *Avicennia marina* can be found in all mangrove zoning areas. Overall, mangrove forests in Gunung Anyar Surabaya are regarded as slightly dense, referring to the Decree of the Minister of Environment No. 201 of 2004.

The measurements of Cu heavy metal concentrations in the study area show that the absorption of heavy metals in the *Avicennia marina* has a BCF value < 1. *Avicennia marina* can be categorized as an excluder plant preventing heavy metal from entering the roots into other tissues. *Avicennia marina* can prevent the entry of heavy metals Cu into other networks so that the concentration of heavy metal Cu in the roots is more than the concentration of heavy metal Cu in the leaves.

The relationship between mangrove density and gastropod habitat is crucial for assessing a healthy ecosystem. Various kinds of activities in mangrove ecosystems would affect the condition of gastropod habitats [29]. Animal adaptation includes gastropod resistance to water loss. A gastropod avoids water loss by using the operculum to close the gap in its shell. Gastropods will generally settle in the mud substrate to avoid tides. The environment, habitat, food availability, competition, and predation influence the abundance and distribution of gastropods.

Concerning water pollution and micro-plastics, the results of micro-plastic research on water, sediments, and blackfish (*Hexanematichthys sagor*) in the waters of Gunung Anyar showed micro-plastic contamination. The average micro-plastic abundance is 3,533.33 ± 521.27 particles/m³ in water, 758.56 ± 34.33 particles/kg in sediments, and 8.88 ± 2.22 particles/gram in blackfish [30]. Micro-plastics found in water samples from the waters of Gunung Anyar indicate that there are micro-plastic contents. The results of the calculation of the average abundance of micro-plastics are 3533.33 particles/m3.

Another component that is also important for integrated assessment is the environment's carrying capacity and land suitability as a mangrove estuary eco-tourism area. Carrying capacity analysis is used to consider plans for developing sustainable mangrove tourism [31].

The environmental carrying capacity of the area is adjusted to the characteristics of the location, the potential of the resources, the designation of each area, and the Lp (width area or length of the area utilized with unit m^2) and Lt (unit area for a particular category with unit m^2 or m).

Mangrove areas are important habitats for mudskippers. The previous analysis data show a relationship between mangrove density and mudskipper density [32].

3. Results

3.1. AHP Results

An AHP analysis was carried to determine which environmental factors could be considered priorities in environmental assessment and their relation to sustainability. Figures 3 and 4 display the AHP results for the average concentration of metals and micro-plastic pollution. Figure 3 indicates that the average concentration of heavy metals (Cu) in water is 0.026 + 0.015 mg/L, which is the main factor in explaining these variables with a coefficient of 0.599. At the same time, the measurement of micro-plastic types in blackfish samples found that 8.88 + 2.22 fiber types are the main priority in explaining these variables with a coefficient of 0.470.

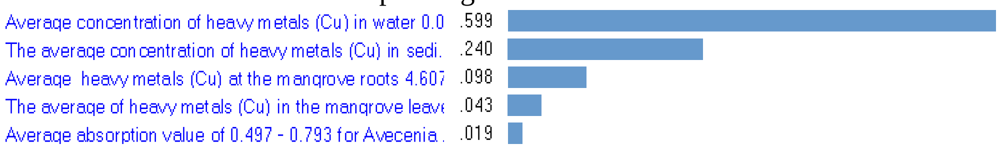

Fig. 3 Synthesis for water pollution (heavy metals)

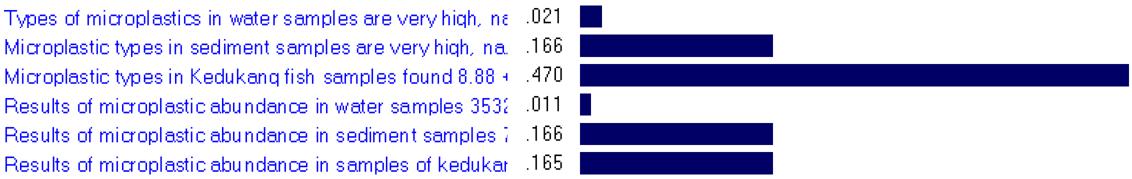

Fig. 4 Synthesis for water pollution and microplastics

Figures 5 and 6 display the AHP results concerning mangrove density and its relationship with gastropod and mudskippers. As shown in Figure 5, the relationship of mangroves with gastropod density, which has a strong relationship, is the main factor in explaining these variables with a coefficient of 0.479. The relationship between mangrove density and mudskipper density shows those mudskippers' fish density values range from 3.6 individuals/m^2 to 9.2 individuals/m2 and are the main priorities in explaining these variables with a coefficient of 0.571.

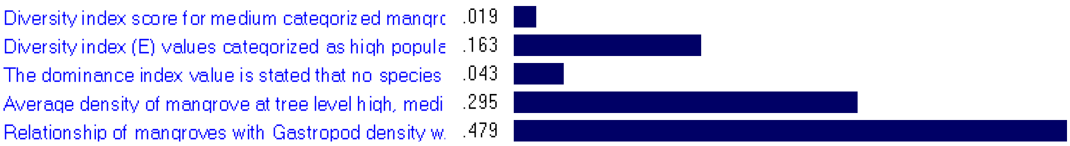

Fig. 5 Synthesis for mangrove density and gastropod density

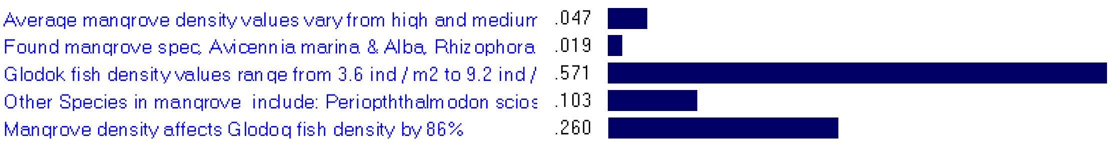

Fig. 6 Synthesis for the density of mangroves and mudskipper density

Since mangroves in estuarine areas are also used for eco-tourism, it is important to determine the carrying capacity related to eco-tourism. Figure 7 displays the AHP results regarding the environment's carrying capacity and land suitability as a mangrove estuary eco-tourism area. It shows that land suitability for mangrove tourism has a corresponding Tourism Conformity Index, which is the main factor in explaining these variables with a coefficient of 0.598.

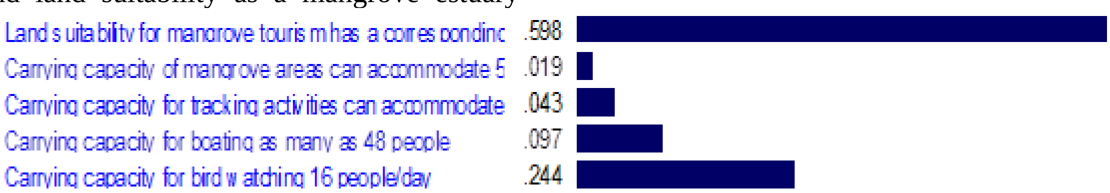

Fig. 7 Synthesis for the carrying capacity of the environment and suitability of the land as a mangrove estuary ecosystem

3.2. PLS Analysis

Convergent validity test results using factor loading values obtained loading values from several indicators <0.500. Thus, this study does not meet the criteria of convergent validity. The results of the discriminant validity test using cross-loading values obtained the values from the loading factor in the columns of each variable of several indicators (in bold), which are not the highest values compared to the cross-loading values of other variables, so they do not meet the discriminant validity criteria. The construct reliability test results using composite reliability and Cronbach's Alpha values obtained test values <0.600, so they do not meet the construct reliability criteria. These results indicate that the inner model test was not met and needs to be improved. Calculations using the preliminary inner model show that each variable has the following composite reliability: CCES: 0.347, CSAM: 0.432, DMG: 0.065, MDG: 0.588, WP: 0.066, and WPM: 0.130. The convergent validity test using factor-loading values obtained loading values > 0.500, meeting the convergent validity criteria. The results of the discriminant validity test using the cross-loading value obtained from the loading factor in the column of each variable are the highest values compared to the value of the cross-loading of other variables, so they meet the discriminant validity criteria. The results of the construct reliability test using the composite reliability value and Cronbach's Alpha value obtained a test value > 0.600, so they meet the construct reliability criteria.

Calculations using the preliminary outer model test produced each variable with composite reliability as follows: CCES: 0.906, CSAM: 0.906, DMG: 0.774, MDG: 0.911, WP: 0.774, and WPM: 1.00. The convergent validity test using factor-loading values obtained loading values > 0.500, meeting the convergent validity criteria. The results of the discriminant validity test using the cross-loading value obtained from the loading factor in the column of each variable (bold) are the highest values compared to the value of the cross-loading of other variables, so they meet the discriminant validity criteria. The results of the construct reliability test using the Composite Reliability value and the Cronbach's Alpha value obtained the test value > 0.600, so they meet the construct reliability criteria. Therefore, the final inner model test result shows that each variable has the R square: CSAM: 0.421, WPM: 0.157, MDG:0.038, DMG: 0.325, and CCES: 0.594. Calculation Q2 is as follows:

$Q^2 = 1 – (1 – R12) (1 – R22) (1 – R32) (1 – R42) (1 – R52)$

$Q^2 = 1 – (1 – 0.421) (1 – 0.157) (1 – 0.038) (1 – 0.325) (1 – 0.594)$

$Q^2 = 1 – (0.579) (0.843) (0.962) (0.675) (0.406)$

$Q^2 = 1 – 0.129$

$Q^2 = 0.871$

The R-square value of each endogenous variable shows the influence of exogenous variables on endogenous variables. The higher the R-square value indicates the greater effect. The Q-square predictive relevance (Q2) of 0.871 indicates that the diversity of the Carrying Capacity of the Environment and Suitability of the Land (CCES) can be explained by the overall model of 87.1 percent, or in other words, the contribution of Water Pollution (WP), Carbon Stock Variable and Carbon Absorption (WP) CSAM), Water Pollution and Microplastics (WPM), Mangrove Density and Gastropod Density (MDG), Density of Mangroves and Mudskippers (DMG) on Carrying Capacity of the Environment and Suitability of the Land (CCES) as a whole (direct influence and indirect effect) of 87. 1 percent. In comparison, the remaining 12.9 percent is contributed by factors not discussed in this study.

The R-square value of each endogenous variable shows the influence of exogenous variables on endogenous variables. The higher the R-square value, the greater the effect. The Q-square predictive relevance (Q2) of 0.871 indicates that the diversity of Carrying Capacity of the Environment and Suitability of the Land (CCES) can be explained by the overall model of 87.1 percent, or in other words, the contribution of Water Pollution (WP), Carbon Stock Variable and Carbon Absorption (WP) CSAM), Water Pollution and Micro-plastics (WPM), Mangrove Density and Gastropod Density (MDG), Density of Mangroves and Mudskippers (DMG) on the Carrying Capacity of the Environment and Suitability of the Land (CCES) as a whole (direct influence and indirect effect) of 87.1 percent. In comparison, the remaining 12.9 percent is contributed by factors not discussed in this study.

Based on hypothesis testing results from each variable, some are accepted, and some are rejected. The accepted variables are H1, H2, H4, H5, H8, H9, and H10. H1 states that Water Pollution (WP) affects the Carbon Stock Variable and Carbon Absorption (CSAM). It means that higher Water Pollution (WP) will increase the Carbon Stock Variable and Carbon Absorption (CSAM). H2 states that Water Pollution (WP) influences Mangrove Density and Gastropod Density (MDG). It means that the higher the Water Pollution (WP), the lower the Mangrove Density and Gastropod (MDG). H4 states that Stock Variable and Carbon Absorption (CSAM) influences Water Pollution and Micro-plastics (WPM). It means that the higher the Stock Variable and Carbon Absorption (CSAM), the higher the Water Pollution and Micro-plastics (WPM).

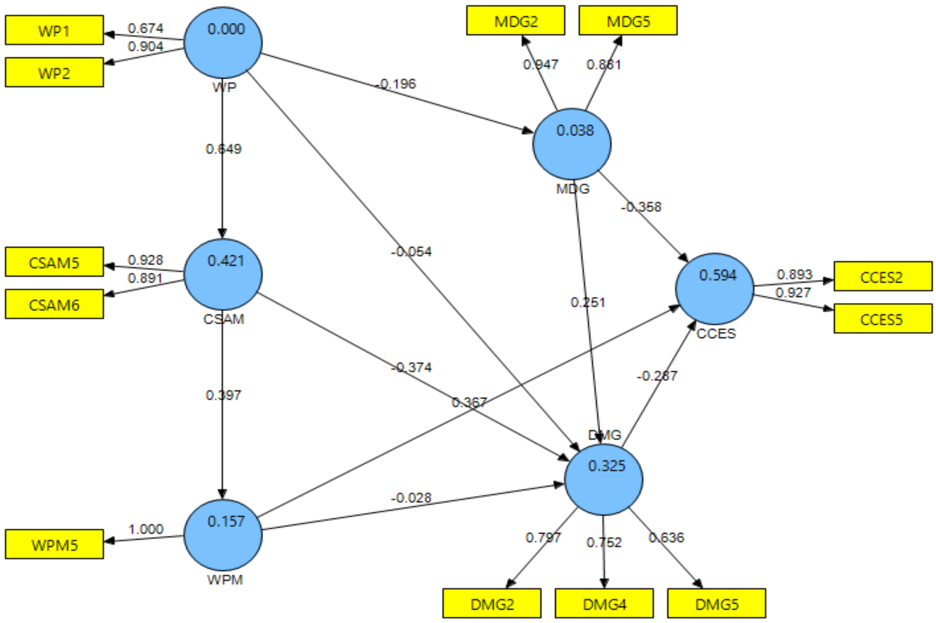

Fig. 10 Final model of research with partial least squares

H5 states that Carbon Stock variables and Carbon Absorption (CSAM) affect the Density of Mangroves and Mudskippers (DMG). It means that the higher the Carbon Stock Variable and Carbon Absorption (CSAM), the lower the Density of Mangroves and Mudskippers (DMG). H8 states that Mangrove Density and Gastropod Density (MDG) influence the Density of Mangroves and Mudskippers (DMG). It means that the higher the Mangrove Density and Gastropod Density (MDG), the higher the Density of Mangroves and Mudskippers (DMG). H9 states that Mangrove Density and Gastropod Density (MDG) influence the Carrying Capacity of the Environment. It means that the higher the Mangrove Density and Gastropod Density (MDG), the lower the Carrying Capacity of the Environment and Suitability of the Land (CCES). H10 states that the Density of Mangroves and Mudskippers (DMG) influences the Carrying Capacity of the Environment and the Suitability of the Land (CCES). It means that the higher the Density of Mangroves and Mudskippers (DMG), the lower the Carrying Capacity of the Environment and Suitability of the Land (CCES).

Meanwhile, the rejected variables include H6, Water Pollution, and Micro-plastics (WPM), which influences the Density of Mangroves and Mudskippers (DMG). It means that high Water Pollution and Micro-plastics (WPM) will not affect the Density of Mangroves and Mudskippers (DMG).

4. Discussion

The variables studied based on AHP analysis could be discussed as follows. Firstly, based on the results of AHP analysis that the variable water pollution (heavy metals) obtained an alternative average concentration of heavy metals (Cu) in water 0.026 0.015 mg/L is the main factor in explaining these variables with a coefficient of 0.599. Then, the focus to solve the heavy metal problem in the Gunung Anyar estuary is to construct an offsite wastewater treatment system. For this reason, it is necessary to have a policy from the Surabaya City government that every industry, human settlement area, and trade area that discharges waste into estuarine waters must first ensure that the waste is processed through a water treatment plant system. Based on previous research, wastewater treatment in the estuary region is also useful for collecting micro-plastics, particles, microbeads, and fibers, including heavy metals [36]. The point source of heavy metals in the water and sediments must be closely monitored [37].

Secondly, the priority that requires attention is the relationship between mangrove density and gastropod density with a coefficient of 0.479. This means that the density of mangroves should be a major concern, given that mangroves in estuaries are currently showing signs of degradation. The decision of the Surabaya City government to conserve estuary areas to become forested areas is the right decision. There are works [38], which analyze best practices and recommendations for implementing mangrove rehabilitation and restoration (R/R) projects in the East Atlantic-Pacific and Indo-Western biogeographic areas over the past 20 years. The results of his research show that every R/R project, whether successful or not, must be published. Therefore, data and information must be analyzed for further development of mangrove R/R practices. For this reason, protection and preservation are needed to protect and conserve the most productive and most threatened coastal ecosystems in the world. Restoration in coastal areas is not only a matter of selecting and planting suitable seeds for the habitat, then maintaining and monitoring their growth but engaging community participation packaged in the co-management system [21].

Thirdly, water pollution and micro-plastics variables are the main factors that require attention. The solution is to build a water treatment plant [36]. Humans affected by toxicity associated with consuming fish contaminated by micro-plastics might depend on the size, related chemicals, and doses related to the marine environment [39]. Thus, micro-plastics may pose risks to human health, especially with increased direct exposure to plastic and localized chemical material. While the impact of micro-plastics on human health is uncertain, it cannot be ignored, and it presents a justification for mitigating the increased entry of plastics into the environment. The mitigation that needs to be done is to encourage the government and population of Surabaya, including industries and households, to reduce plastics.

Fourthly, the environmental carrying capacity and land suitability variables as mangrove estuary eco-tourism areas have obtained minimal alternative land suitable for mangrove tourism, which needs attention, increasing the appropriate tourism conformity index. The tourism suitability index states how appropriate are the existing resources in an area or area to be developed [40]. Mangrove-based tourism in the mangrove tourism suitability refers to the criteria for establishing marine eco-tourism zones. Mangrove tourism along with the biota and its habitat can be used as a tourist attraction. Eight tourism activities that can be carried out in a mangrove eco-tourism area are photography, mangrove tracking, bird watching, tower observation, mangrove observation (education), mangrove nurseries, boat tours, and enjoying the sunrise atmosphere [41].

Fifth, the variable density of mangrove and mudskipper density obtained alternative mudskipper density values ranging from 3.6 individuals/m^2 to 9.2 individuals/m^2, which are the priorities to be addressed. Mangroves play an important role in maintaining mudskipper populations and preventing the reduction of mud layers [41]. The thickness of the mud layer also has an important role in mangrove and non-mangrove habitats. The mudskipper populations are used as bio-indicators of pollution. Pollutants entering the area can be monitored through the abundance and distribution of mudskippers in the mangrove forest. For this reason, mudskipper populations need to be protected from pollutants. The decreasing mudskipper density in the mangrove forest in the Gunung Anyar estuary shows that the mudskipper habitat is being polluted.

Sixth, to maintain the capacity of mangrove as carbon absorption, it requires maintaining an area of 40 hectares of mangrove as a main policy. The negative relationship between carbon stocks and wood density changes indicates that the availability of resources and restrictions can make lighter wood species dominate heavier wood species [42]. Therefore, to increase the absorption and carbon stock, mangrove density needs to be increased, especially in the third category.

The PLS results show that Hypotheses 1, 2, 4, 5, 7, 8, 9, and 10 are accepted. Thus, in the integrated estuary ecosystems, variable water pollution affects carbon stock and carbon absorption. Higher water pollution will cause a higher stock and carbon absorption and influence mangrove density and gastropod density. It means that the higher the water pollution, the lower the mangrove density and gastropod density. Carbon stock and carbon absorption were influenced by water pollution and micro-plastics [33, 34, 35]. The higher the stock and carbon absorption, the higher the water pollution and micro-plastics.

Meanwhile, carbon stock and carbon absorption affect the density of mangroves and mudskippers. It means that the higher the stock and carbon absorption, the lower the density of mangroves and mudskippers. Water pollution and micro-plastics influence the environment carrying capacity and land suitability. It means that the higher the environment carrying capacity and land suitability, the less water pollution. Mangrove density and gastropod density influences the density of mangroves and mudskippers. It means that the higher the mangrove and gastropod density, the higher the mangroves and mudskipper fish density. Mangrove density and gastropod density influences the carrying capacity of the environment. It means that the higher the mangrove density and gastropod density (MDG), the lower the environment carrying capacity and land suitability. The mangroves and mudskippers' densities also influence the carrying capacity of the environment and the suitability of the land.

5. Conclusion

Integrated assessment of the estuarine area is very important for managing the ecosystem services of coastal areas and urban development to support sustainable development agendas. Integrated assessment involving stakeholder participation and support based on biophysical data related to pollution and its impact on the ecosystem would better manage coastal areas. Sustainable development agendas, especially for urban areas, could be achieved by reducing pollution, making the ecosystem healthier, and positively affecting the livelihood of the communities.

The study results in Gunung Anyar Surabaya show that efforts are to prevent water pollution, plastic waste disposal, deforestation of mangroves, decrease mudskipper and gastropod populations, and lower carbon sequestration and storage needed. The Surabaya City government needs to formulate a policy to prevent estuary water pollution by prohibiting waste disposal by any industrial estate, housing, and direct trade to estuary water bodies if not treated first through water treatment plants onsite and onsite offsite.

In addition to optimizing the use of estuaries for the great forest park area, it is necessary to conduct an integrated ecological assessment involving various environmental disciplines. The results of this study indicate that research related to water pollution, mangrove forest density, carbon sequestration, and stock, the presence of mudskippers, and plastic discharge is only used as baseline data to formulate an integrated Gunung Anyar estuary management policy. Nevertheless, Gunung Anyar estuary research also requires economic, social, and cultural research. The limitation of this study is that it only examines the bio-geophysical aspects and has not discussed the socio-economic parameters in more depth. Therefore, it needs to assess the ecological balance of bio-geophysical, social-economic, and culture from a research perspective.

References

[1] PAGLIOSA P, FONSECA A, BARBOSA F, BRAGA E. Urbanization impact on subtropical estuaries: a comparative study of water properties in urban areas and protected areas. *Journal of Coastal Research SI39*, 2006, 731–735.

[2] CONDON R, STEINBERG D, BRONK D. Production of dissolved organic matter and inorganic nutrients by gelatinous zooplankton in the York River estuary, Chesapeake Bay. *Journal of Plankton Research*, 2010, 32: 153–170.

[3] GESAMP and Advisory Committee on Protection of the Sea. A sea of troubles. *GESAMP Reports and Studies*, 2001, 70: 1–35.

[4] QIN H, SU Q, KHU ST, TANG N. Water quality changes during rapid urbanization in the Shenzhen River Catchment: an integrated view of socio-economic and infrastructure development. *Sustainability*, 2014, 6: 7433–7451.

[5] LEHMANN S. Can rapid urbanization ever lead to low carbon cities? The case of Shanghai in comparison to Potsdamer Platz Berlin. *Sustainable Cities and Society*, 2012, 3: 1–12.

[6] RANA MMP. Urbanization and sustainability: challenges and strategy for sustainable development. *Environment, Development, and Sustainability*, 2011, 13: 237–256.

[7] PINTO R, PATRICIO J, NETO JM; SALAS F, MARQUES J. Assessing estuarine quality under the ecosystem services scope: ecological and socio-economic aspects. *Ecological Complexity*, 2010, 7: 389–402.

[8] WOLANSKI E, ANDUTTA F, DELHEZ E. Estuarine hydrology. *Encyclopedia of Lakes and Reservoirs*, 2013.

[9] SANGER D, BLAIR A, DIDONATO G, WASHBURN T, JONES S, CHAPMAN R, BERGQUIST D, RIEKERK G, WIRTH E, STEWART J, WHITE D, VANDIVER L, WHITE S, WHITALL D. Support for integrated ecosystem assessments of NOAA's National Estuarine Research Reserves System (NERRS). *Volume I: The Impacts of Coastal Development on the Ecology and Human Well-Being of Tidal Creek Ecosystems of the US Southeast*, 2008.

[10] RUDIANTO. *Restoration coastal ecosystem*. Brawijaya University Press, Malang, Indonesia, 2018.

[11] BOEREMA A, MEIRE P. Management for estuarine ecosystem services: a review. *Ecological Engineering*, 2017, 98: 172–182.

[12] BORJA A, ELLIOTT M, ANDERSEN J, BERG T, CARSTENSEN J, HALPERN B, HEISKANEN AS; KORPINEN S, STEWART J, MARTIN G, RODRIGUEZ-EZPELATA N. Overview of integrative assessment of marine systems: the ecosystem approach in practice. *Frontiers in Marine Science*, 2016, 3.

[13] DE MIRANDA LB, ANDUTTA FP, KJERFVE B, FILHO BMC. Fundamentals of estuarine physical oceanography. *Ocean Engineering & Oceanography*, 2017, 8.

[14] MUNIZ P, VENTURINI N, MARTINS CC, MUNSHI AB, GARCIA-RODRIGUEZ F, BRUGNOLI E, DAUNER ALL, BICEGO MC, GARCIA-ALONSO J. Integrated assessment of contaminants and monitoring of an urbanized temperate harbor (Montevideo, Uruguay): a 12-year comparison. *Brazilian Journal of Oceanography*, 2015, 63(3): 311–330.

[15] SHIN JY, ARTIGAS F, HOBBLE C, LEE Y–S. A multivariate approach assesses anthropogenic influences on surface water quality in the urban estuary, northern New Jersey. *Environmental Monitoring and Assessment*, 2013, 185: 2777–2794.

[16] BRICKER SB, CLEMENT CG, PIRHALLA DE, ORLANDO SP, FARROW DRG *National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries*. Silver Spring, MD: NOAA, National Ocean Service, Special Projects Office, and the National Centers for Coastal Ocean Science, 1999.

[17] BRICKERA SB, FERREIRA JG, SIMASB T. An integrated methodology for assessment of estuarine trophic status. *Ecological Modelling*, 2003, 169: 39–60.

[18] JIN MY, LEE JJ, OH HJ, NAM GS, JEONG KW, OH JM, CHANG KH. The response of catchment ecosystems in eutrophic agricultural reservoirs to water quality management using DOM fluorescence. *Sustainability*, 2019, 11: 7207.

[19] BORJA Á, DAUER DM, ELLIOT M. Medium-and long-term recovery of estuarine and coastal ecosystems: patterns, rates, and restoration effectiveness. *Estuaries and Coasts*, 2010, 33: 1249–1260.

[20] PAGLIOSA PR, FONSECA A, BARBOSA, FAR, SOURCE EB. Urbanization impact on subtropical estuaries: a comparative study of water properties in urban areas and protected areas. Journal of Coastal Research, Special Issue No. 39. *Proceedings of the 8th International Coastal Symposium (ICS 2004)*, 2004, Vol. II(Winter 2006): 731–73.

[21] RUDIANTO. Coastal village mangrove ecosystem restoration based on co-management restoration of mangrove ecosystem in coastal village based on management. *Journal of Fisheries, Gadjah Mada University*, 2018, 20(1): 1–12.

[22] ANDRADI-BROWN D, HOWE C, MACE GM, KNIGHT AT. Do mangrove forest restoration or rehabilitation activities return biodiversity to pre-impact levels? *Environmental Evidence*, 2013, 2.

[23] FIELD C. Rehabilitation of mangrove ecosystems: an overview. *Marine Pollution Bulletin*, 1999, 37: 383–392.

[24] LEWIS RR. III. Ecologically based goal setting in the mangrove forest and tidal marsh restoration. *Ecological Engineering*, 2000, 15: 191–198.

[25] MITRA A, ZAMAN S. *Basics of marine and estuarine ecology. Department of Marine Science*. University of Calcutta Kolkata, West Bengal, India, 2018.

[26] DIEFENDERFER RM, THOM HL, ADKINS JE. *A systematic approach to coastal restoration. National Oceanic and Atmospheric Administration Coastal Services Center. Contract EA1330-02-RQ-0029 Battelle Contract 44188. Battelle Memorial Institute Pacific Northwest Division Richland, Washington*. 2003.

[26] CENTRAL BUREAU OF STATISTICS. *Regional Statistics of the City of Surabaya in 2020. Central Bureau of*

Statistics for the City of Surabaya. Regional Accounts Section and Surabaya City Statistical Analysis. https://surabayakota.bps.go.id/publication/download.html?nrbvfeve=MDdiYzY3ZmI5OGUxZGM2YtdkYTUxNzMx&xzmn=aHR0cHM6Ly9zdXJhYmF5YWtvdGEuYnBzLmdAvLMDkL3BM, 2020.
[27] SURABAYA CITY GOVERNMENT. *Regional Medium-Term Development Plan of Surabaya City. 2016-2021 (Regional Regulation Number 10 of 2016)*. https://bappeko.surabaya.go.id/images/File%20Upload/RPJMD-2016-2021.pdf, 2015.
[28] SARINASTITI, FF *Analysis of copper (Cu) heavy metal concentration in Avicennia marina mangroves in Gunung Anyar mangrove ecosystem, Surabaya. Study Program of Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[29] WIDYAWATII N. *Relationship between mangrove density and density. Gastropods in Gunung Anyar Mangrove Ecosystem, Surabaya. Study Program of Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[30] SYIFA AN. Microplastic content in water, sediments, and blackfish (Hexanematichthys sagor) in *Gunung Anyar, Surabaya, East Java. Study Program of Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[31] PUTRI HAI. *Analysis of land suitability and carrying capacity as eco-tourism area in Gunung Anyar mangrove estuary, Surabaya, East Java. Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[32] HARTIYANINGSIH P. *Relationship between mangrove and mudskipper density (Family: Gobiidae) in the Gunung Anyar mangrove ecosystem, Surabaya, East Java. Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[33] MILLATA WA. *Estimating estimated carbon stock and carbon dioxide absorption in Gunung Anyar, Surabaya, and East Java mangrove ecosystems. Marine Sciences Department of Fisheries and Marine Resource Utilization, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Thesis*. 2019.
[34] POEDJIRAHAJOE E, MARSONO D, WARDHANI KF. *Use of principal component analysis in the spatial distribution of mangrove vegetation on the north coast of Pemalang. Department of Forest Resources Conservation*, 2016.
[35] HOWARD J, HOYT S, ISENSEE K, TELSZEWSKI M, PIDGEON E. *Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses*. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature, Arlington, Virginia, 2014.
[36] CONLEY K, CLUM A, DEEPE J, LANE H, BECKINGHAM B. Wastewater treatment plants as a source of microplastics to an urban estuary: removal efficiencies and loading per capita over one year. *Water Research X*, 2019, 3.
[37] MIR MA, ALI ML, ISLAM MS, RAHMAN MZ. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management*, 2016, 5: 27–35.
[38] PORTILLO JL, LEWIS R, SAENGER P, RIVERA-MONROY VH. Mangrove forest restoration and rehabilitation. *RG*, 2017.
[39] SMITH M, LOVE DC, ROCHMAN CM, NEFF RA. Microplastics in seafood and the implications for human health. *Current Environmental Health Reports*, 2018.
[40] IINSANI N, WIRAHAYU YA, ARIF DA, SABILAU, OG. Feasibility study, carrying capacity, and eco-tourism activities in the Blekok Village mangrove area of Situbondo Regency. *Sumatra Journal of Disaster, Geography and Geography Education*, 2019, 3(2): 175–181.
[41] SOLANKI D, KANEJIVA J, GOHIL B. Population status of mudskippers in mangrove and non-mangrove area of Ghogha Coast, Bhavnagar Gujarat, India. *RG Journal*, 2017.
[42] RAY R, GANGULY D, CHOWDURY C, YANA TK. Carbon sequestration and an annual increase of carbon stock in a mangrove forest. *RG Journal Atmospheric Environment*, 2011, 45(28): 5016–5024.

参考文:

[1] PAGLIOSA P, FONSECA A, BARBOSA F, BRAGA E. 城市化對亞熱帶河口的影響：城市地區和保護區水特性的比較研究。海岸研究雜誌 SI39, 2006, 731–735。
[2] CONDON R, STEINBERG D, BRONK D。切薩皮克灣約克河河口凝膠狀浮游動物對溶解有機物和無機營養物的生產。浮游生物研究雜誌，2010，32：153-170。
[3] 通用電氣和海洋保護諮詢委員會。煩惱海。 通用電氣 報告和研究，2001 年，70：1-35。
[4] QIN H, SU Q, KHU ST, TANG N。 深圳河流域快速城市化過程中的水質變化：社會經濟和基礎設施發展的綜合視角。可持續性，2014，6：7433-7451。
[5] LEHMANN S。 快速的城市化能帶來低碳城市嗎？上海與柏林波茨坦廣場的比較。可持續城市與社會，2012 年，3：1-12。
[6] RANA MMP。城市化和可持續性：可持續發展的挑戰和戰略。環境、發展和可持續性，2011 年，13：237-256。
[7] PINTO R, PATRICIO J, NETO JM; SALAS F, MARQUES J。 在生態系統服務範圍內評估河口質量：生態和社會經濟方面。生態復雜性，2010，7：389-402。
[8] WOLANSKI E、ANDUTTA F、DELHEZ E. 河口水文學。湖泊和水庫百科全書，2013 年。
[9] SANGER D、BLAIR A、DIDONATO G、WASHBURN T、JONES S、CHAPMAN R、BERGQUIST D、RIEKERK G、WIRTH E、STEWART J、WHITE D、VANDIVER L、WHITE S、WHITALL D。支持綜合生態系統評估美国国家海洋和大气管理局 的國家河口研究儲備系統。第 I 卷：沿海開發對美國東南部潮汐溪生態系統生態和人類福祉的影響，2008 年。
[10] RUDIANTO。恢復沿海生態系統。 布拉維賈亞大學出版社，印度尼西亞瑪瑯，2018 年。
[11] BOEREMA A, MEIRE P. 河口生態系統服務管理：綜述。生態工程，2017，98：172-182。

[12] BORJA A, ELLIOTT M, ANDERSEN J, BERG T, CARSTENSEN J, HALPERN B, HEISKANEN AS; KORPINEN S, STEWART J, MARTIN G, RODRIGUEZ-EZPELATA N. 海洋系統綜合評估概述：實踐中的生態系統方法。海洋科學前沿，2016，3。

[13] DE MIRANDA LB、ANDUTTA FP、KJERFVE B、FILHO BMC。河口物理海洋學的基礎。海洋工程與海洋學，2017，8。

[14] MUNIZ P, VENTURINI N, MARTINS CC, MUNSHI AB, GARCIA-RODRIGUEZ F, BRUGNOLI E, DAUNER ALL, BICEGO MC, GARCIA-ALONSO J. 污染物綜合評估和城市化溫帶港口監測（烏拉圭蒙得維的亞）：12 年的比較。巴西海洋學雜誌，2015 年，63(3)：311–330。

[15] SHIN JY、ARTIGAS F、HOBBLE C、LEE Y-S。評估人為對新澤西州北部城市河口地表水質量的影響：多變量方法。環境監測與評估，2013 年，185：2777-2794。

[16] BRICKER SB、CLEMENT CG、PIRHALLA DE、ORLANDO SP、FARROW DRG。國家河口富營養化評估：國家河口營養豐富的影響。馬里蘭州 銀泉：美國國家海洋和大氣管理局、國家海洋局、特別項目辦公室和國家沿海海洋科學中心，1999 年。

[17] BRICKERA SB, FERREIRA JG, SIMASB T. 一種評估河口營養狀態的綜合方法。生態建模，2003，169：39-60。

[18] JIN MY、LEE JJ、OH HJ、NAM GS、JEONG KW、OH JM、CHANG KH。富營養化農業水庫流域生態系統對使用 多米 熒光進行水質管理的響應。可持續性，2019 年，11：7207。

[19] BORJA Á, DAUER DM, ELLIOT M. 河口和沿海生態系統的中長期恢復：模式、速率和恢復效果。河口和海岸，2010 年，33：1249-1260。

[20] PAGLIOSA PR, FONSECA A, BARBOSA, FAR, SOURCE EB。城市化對亞熱帶河口的影響：城市地區和保護區水特性的比較研究。海岸研究雜誌，特刊第 39 號。第八屆國際海岸研討會論文集，2004 年，卷。 II（2006 年冬季）：731-73。

[21] RUDIANTO。 基於協同管理的沿海村莊紅樹林生態系統修復 以管理為基礎的沿海村莊紅樹林生態系統修復漁業雜誌，加札馬達大學，2018 年，20(1)：1-12。

[22] ANDRADI-BROWN D、HOWE C、MACE GM、KNIGHT AT。紅樹林恢復或恢復活動是否使生物多樣性恢復到受災前的水平？環境證據，2013，2。

[23] FIELD C. 紅樹林生態系統的恢復：概述。海洋污染公報，1999 年，37：383-392。

[24] 劉易斯 RR。三、基於生態學的紅樹林目標設定和潮汐沼澤恢復。生態工程，2000，15：191-198。

[25] MITRA A, ZAMAN S. 海洋和河口生態學基礎。海洋科學系。加爾各答大學加爾各答，印度西孟加拉邦，2018 年。

[26] DIEFENDERFER RM、THOM HL、ADKINS JE。沿海恢復的系統方法。國家海洋和大氣管理局海岸服務中心。合同 EA1330-02-RQ-0029 巴特尔合同 44188。巴特爾紀念研究所太平洋西北分部，華盛頓州里奇蘭。2003 年。

[26] 中央統計局。泗水市 2020 年區域統計數據。泗水市中央統計局。區域賬戶部分和泗水市統計分析。https://surabayakota.bps.go.id/publication/download.html?nrbvfeve=MDdiYzY3ZmI5OGUxZGM2YtdkYTUxNzMx&xzmn=aHR0cHM6Ly9zdXJhYmF5YWtvdGEuYnBzLmdAvLMD20L3

[27] 泗水市政府。泗水市區域中期發展計劃。 2016-2021（2016 年第 10 號地區法規）。https://bappeko.surabaya.go.id/images/File%20Upload/RPJMD-2016-2021.pdf，2015 年。

[28] SARINASTITI FF。 泗水 古農安雅爾紅樹林生態系統中 海葵紅樹林中銅 重金屬濃度的分析。海洋科學研究計劃，漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[29] WIDYAWATII N. 紅樹林密度與密度之間的關係。泗水 古農安雅爾紅樹林生態系統中的腹足類動物。海洋科學研究計劃，漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[30] SYIFA AN。 東爪哇泗水 古農安雅爾水域的水、沉積物和黑魚中的微塑料含量。海洋科學研究計劃漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[31] PUTRI HAI。東爪哇泗水 古農安雅爾紅樹林河口生態旅遊區土地適宜性和承載能力分析。海洋科學計劃 漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[32] HARTIYANINGSIH P. 東爪哇泗水古農安雅爾紅樹林生態系統中紅樹林與彈塗魚密度之間的關係。海洋科學計劃 漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[33] MILLATA WA。東爪哇泗水 古農安雅爾紅樹林生態系統中估算的碳儲量和二氧化碳吸收分析。海洋科學計劃 漁業和海洋資源利用系，漁業和海洋科學學院，布拉維賈亞大學。論文。 2019。

[34] POEDJIRAHAJOE E、MARSONO D、WARDHANI KF。主成分分析在八馬朗北岸紅樹林植被空間分佈中的應用。森林資源保護司，2016。

[35] HOWARD J、HOYT S、ISENSEE K、TELSZEWSKI M、PIDGEON E。沿海藍碳：評估紅樹林、潮汐鹽沼和海草中碳儲量和排放因子的方法。保護國際，教科文組織政府間海洋學委員會，國際自然保護聯盟，弗吉尼亞州阿靈頓，2014 年。

[36] CONLEY K, CLUM A, DEEPE J, LANE H, BECKINGHAM B. 作為城市河口微塑料來源的污水處理廠：一年內的去除效率和人均負荷。水研究 X, 2019, 3.

[37] MIR MA、ALI ML、伊斯蘭女士、拉赫曼 MZ。孟加拉國卡納普里河水和沈積物中重金屬的初步評價。環境納米技術，監測與管理，2016，5：27-35。

[38] PORTILLO JL, LEWIS R, SAENGER P, RIVERA-MONROY VH。紅樹林恢復和恢復。 RG，2017。

[39] SMITH M，愛 DC，ROCHMAN CM，NEFF RA。海產品中的微塑料及其對人類健康的影響。當前環境健康報告，2018 年。

[40] IINSANI N、WIRAHAYU YA、ARIF DA、SABILAU、OG。 西圖邦多攝政布萊克村紅樹林區的可行性研究、承載能力和生態旅遊活動。蘇門答臘災害、地理和地理教育雜誌，2019 年，3(2)：175–181。

[41] SOLANKI D, KANEJIVA J, GOHIL B。印度古吉拉特邦古吉拉特邦 戈加 海岸紅樹林和非紅樹林地區彈塗魚的種群狀況。RG 雜誌，2017 年。
[42] RAY R、GANGULY D、CHOWDURY C、YANA TK。紅樹林中的碳固存和每年增加的碳儲量。RG 雜誌 大氣環境，2011，45(28)：5016-5024。