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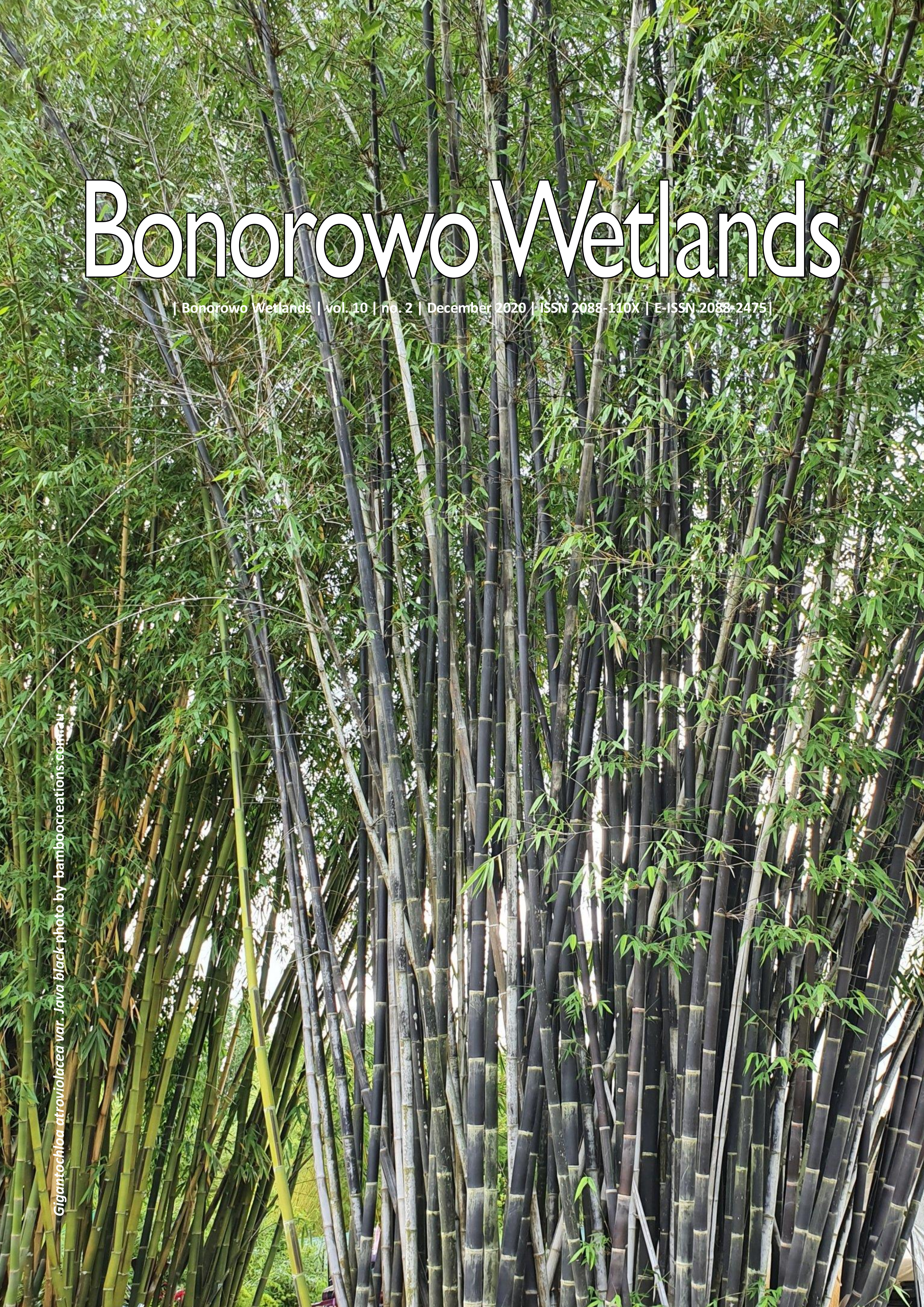

Gigantochloa atroviolacea var. *Java black* photo by bamboocreations.com.au

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Community structure of phytoplankton in the surface and thermocline layers of Sangihe and Talaud waters, Indonesia

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[1]Departement of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada. Jl. Flora, Bulaksumur, Sleman 55281, Yogyakarta, Indonesia. Tel.: +62-274-563062, ♥email: lely412@yahoo.com

[2]Research Center for Oceanography, Indonesia Institute of Sciences (P2O-LIPI). East Ancol, North Jakarta 14430, Jakarta, Indonesia

Manuscript received: 9 July 2019. Revision accepted: 15 August 2019.

Abstract. *Sriwijayanti LA, Djumanto, Setiawan RY, Firdaus MR, Fitriya N, Sugeha HY. 2019. Community structure of phytoplankton in the surface and thermocline layers of Sangihe and Talaud waters, Indonesia. Bonorowo Wetlands 9: 57-64.* This study aimed to determine the species dominance and distribution and community structure of phytoplankton in the surface and thermocline layers of Sangihe and Talaud waters Indonesia. Phytoplankton samples were collected at the Sangihe-Talaud waters in October 2018 at 14 research stations. Water samples were collected at 5 m (surface) and thermoclines layers using a rosette sampler equipped with a Conductivity, Temperature, and Depth (CTD) recorder. Samples were concentrated to 40 ml using hand plankton net (mesh size 20 µm), then preserved with 4% formaldehyde. Phytoplankton species were identified using a guidebook based on morphological character traits. The cell count of each plankton species was calculated using a Sedgwick rafter counting cell chamber. The result showed 4 classes of phytoplankton (Bacillariophyceae, Dinophyceae, Cyanophyceae, and Raphydophyceae), consisting of 59 species in the surface 56 species in the thermocline, respectively. The abundance of phytoplankton at the surface ranged from 77,333-4,024,000 cell m^{-3}, meanwhile in the thermocline layer, 8,000-542,222 cell m^{-3}. The average phytoplankton diversity of the surface was 0.82, and the thermocline was 1.71. The surface layer was dominated by *Leptocylindrus danicus* (8.92 x 106 cell m^{-3}), *Trichodesmium erythareum* (5.83 x 106 cell m^{-3}), and *Detonula converfacea* (0.62 x 106 cell m^{-3}). The thermocline layer was dominated by *Chaetoceros affinis* (2.74 x 105 cell m^{-3}), *Thalassionema nitzchioides* (2.21 x 105 cell m^{-3}), and *Chaertoceros dichaeta* (1.38 x 105 cell m^{-3}). The low phytoplankton abundance found at stations 12 and 13 was caused by higher salinity concentrations. The highest phytoplankton abundance was found in the stations with warmer temperatures, both on the surface and in the thermocline. The shallow depth thermocline layer (75-100 m) is more abundant than the deeper thermocline layer (110-150 m). The temperature was the environmental parameter that had the greatest influence on the abundance and species of phytoplankton; the phytoplankton in the surface layer reached 10 times more abundant than the thermocline layer.

Keywords: Phytoplankton, surface, thermocline, tropical

INTRODUCTION

Plankton is a group of microscopic organisms found in almost all types of waters, moving passively following the flow; their biomass in marine waters reaches 98% of all micro-sized organisms (Sardet 2015). Phytoplankton is a group of plankton that can photosynthesize and contribute to almost half of the total global net primary productivity (Falkowski et al. 1998). As a primary producer, phytoplankton is a food source for all populations in the sea (Lagus et al., 2004; Sardet, 2015; Rowe et al., 2017). The first consumer of phytoplankton is zooplankton, a food source of marine biotas such as fish, shrimp, lobsters, crabs, and various types of small fish. Many studies show that phytoplankton has a positive correlation between high commercial fish catches such as mackerel (Tangke 2012), sardinella (Putra et al. 2012), and tuna (Tangke et al. 2015; Tangke et al. 2016). In addition, the four types of high commercial fish mostly live in the thermocline layer. However, the existents of phytoplankton tend to follow the movement towards water currents. It is also significantly affected by physical and chemical changes in the waters. Depth, temperature, and salinity are crucial parameters determining the phytoplankton community structure horizontally and vertically (Sardet 2015).

The water column vertically has a different density gradient depending on the temperature and depth. The temperature will decrease to seawater depth. Otherwise, water pressure will increase. The temperature will drop dramatically at a certain depth, called the thermocline layer. In addition to temperature, salinity also has a similar pattern, which will increase dramatically at a certain depth, and it is referred to as a halocline layer. The thermocline and halocline layers create unique conditions that make phytoplankton adaptable to survive. Phytoplankton communities make different adaptations so that there are variations in community structure between water columns based on their abilities and characteristics of life.

Sangihe Talaud waters directly adjacent to the Mindanao Islands (southern Philippines) have water masses affected by North Pacific waters (Gordon 2005). This water mass will flow through the thermocline layer (Koch-Larrouy et al. 2007) to provide different water conditions with the surface layer. Indirectly it will form the structure of the phytoplankton community that lives in it. Various studies on plankton dynamics have been carried out in Indonesian waters. However, research on the phytoplankton community structure in Indonesia's surface and thermocline layers is rarely reported, especially in the Sangihe Talaud waters. Phytoplankton is the basis of the food chain. Research on the abundance and species of phytoplankton in the surface and thermocline layers is very important, especially in waters that become fishing ground for fishes with high economic value. Therefore, this study aims to determine the phytoplankton community structure in the surface layer and thermocline in the Sangihe Talaud Sea Waters.

MATERIALS AND METHODS

Study area

The research was conducted at Sangihe Talaud Waters in October 2018. Sampling was carried out at 14 research stations located on the northeastern side of Sulawesi Island (2 ° 4 '13 "- 4 ° 44 '22" N) and (125 ° 9 '28 " - 125 ° 56 '57 "E) (Figure 1). Sampling was done using the Baruna Jaya VIII Research Vessel belonging to the Indonesian Institute of Sciences (P2O LIPI).

Procedures

The temperature, salinity, and depth parameters were measured using the SBE 911-Plus CTD (Conductivity Temperature Depth) with Carousell Water Sampler Sensor. This tool was equipped with 12 rosette sampler bottles with a capacity of 10 liters, and it was used to take water samples as phytoplankton samples at surface depth (5 m) and thermoclines layers. The phytoplankton samples were filtered using hand plankton net mesh size 20 µm. The collected filtrate was transferred to a 40 ml sample bottle and preserved using 1% Lugol. Phytoplankton enumeration was done using Sedwick-Rafter Counting Cell under a microscope with 100x magnification. Phytoplankton identification was carried out morphologically by referring to the book Yamaji (1976), Shirota (1996), and Omura et al. (2012).

Data analysis

The results of enumeration and identification of phytoplankton were then used to analyze phytoplankton communities based on their abundance. Phytoplankton abundance was calculated using a formula according to Perry (2003), which was modified by Huliselan et al. (2006):

$$D = (Nf*Vp)/v$$

D = plankton abundance (ind / m³)
Nf = number of cells per 1 ml
Vp = dilution volume (ml)
V = volume of filtered water (m³)

The diversity of phytoplankton is determined by the following equation (Spellerberg and Fedor 2003):

$$H' = - \sum P_i \ln P_i$$

H' = diversity index
Pi = Proportion of species = Pi = ni / N
Ni = number of individuals of a species
N = Total number of individuals of all species

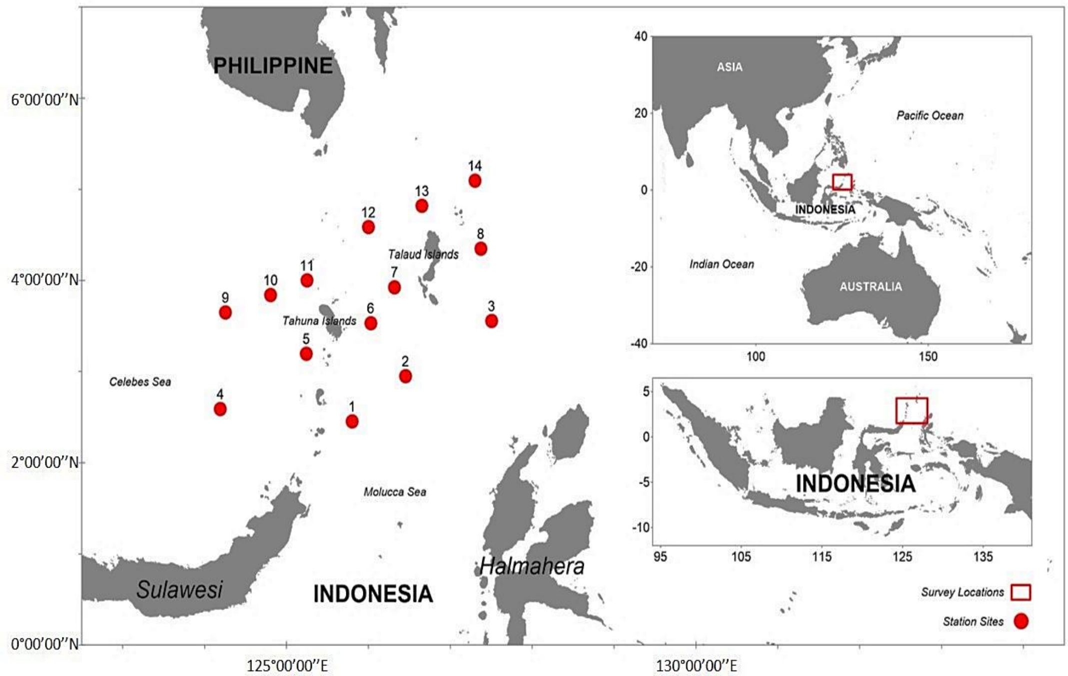

Figure 1. The map showing research station (indicated number 1 to 14) in the Sangihe-Talaud Warters, North Sulawesi, Indonesia

The diversity index was categorized based on Krebs (1989): (i) H'<1.0: small diversity (high ecological pressure), (ii) 1.0 <H'<3.322: medium diversity (productivity is quite good, the ecosystem is quite balanced, pressure is ecologically balanced), (iii) H'> 3.322: high diversity (very high productivity).

The relationship of water quality with the abundance of phytoplankton at each station was mapped in the form of contours using Surfer 9.1.352.

RESULTS AND DISCUSSION

Physical and chemical parameters

The values of physical and chemical parameters of waters such as temperature and salinity in Sangihe Talaud waters were taken up to a depth of 600 m to clearly describe the stratification profile in the thermocline layer and the layer below the thermocline (Steele and Thorpe 2009). Vertical profiles of temperature and salinity in 14 stations are shown in Figure 2.

Figure 2 shows that the water layer increased deeper, causing salinity to increase, but the temperature decreased. The temperature and salinity of the surface were 29.23-30.24°C and 33.55 - 34.31 ‰, while on the thermocline layers were 14.83-27.04°C and 34.5-35.08 ‰, respectively. The average temperature and salinity in the surface was 29.64 ± 0.29°C and 34.07 ± 0.22 ‰, while in the thermocline layers were 19.95 ± 02.23°C and 34.80 ± 0.12 ‰, respectively. The temperature on the surface, 30.24 °C, dropped drastically until the thermocline layer reached 14°C, while the salinity didn't show a significant increase. The average depth in the thermocline layer of the Sangihe-Talaud waters was 130 m.

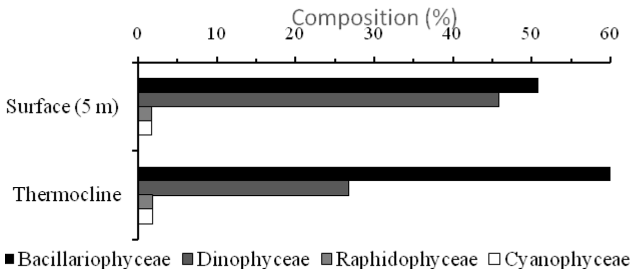

Figure 3. Composition of the number of phytoplankton species based on the class composition of surface and thermoclines layers.

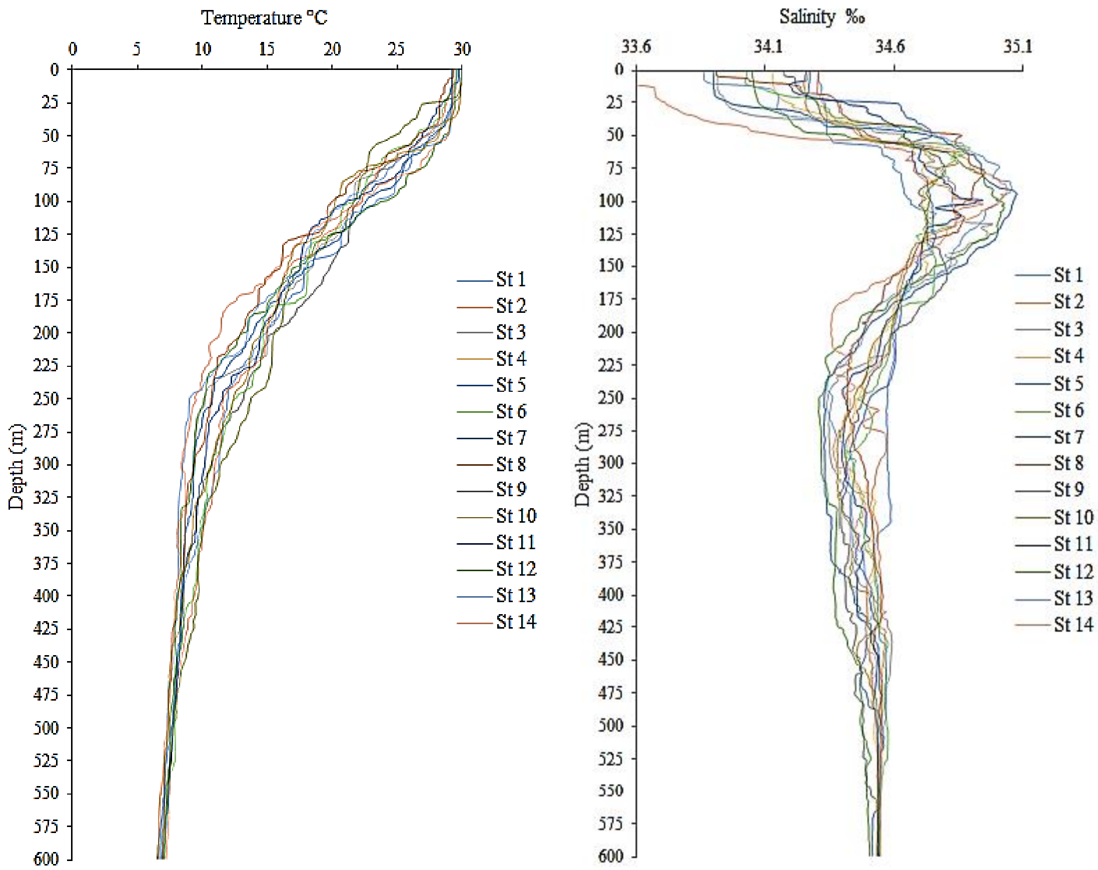

Figure 2. Vertical profile of temperature and salinity in the Sangihe Talaud waters, Indonesia

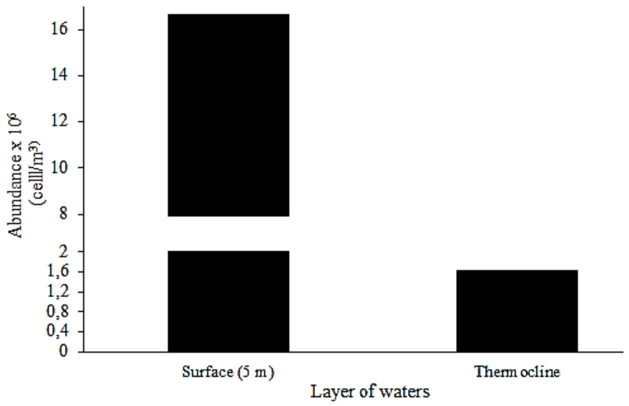

Figure 4. The abundance of phytoplankton on the surface and thermocline layers in the Sangihe-Talaud waters

Abundance and diversity of phytoplankton

Phytoplankton identification consisted of 4 classes, namely Bacillariophyceae, Dinophyceae, Cyanophyceae, and Raphydophyceae, with a total of 59 species on the surface 56 species in the thermocline layers. The number of species based on the phytoplankton class is shown in Figure 3.

The surface was dominated by Bacillariophyceae 50.85%, and Dinophyceae 45.76%, and the remaining was from Cyanophyceae and Raphidophyceaen, each 1.69%. The dominance numbers of the Bacillariophyceae in the thermocline layer were found more significant than the surface at sum 69.64%, the remaining from the Dinophyceae 26.79%, and from the Cyanophyceae and Raphidophyceae each 1.79%. The total abundance of phytoplankton in the surface layer and the thermocline shows a significantly different value, namely the surface layer 10 times greater than the thermocline. This condition is presented in Figure 4.

The phytoplankton abundance in the surface layer ranged 77,333 - 4,024,000 cell m-3; meanwhile, the thermocline layer ranged from 8,000 to 542,222 cell m^{-3}. Phytoplankton dominant and abundant species in surface waters differed from the thermocline layer. The surface was dominated by *Leptocylindrus danicus, Trichodesmium erythareum,* and *Detonula converfacea,* while the thermocline layer was dominated by *Chaetoceros affinis, Thalassionema nitzchioides,* and *Chaertoceros dichaeta* (Figure 5).

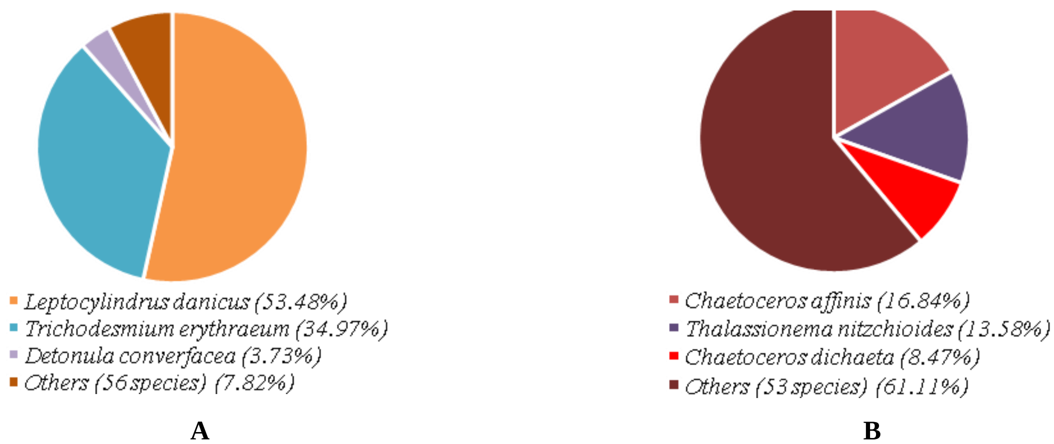

Figure 5. The composition of predominant phytoplankton species on the surface (A) and the thermocline layer (B)

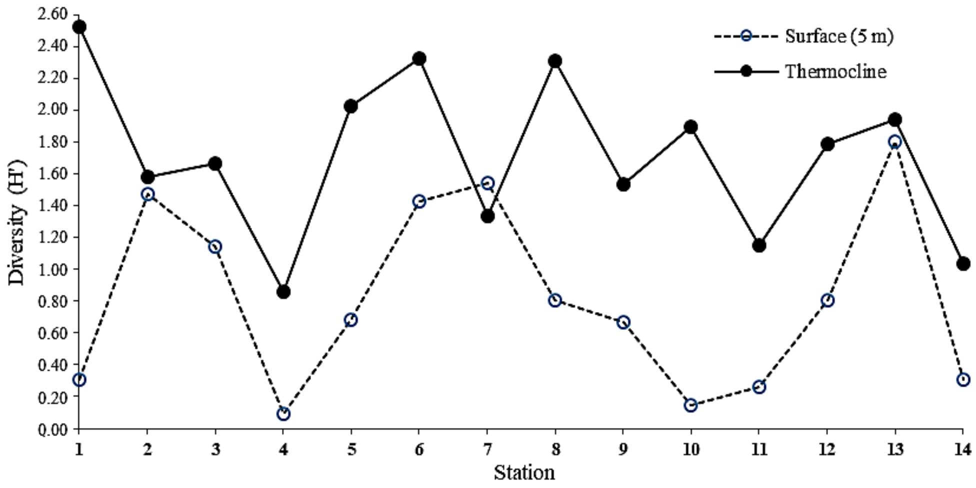

Figure 6. Diversity value (H ') at 14 stations of Sangihe-Talaud waters *(surface and thermocline)*

Among the research stations, especially on the surface, *L. danicus* has an abundance value of 8.92 x 10^6 cell m^{-3}, T. *erythareum* 5.83 x 10^6 cell m^{-3}, and *D. converfacea* 0.62 x 10^6 cell m^{-3}. The smaller value of the total abundance at the thermocline layer was *C. affinis* 2.74 x 10^5 cell m^{-3}, *T. nitzchioides* 2.21 x 10^5 cell m^{-3}, and *C .dichaeta* 1.38 x 10^5 cell m^{-3}. Although the abundance of phytoplankton was concentrated in the surface layer, it was not followed by high phytoplankton diversity values (H'). Figure 6 shows that H 'phytoplankton in the surface was lower than the thermocline layer.

The diversity of Phytoplankton (H') in the surface ranged from 0.089 to 1.807 with an average of 0.81, whereas in the thermocline layer ranged from 0.86 - 2.52 with an average of 1.71. Based on the category of diversity value, the diversity of phytoplankton in the surface layer was small; meanwhile, the thermocline layer was a medium.

Effect of environmental parameters on phytoplankton abundance between stations

The abundance of phytoplankton among stations varied because several stations had a very high abundance, while others were much lower. This is illustrated in Figure 7.

At surface waters, high phytoplankton abundance was found at stations 5, 4, 11, and 1, while low abundance was found at stations 6, 7, 13, and 2. In the thermocline layer, the highest phytoplankton abundance was found at stations 8, 1, 5, and 6, while low abundance was found at stations 14, 11, 10, and 7. Water's physical and chemical properties, such as temperature and salinity, were closely related to phytoplankton’s life, indirectly affecting its distribution. This phenomenon is described as a contour pattern in Figure 8.

Layers with warm temperatures and relatively uniform salinity were found at stations 10, 4, 5, and 11 (29.64°C and 34.07 ‰). This was the reason for the high abundance of phytoplankton in the study area. Thermoclines with an average warm temperature were found at stations 8, 1, 5, and 6. The highest abundance values followed warm temperatures and low thermocline depths (75-100 m). However, stations 12 and 13 with relatively warm temperatures (21°C), high salinity, and relatively shallow depths (100 m) do not have high phytoplankton abundance.

Discussions

Oceanographic parameters observed in the Sangihe Talaud waters influenced each other. Temperature affects salinity by increasing seawater density as depth increases (Thurman 1993; Hadikusumah 2008). In addition, salinity was also related to gravity and buoyancy. When the depth increases, heavier water masses tend to sink to reach equilibrium, and less dense water will rise to the surface. The temperature profile decreases along with increasing depth due to the penetration of sunlight decreases to transfer heat to the deeper water column (Nontji 2002).

The Bacillariophyceae class dominated phytoplankton composition found in the surface or thermocline layer. Extensive distribution for the Bacillariophyceae family in the waters because of their high ability to survive to adapt to various environmental characteristics (Arinardi et al., 1996). The discovery of Bacillariophyceae, which predominates in the thermocline layer, was supported by the ownership of pigments such as fucoxanthin, chlorophyll-a, and chlorophyll-c to utilize them minimal light for photosynthesis (Rissik 2009).

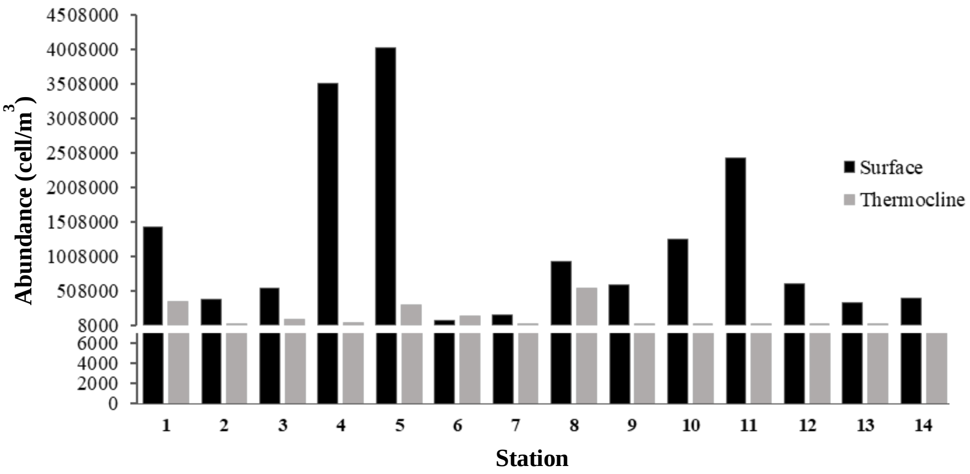

Figure 7. The abundance of total phytoplankton species at each sampling station in the surface and thermocline layer

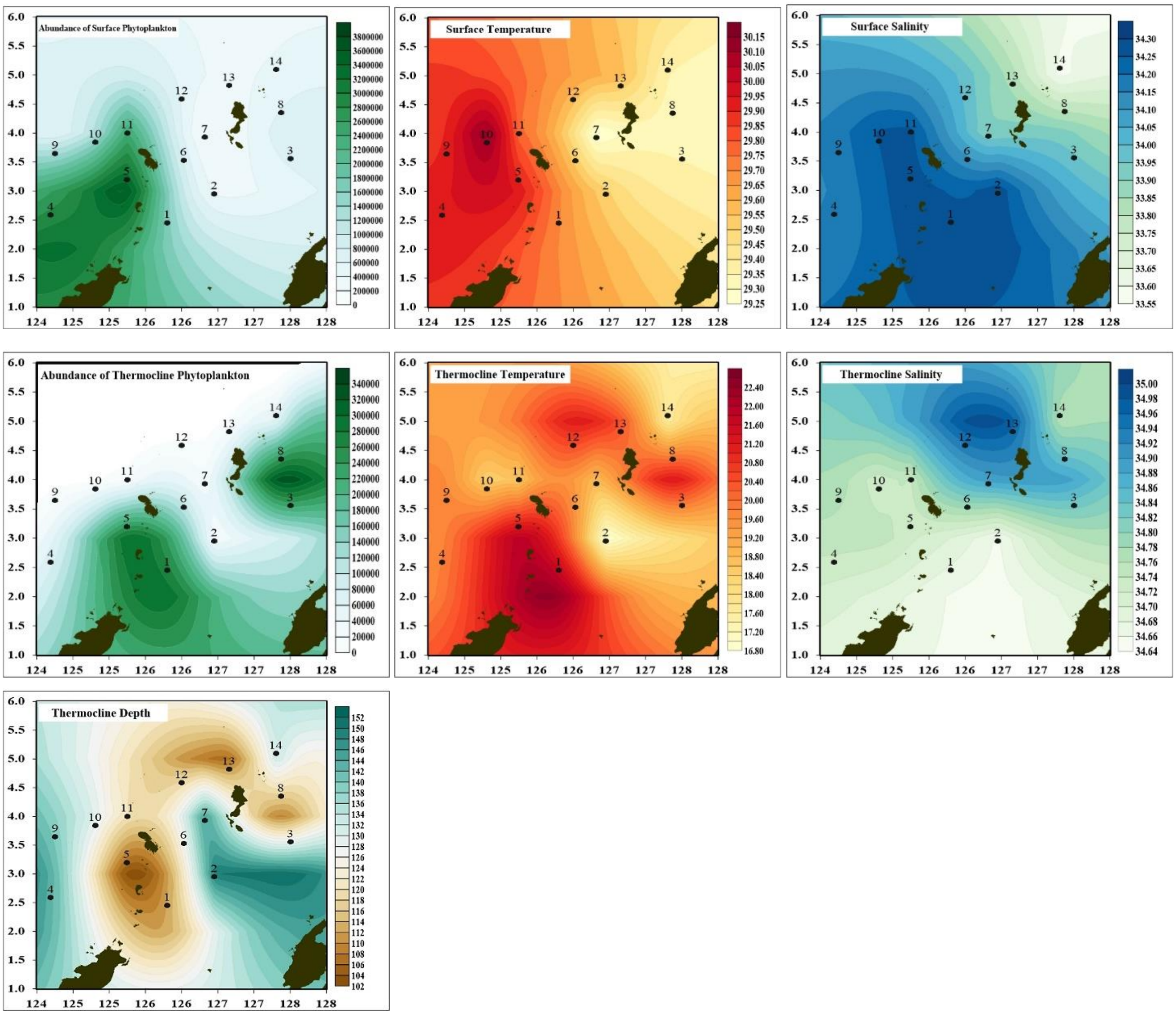

Figure 8. The contours of the relationship of phytoplankton abundance, temperature, salinity, and thermocline depth An explanation of the legend of each picture is presented on each panel

The abundance of phytoplankton in the surface layer and thermocline has a contrast difference, where abundance in the surface layer can reach 4 million cells m^{-3}. At the same time, there are no more than 1 million cells in the thermocline m^{-3}. Differences in aquatic conditions also show variations in the types of phytoplankton that live and affect abundance. The types of phytoplankton with high abundance in the surface layer were *L.danicus,* as much as 53.48%. This phenomenon is common in marine environments worldwide (Karthik 2017). It is known that the species L.*danicus* dominates 95-99% (67,000 cells) of the total abundance of phytoplankton in the Coastal Waters of Andaman and Nicobar, India (Karthik 2017). The ability to tolerate intense light and warm temperatures caused *L. danicus* to live well on the surface layer. This phenomenon was supported by the results of Penelope et al.'s (2016) study, who found that *L. danicus* grew more slowly at 18°C, while at warmer temperatures (25°C) showed good productivity.

The second dominant species in the surface layer was *T. erythraeum* (37.97%); this species was found abundantly in the Sangihe-Talaud waters. Thoha and Fitriya (2010) found *Trichodesmium* sp. dominate 50-95% (4842 - 83,043 cell m^{-3}) in almost all research stations. The community structure of the surface was different from the thermocline layer. The thermocline layer was dominated by the genus *Chaetoceros*, especially *C. affinis*, as much as 16.84%. The second species abundant in the thermocline layer was *T. nitzchoides* 13.58%. Genus *Chaetoceros* has a live strategy to survive by forming cysts during resting stages (Trottet et al., 2018). *Thalassionema* sp. in the South China Sea tended to high abundance in the thermocline layer rather than the surface (Boonyapiwat 2000). The low thermocline layer in light caused differences in environmental conditions from the surface, causing some types of phytoplankton in thermoclines to have unique characteristics to live and develop.

Phytoplankton abundance that varies between stations and layers of water was influenced by temperature and salinity. In general, the temperature will be directly proportional to the abundance of phytoplankton. The optimum temperature supports phytoplankton metabolic activities for cell development. As the founder of this study, stations on the surface with the highest temperature have the highest abundance. Similar conditions also occur to thermocline layers that have an average warm temperature. The thermocline is a euphotic zone that has a limit of a depth of 150 m (Raymont et al., 1980). The thermocline layer can be penetrated by sunlight to support the growth of phytoplankton (Barnes and Mann 1991), but the intensity was limited. A deeper thermocline layer has lower light availability than a shallow thermocline layer. Therefore, phytoplankton at shallow thermocline depths can do photosynthesis better than deeper thermocline layers. This condition was evidenced by the higher abundance of phytoplankton in stations with a depth of 75-100 m compared to 120-150 m. However, two stations were affected by the highest salinity, namely stations 12 and 13, indicating that the abundance of phytoplankton was not directly proportional to salinity. This result was supported by Soedarsono et al. (2013), who found phytoplankton abundance at salinity 40 ‰ of 22.25 cell m^{-3} dropped dramatically to 2.8 cell m-3 at salinity 27.5 ‰. Salinity above the tolerance threshold of phytoplankton causes osmosis stress, which inhibits growth with ion loss, inhibiting the absorption of nutrients, and inhibiting cell movement. Phytoplankton that cannot tolerate high salinity will avoid this area for life. Phytoplankton can survive when only a few species are in extreme conditions by forming cysts or spores (Sachlan 1972). Inappropriate salinity will increase phytoplankton metabolic activity so that its survival will be high, which is supported by increased RNA synthesis and DNA replication (Skarlato et al., 2017).

The composition of phytoplankton species at each observation station affected the diversity of phytoplankton. The diversity values were an indicator of the stability level of the phytoplankton community against environmental disturbances. The phytoplankton diversity in the surface was classified into small categories (Krebs 1989) because most of the H' values were <1.00. The small m of diversity is an indicator occurrence of high ecological pressure. On the other hand, the value of H 'in the majority thermocline layer was> 1.00, which was included in the category of moderate diversity as an indicator of fairly balanced ecosystem conditions. The higher phytoplankton diversity of the thermocline layer was due to the phytoplankton community being dominated by species from Class Bacillariophyceae and Cyanophyceae, which favor low sunlight intensity (Sellers and Markland 1987). Chlorophyll synthesis in species from Class Bacillariophyceae and Cyanophyceae did not require intense light; even powerful light will damage Phyto-oxidative phytoplankton enzymes and cause phytoplankton to die (Wetzel 1975; Barnes and Mann 1991; Riyono 2007). High phytoplankton diversity values in the surface and thermocline layer tended to be found at stations close to the island (Station 13 - Talaud Island, Station 1 - Sangihe Island). Meanwhile, the lowest diversity values in the surface and thermocline layers were found at stations far from the island (Station 4). High phytoplankton diversity values at stations close to the island were caused by nutrient input from the mainland. Many species of phytoplankton need nutrients to increase growth. Meanwhile, stations far from the mainland have fewer nutrient inputs, so the diversity was low.

To conclude, the total abundance of phytoplankton on the surface was 10 times greater than the thermocline layer. The phytoplankton abundance ranges from 77,333 to 4,024,000 cell m-3 on the surface and 8,000 to 542,222 cell m^{-3} in the thermocline layer. The differences in water conditions affect the variations in the species of phytoplankton. The surface layer was dominated by *Leptocylindrus danicus, Trichodesmium erythareum,* and *Detonula converfacea;* meanwhile, the thermocline was dominated by *Chaetoceros affinis, Thalassionema nitzchioides*, and *Chertoceros dichaeta.* Environmental parameters of temperature, salinity, and depth influenced the abundance of phytoplankton. Temperature shows a stronger influence on phytoplankton in the surface layer.

Similar conditions were found in the shallower thermocline depths (75-100 m), and areas with relatively high temperatures (21°C) have relatively high abundance. But the abundance of phytoplankton in the thermocline layer will be inversely proportional to salinity.

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Challenges and opportunities of participatory management of Upland Wetland in Kiambu County, Kenya

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Abstract. *Kinyariro MS, Njuguna SG, Macharia G. 2020. Challenges and opportunities of participatory management of Upland Wetland in Kiambu county, Kenya. Bonorowo Wetlands 10: 78-91.* Wetlands are continuously degraded through agricultural activities, pollution, and settlements. For example, in the Lari sub-district, increased population pressure decreased soil fertility, unreliable rainfall, and the search for food security forced farmers to encroach on the seemingly idle Upland Wetlands. Opportunities for wetland conservation lie in participatory approaches applied locally to conserve this vital natural resource. The main water of the Ruiru river comes from the Upland Wetlands harvested by the Nairobi Water and Waste Company in the Githunguri sub-district at the Ruiru dam. This research is critical because the water company does not have in-depth information about its catchment area, which leads to encroachment and ultimately rationing of water in the city of Nairobi. This study aims to document the causes of wetland degradation in the highlands, assess the level of community participation, and determine the level of awareness of the importance of wetlands and the possible contribution of farmer involvement in catchment management. The sampling method used to select the research unit was stratified and random sampling where farmers and Ruiru dam workers were given a questionnaire. Purposive sampling was used to determine the WARMA manager, WRUA officer, and six older people interviewed. 40 farmers from the Lari 107 settlement scheme where the wetlands are located, and four workers of the Ruiru dam were given questionnaires. Data analysis was performed using the Chi-square package computer, T-test, and SPSS. Percentages for qualitative data are presented using tables, bar charts, and pie charts. The wetland mapping was carried out using GIS and Google Earth. The study results found that the total land cover of upland rice fields was 129.6 Ha after deducting 105.4. Ha for the last thirty years due to encroachment. The study revealed that 65% of respondents had lived in the area for more than 20 years. Farmers drain wetlands primarily for food supply (50%) to generate income (25%), while 10% control waterborne diseases. Participation rates are negligible, with only 2.5% of respondents participating in wetland conservation. Community-based conservation groups like WRUA still lack in this area. Environmental impacts include loss of biodiversity, destruction of ornithological habitat, and loss of hydro plant species. Social effects include outbreaks of waterborne diseases such as typhoid, water pollution, and weak community conservation infrastructure. However, there is a chance for community involvement, where the majority of the population is ready to carry out conservation ($X2 = 0.127$, $p = 0.001$). The formation of community-based conservation groups such as the Water Resources Users Association, the Association of Riverland Owners, and the Watershed Advisory Committee was proposed as the primary solution. Devolution of water resources is also proposed to ensure local people benefit from selling water to city residents. Such efforts would provide an adequate water supply to Nairobi and the surrounding satellite cities.

Keywords: Kiambu, Kenya, participatory management, Ruiru, Upland Wetland

INTRODUCTION

Global and local water cycles strongly rely on healthy and productive wetlands. The wetland provides clean drinking water, irrigation for agriculture, flood control, supporting biodiversity, and propping up fisheries and tourism industry in many locations (UNEP 2005). Under Ramsar Convention, wetlands are defined as “Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, blackish, fresh, salty, including areas of marine water the depth of which at low tide does not exceed six meters" (Howard 1992; Aron et al. 2007).

Whether natural or artificial, wetlands play many functions, such as sources of rivers, replenishing aquifers, and homes for various animals. Wetlands also combine fresh water and dry land and are thus called ecotones (Tobin and Deshek 2001). This ecosystem's vegetation filters silt from agricultural land, providing a source of safe drinking water. Despite the high value of these ecosystems’ services, wetlands continue to be degraded or lost rapidly (TEEB 2013). Fortunately, wetlands' economic, social, cultural, biodiversity, and ecological significance are widely acknowledged, and global efforts are being made to prevent further degradation and loss of biodiversity (Canari Policy Brief 2002).

At the same time, change and utilization of land are projected to have an enormous impact on biodiversity, followed by nitrogen deposition, species, and increasing carbon (IV) oxide in the atmosphere (Sexton et al. 2001). The effect of land-use change is expected to be more severe in the tropics. Furthermore, natural habitat destruction resulting from anthropogenic activities has been identified as one of the primary drivers of environmental degradation. This is more prevalent in the developing world, where poverty and ignorance of biodiversity values are out of control. In Kenya, a study has shown that wetlands are not fully appreciated. Despite offering ecological, social, and economic benefits, there is a lack of concerted effort to advocate for sustainable use (NEMA 2011).

Kenya's vulnerability to the effect of that mismanagement and water catchment degradation has called for significant policy response and action (Cahokia 2000). One important policy change is a shift from centralized to participatory water governance (WRMA 2006). A participatory approach is essential, given that several water catchments are privately owned under self-owned land tenure systems. For example, in the Trans-Nzoia region, 91% of the wetlands that make up the main catchment area in Kenya are privately owned. Due to different tenure systems, there has been recorded loss and degradation of wetlands, causing adverse effects to this fragile water resource. (Kecha et al. 2007).

Kenya has central wetlands such as Lake Nakuru and Naivasha, which have been allocated wetlands of international importance, and small land which offers suitable disposal into rivers (Cahokia 2000). These include the Ruiru river and its associated wetlands. Local communities do not associate themselves with the benefits, which results in their drainage, primarily when they associate wetlands with vices such as malaria, bilharzia, and flooding that constantly destroys their crops. At the same time, the rivers originating from these wetlands are tapped with water to be sold to people living in the city or used to generate electricity without giving any benefit to local people who have acted as custodians of the resource since time immemorial.

The colonial government had built several infrastructures in this area, such as the Ruiru Dam, which was meant to supply water to the Nairobi District and its surroundings. Ruiru dam exploration started in 1926, and after many trials, a 225mm diameter steel pipe was laid to transmit water to Nairobi in 1938 and, by the construction of the dam had commenced. In 1946, another pipe with a diameter of 300mm was laid parallel to the previous pipe measuring 225mm. The dam was completed in 1950 when a pipe of diameter 400mm was applied, which was connected with another diameter 300mm diameter on the route of Ruiru junction, thereby making the gross yield of the reservoir 22,700m3/day that is; 98% reliable. The designed capacity is to fulfill 23,000m3 / day in a transmission system that empties its water to the Kabete Water Treatment Plant, ultimately distributing water to Nairobi. The designed capacity was meant to fulfill 23,000m3 / day in a transmission system that empties its water to the Kabete Water Treatment Plant, ultimately distributing water to Nairobi.

Ruiru Dam has a vast catchment area that covers 6,680 ha. WRMA manages the catchment area with liaison with Athi Water Management Authority (AWMA). Most of this area is in Lari Subdistrict, such as Upland Forest, Kereita Forest, and Upland Wetland. This wetland happens to be the primary source of the Ruiru River, which drains its water into the dam. Locals initially conserved the wetland through taboos and beliefs. Traditionally the local people used it through harvesting reeds for roofing and clay for pottery. Cultural practices such as circumcision were ongoing in this area, and both people used it as a food source by collecting duck eggs and meat.

The wetlands remained intact in use for the above purposes until the arrival of the Europeans. After colonization, the area under wetland and the surrounding were demarcated and allocated to white settlers who started draining it. As Kenya attained independence, Lari Sub-County, a division of Kiambu County, was earmarked as a settlement area for landless Africans. Therefore, Lari's settlement scheme was created to settle the land with fewer citizens. The area was subdivided in 1963 into 107 parcels of land that came to be known as the Lari 107 Settlement Scheme, a name it has retained to date. The touching land wetlands were divided into 50 hectares, and the wetlands were allocated for grazing. This area's privatization began with poor Africans settling in this region.

The inhabitants of Lari do not currently associate these wetlands with many economic benefits, so their immediate alternative is to drain them for farming to increase their income. Although sustainable utilization of this wetland is vital to our country, the battle cannot be won without local "s people's participation. The draining of these wetlands has resulted in the loss of social, economic, and ecological benefits in this area, including neighboring cities such as the metropolitan city of Nairobi, whose water comes from the Ruiru River. Water quality in the wetlands is deteriorating due to siltation, agricultural chemical contamination, and biological pollution originating from the upcoming town of Lari and the rapidly growing factories in the area.

This study was conducted in the newly created Lari sub-county where the wetland is situated, and the Githunguri sub-county hosts Ruiru dam. The two sub-counties were earlier under the former larger Kiambu sub-county. The objective of this study was: (i) To assess the level of awareness of local communities on the importance of wetlands and the organizations that protect them. (ii) To document major causes of Upland Wetland degradation. (iii) To assess the extent of community participation in the management of Upland Wetland and investigate their possible contributions to its conservation. (iv) To define the opportunities and challenges faced in participatory wetland management in the Upland.

MATERIALS AND METHODS

This chapter describes the study area, research design, data collection procedure, method of data analysis, and results presentation.

The study area

The study was carried out in Ruiru sub-ward, Lari/Kirenga ward, in the newly created Lari sub-county part of Kiambu County (Figure 1). The wetland mapping was done using GIS, as shown by Figure 2. The area was selected since being the main catchment area of the Ruiru River, which supplies water to the Nairobi District. Initially, this area was called the Lari 107 Settlement Scheme, created by the colonial government to resettle the Mau Mau victims and landless people. It is bordered by

Limuru sub-county to the south, Githunguri sub-county to the east, and Naivasha sub-county to the west. It is connected to Nairobi by Mombasa-Kisumu Railway and Nairobi-Naivasha Highway.

Lari sub-county is a good water catchment area that includes the Upland Forest and Kereita Forest, which are collectively called the Kikuyu East Slope. Two forests plus wetlands send a lot of water to the Githunguri sub-county, and some of it is dammed at the Ruiru I Dam. The water collected in the dam is then pumped to Nairobi and its surroundings, such as Kiambu. As the river flows downstream, it supplies water to other large cities like Ruiru before joining the Athi River.

Target population

The study targets Upland Wetland adjacent community, community-based wetland conservation groups such as WRUA, WRMA, Ruiru Dam Employees, and local leaders. The sub-ward is found in the Lari-Kirenga ward, a population of 27,871 as per the 2009 census.

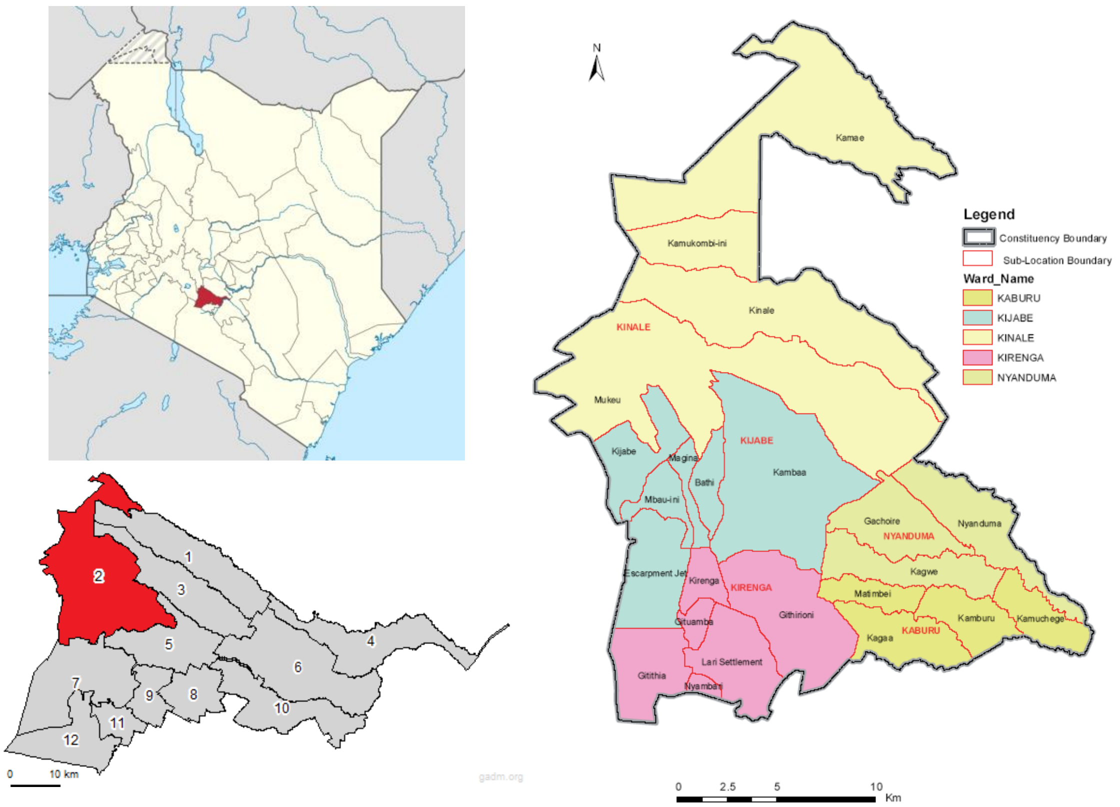

Figure 1. Map of Lari Sub County, Kiambu County, Kenya

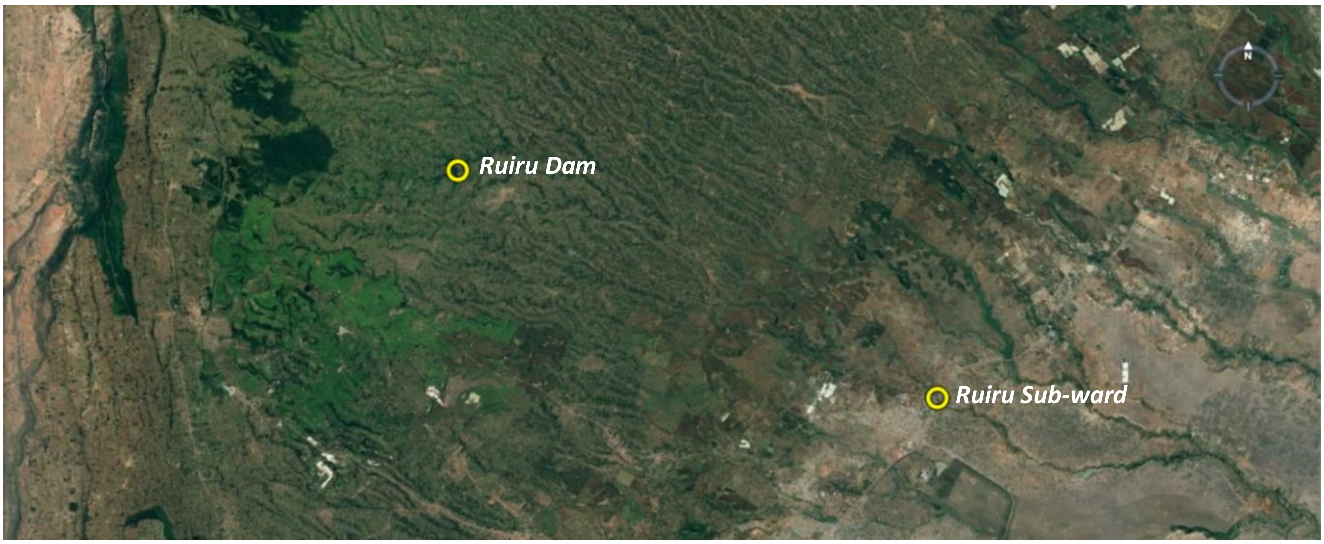

Figure 2. GIS of Upland Wetland in Ruiru sub-ward, Kenya

Climate

The area is in Agroecological Zone II with the type of bimodal rainfall. Long rains are experienced between March-May and short rains between October-November. Altitude ranges from 2000-24mm00 m above sea level, and the total amount of precipitation can vary from 1500-2200 mm. High temperatures occur from January to March at around 220°C, while low temperatures occur in July at 120°C. Lari sub-district has fine loam soils, which are known for vegetable production. Siltation in wetlands introduces it as a thin layer of soil even though the main soil in the study area is clay soil. The ground is suitable for growing vegetables, corn, and potatoes for household use and sale.

Economic activities

The main economic activity of the Lari people is agriculture. Thus, this sub-county has supplied fresh vegetables like spinach, kales, cabbages, and carrots to Nairobi County for a long time. Dairy farming developed rapidly after introducing the milk processing industry called Sundale. The farmer also raises pigs as a Farmer's Choice Company that raises and slaughters pigs in his factory. The Nairobi-Naivasha Highway crosses the sub-county and the Mombasa-Kisumu Railway. Both make the area suitable for commercial activities. Mining also occurs mainly in the Kereita Forest, where the Carbacid Company harvests the carbon IV oxide. Forestry takes place in the forests of the Uplands and Kereita, where softwood trees are mostly planted.

Research design and sampling procedure

Sampling design

This study used a descriptive survey research design. The design is used to collect data from population members to determine the Ruiru sub-ward (village) population status. The choice was made because the study focused on conserving and managing existing wetlands. The head of the household is interviewed, and if they are not available, we substituted with the spouse or child over 18 years of age. This ensured that members of every gender were incorporated.

Sample size

The sample size (Table 1) was determined using Mugenda and Mugenda (1999) proposed formula.

$n=N/1+ (0.1)^2$

n: sample size required

N: size of population (Target) e=sampling error (10 % points)

Table 1. Respondent distribution

No of members	N	N	%	ratio	Sample size
Farmers	107	40	80	0.8	39
Others	10	10	20	0.2	10
Total	117	50	100	1	49

Sampling procedure

This study used simple random sampling and systematic sampling to select 40 respondents living within a 1 km radius around the wetlands. The farmers given a questionnaire were obtained using a stratified sampling technique from eight villages in the Ruiru sub-location. The 40 questionnaires distributed in the villages were as follows: Kimotu 5, Kimonditi 5, Upper Scheme 5, Lower Scheme 5, Kibuto 5, Guan B 5, Karia 5, and Gwagacira 5. The 40 farmers represented 37% of the 107 native Lari Settlement Scheme members allocated agricultural land around wetlands. The original list was obtained from the archive of regional heads. Random sampling was also carried out for each 40 farmers to obtain household respondents who filled out the questionnaire. Purposive sampling was carried out to get the elderly because of the historical aspects of the rice fields. A total of six elderly were chosen deliberately, three from each gender. Two focus groups were formed involving local leaders and employees of the Ruiru dam. Purposive sampling was also carried out to select two key respondents from the WRMA and WRUA offices.

Data collection tool

Primary and secondary data collection methods were used to obtain information from the sample unit. Preliminary data were collected using GIS, structured questionnaires, oral interviews, and direct observation. GIS was used to map wetlands, calculate their area, and determine changes in land cover in land use over the last thirty years.

Field recording was one of the qualitative data collection methods used in this study. Direct observations of the activity and the physical environment in the wetlands were carried out for six months. Secondary data was collected from documents, publications, NEMA, NWSC, and WRMA reports. Secondary data were reviewed to complement the respondent's opinions and observations during the field visit.

Reliability and validity

The research instrument's reliability was carried out through a pre-test pilot study in units that were not included in the study. Recorded ambiguities, weaknesses, and inconsistencies are corrected before actual data collection.

The random procedure in selecting sample units is carried out to eliminate bias to reflect the image of the total population. Repetition of statistical tests was used to justify the validity of the study. Performing the test more than once and comparing the results confirm the procedures' validity and reliability. The study findings were compared with previous ones, and there was not much difference between the two.

Pre-test

A pre-test of research was done in January 2012 to check the practicability of the study. Study objectives, achievability, and suitability of research tools were done. Poorly answered questions were redone, plus those respondents could not understand. Interviews were held with local leaders during this period, and ten farmers filled out the sample questionnaire.

Methods of data collection

Questionnaires

Questionnaires were given to 40 farmers "s 1km radius of the wetland—questions comprised nominal, ordinal, scale, and ratio measurement.

Key informative interviews

This was done by a WRMA official in Kiambu District who explained WRMA activities and the main catchment areas in the district. WRUA officials at the district headquarters also provided a list of WRUA groups officially registered in the district and their main activities. They also offer registration procedures to WRUA and WDC activities. The elderly from the Ruiru sub-ward recounts the history of the wetlands and their early use.

Focus groups discussions

Two focus groups constituted local leaders, and Ruiru Dam employees were involved. Focus groups mainly looked at significant causes of degradation, alternative uses, and what it takes to introduce participatory wetland management in the Ruiru sub-ward.

Data analysis

Data analysis involves the computation of descriptive and inferential statistics. The analyzed findings are presented using pie charts, tables, photos, and bar charts. Qualitative information is obtained through scheduled interviews and observations taken verbatim, and documented photographs of critical areas in the watershed are obtained. Changes in land cover for land use are carried out using a GIS. Inferential statistics were performed using Pearson's (x2) t-test and Chi-square. The t-test is used to determine whether the two data sets collected and analyzed differ significantly from each other. Chi-square helps in testing the independence of the responses given by respondents. Here the SPSS version is used.

RESULTS AND DISCUSSION

Respondent demographic information

Respondents who were sampled in this study were aged 10-30 years (10%), 30-50 years (60%), 50-70 years (27%), and over 70 years (3%) (Figure 3). However, demographic data show very few older adults in Ruiru sub-ward. This can be attributed to the Mau Mau uprising and the Lari Massacre in the early 1950s, resulting in the majority of the population being killed. In contrast, others died in detention or were displaced from the area.

There were slightly more male residents living in the study area (55%) than female residents (45%) who participated in the study. This shows that gender is evenly distributed in the sampling of citizens. More men were recorded because much of the data was taken from farms where men were more involved because of manual labor.

The results of the study found that the population in Riuru sub-district where the wetlands are located, the majority (65.0%) have lived for more than 20 years, (2.5%) have lived between 15-20 years, (20%) have lived between 10 years-15 years while 12.5% of the population has lived in the area for less than five years as shown in Figure 4. Therefore, the low level of immigration in this area is the increase in population due to births, which threatens natural resources.

The study revealed that residents' highest level of education was diploma (5%), and those with a primary level of education were 35%. In comparison, those who had a secondary level of education were 60%, as shown by Table 3.

The highest education level was not significantly different between the male and female populations ($\chi2$ = 4.887, p = 0.087). However, more men (50.0%) have secondary education while women (77.8%) have a high school education, as shown in Table 4.

Table 3. Education levels of residents of Ruiru sub-ward, Kenya

Education level	Frequency	Percentage (%)
Primary level	24	60
Secondary level	14	35
Diploma	2	5
Total	40	100

Table 4. Level of respondents by gender

Education level	Gender of the respondents		Total Frequency	Percentage
	Male	Female		
Primary	45.5%	77.8%	24	60.0%
Secondary	50%	16.7%	14	35.0%
Tertiary	4.5%	5.6%	2	5.0%
Total	100%	100%	40	100%

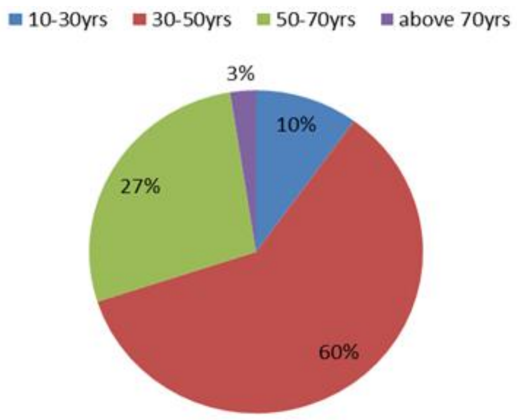

Figure 3. Ruiru sub-ward residents, Kenya

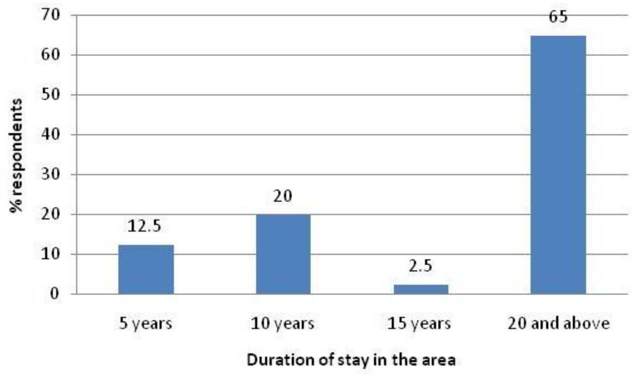

Figure 4. Resident duration of stay at Ruiru sub-ward, Kenya

The current use of wetlands by farmers has no significant relationship with their education level ($\chi 2$ = 10.435, P = 0.236). About 50% of the population has primary school education, 46.2% middle school, and 4.8% tertiary education. In addition, highly educated communities also drain wetlands for farming. However, at the diploma level, the representation level of significance of 50% indicates conservation efforts by practicing preservation. The current use of wetlands by farmers does not depend on their level of education (Table 5).

The study found that people of Ruiru sub-ward had acquired their land differently, with 30% inheriting, 30% buying their land, and 37% were settled in this place while 3% of respondents leased their land Figure 5.

A closer look at land acquisition methods shows that residents in the 30 - 50 age group have the most diverse ways of owning land, from buying inheriting to settlements on their parents' lands (Table 6).

Community awareness on wetland importance

Within this community, 55% are aware of the importance of wetlands, while 45.0% of the population are unaware of the extent of wetlands, as shown in Figure 6. The results showed similarities to those carried out in the Kisii wetland, which showed that 60% of the population considered wetlands essential or very important (Mironga 2005).

Table 5. Current wetland using about the education level of respondents

Wetland use	Primary	Secondary	Tertiary
Crop farming	50%	46.2%	50%
Grazing	29.1%	20.8%	0 %
Tree planting	8.3%	15%	0 %
None	4.3%	10%	50%
Settlement	8.3%	8%	0 %
Total	100%	100%	100%

Table 6. Land acquisition methods

Ages (Years)	Method of land acquisition				
	Buying	Settlement	Inheritance	Other	Total
10–30	100%	0%	0%	0%	100%
30–50	25%	33.4%	37.5%	4.1%	100%
50–70	18.2%	63.6%	18.2%	0%	100%
Over 70	0%	100%	0%	0%	100%

Table 7. The importance attached to wetland by residents

Wetland importance	Percentage
Source of water	45
Supply of forage	27.5
Nature conservation	12.5
Cultural importance	12.5
No importance	2.5
Total	100

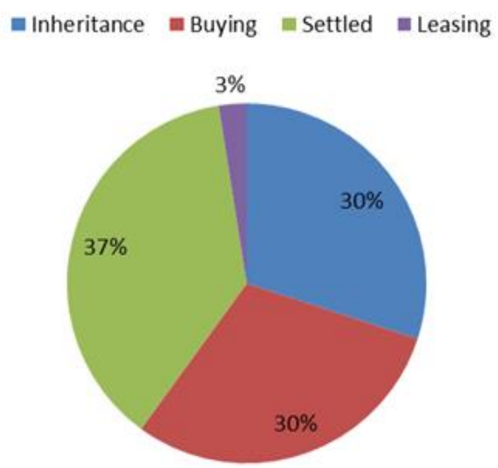

Figure 5. Methods of land acquisition by residents

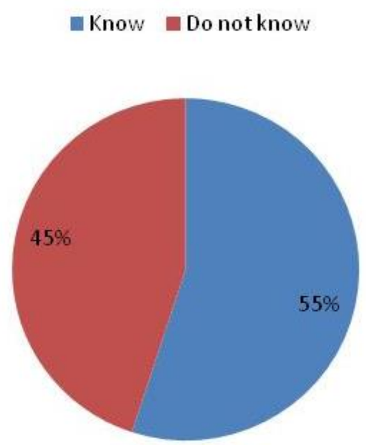

Figure 6. Respondent's knowledge of the importance of Upland Wetland

The inherent interests of wetlands include 45.0% of water sources, 27.5% of forage, 12.5% of nature preservation, 12.5% of cultural attractions, while 2.5% of the population does not attach wetlands to Table 7. By emphasizing the availability of water, preservation of natural and cultural values, residents appreciate the role of wetland services that help community socio-economic development. This study is consistent with FAOs, which shows that Kenya's wetlands play essential roles: providing habitat for wildlife and fish, food, fish, building materials for flood control, and water purification (FAO 2008).

The study found that although the conservation value of biodiversity is up to 12.5%, this area can become an ornithological paradise because birds are often seen to become residential birds. The goliath heron (Figure 7) migrating over many wetland areas in Africa is seen building large nests on reed and papyrus platforms. They are so frequent that respondents consider them an indicator species of wetland conditions.

Other birds were sacred ibises that usually sat still and congregated in different parts of the wetlands. Egyptian geese were only seen during the long rains in April. They were found in pairs swimming in waterlogged agricultural land and grassy plots. On the other hand, Hadada ibises appeared in large groups, staying in the area longer than other birds.

Egyptian geese (Figure 8) were also observed roaming in drained wetlands. These birds are migratory, and they visit many east African wetlands, especially during winter in their residential areas. Respondents indicated that these birds were abundant in wetlands before drainage, and they acknowledged that this is one of the negative impacts of drainage. This study shows similarities to that in Kimana, where year-round agriculture increased human-wildlife conflicts as wildlife from Amboseli National Park was forced to pass through the remaining narrow gaps due to the destruction of their habitat (Claridge and Callaghan 1997).

Therefore, this area can be an excellent tourist attraction, thus providing an alternative land use that encourages conservation and generates income for residents. Biodiversity in the study area also appears to be under threat, including water quality, as many farmers prefer chemicals in their farms and organic farming, leading to eutrophication into rivers and eventually the Ruiru dam. The majority of farmers, by 40.0%, prefer chemicals while 30.0% prefer organic agriculture, as illustrated in Figure 9.

Organic waste generated in farming activities eventually will cause eutrophication in Ruiru Dam. Fish in the dam will suffer from oxygen stress denying NWSC indicator species used to monitor water quality. The river was also experiencing heavy siltation from farming activities, as shown in Figure 10.

Figure 7. Frequenting birds in Upland Wetland, Kenya

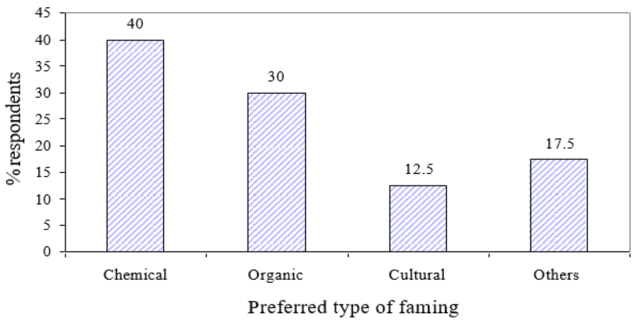

Figure 9. Preferred type of farming in Ruiru sub-ward, Kenya

Figure 8. Migratory Egyptian goose in demarcated Upland Wetland, Kenya

Figure 10. Siltation in Ruiru River, Kenya

Likewise, the water table decreases as the community's shallow well dry up at an alarming rate. The respondents' shallow wells had to be submerged from 40 million to 50 million, making a difference of 10 million in a year. Thus, there is a possibility that future generations will lack water in this area even as the wetlands dry up, making the Ruiru Dam White Elephant project.

Hypothesis (H1): "The number of people who know the importance of wetlands is less than the number of people"). Based on the findings of this study, the researcher cannot accept the null hypothesis, from the statistics showing that although 45% of respondents do not know the importance of wetlands, they consider conservation in their farming activities (X2 = 2.513, p. = 0.133). In this case, ignorance can be one of the factors causing wetland drainage. Natural resource sabotage also appears to be working in this area, especially after residents are fed up with the NWSC harvesting their water selling it without benefiting them.

Causes of wetland degradation

Among the sample population, 92.5% had part of their land under wetlands, while only 7.5% had no land under the wetlands due to inherited demarcation. The study found that the degradation of the Upland Wetlands began after state colonization. Before colonization, the area was used as a source of reeds, clay for pottery making, and an initiation site for the Kikuyu youth. This area was used sustainably until the Europeans arrived when white settlers allocated this area and drained the wetlands to grow wheat and wheat for livestock. A dam was also built on the upper side to supply water to the livestock, further draining this wetland. Uplands Bacon Factory was also established in the hog raising area. The plant drained the lower part of the wetland for dam construction and started dumping waste into the remaining wetlands, a problem that continues today.

After independence, Lari Sub-district was allocated as a residential area for landless Africans. At that time, most of the elderly who could have passed on traditional knowledge of wetland conservation had died during the Mau Mau rebellion. The unity of the local people has also been paralyzed due to the counteroffensive by the Mau Mau under the notorious Lari Massacre. The management of this settlement scheme, known as the Runaway Settlement Scheme 107, included the sub-divided wetlands and was therefore individual.

Most residents who obtain land parcels that touch 50 hectares of wetlands per person use it for grazing. These land uses persisted into the past when population explosions, land fragmentation, and the demand for fresh vegetables from nearby cities increased. Farmers started drying out this wetland to grow crops even though they claimed it was the source of liver worms and poisoning from factory waste that killed their livestock.

To investigate the current extent of degradation, environmental software was used to conduct the assessment, with ArcGIS V.10.2 and the Google Earth program, which provided high-resolution imagery for validation. Radiometric calibration is performed to obtain images based on various factors such as exposure time, plane observation, and dark currents. Then Top of the Atmosphere Calibration (TAC) is performed on the image. Because the view was so big, the sub-setting was done by cutting the plane with a shapefile created with supports around the Ruiru sub-ward. Before selecting a training location, different track combinations were used to assess the best variety for viewing wetlands, as shown in Table 8.

Pseudo-natural colors 7-4-2 have been tested, but (4-3-2) false colors Near Infra-Red, Red, and Green Infra-red combination featuring delineation of wetlands and agricultural land are better used. It is also the most conventional band combination used in remote sensing for vegetation, crop, and wetland analysis. Using Google Earth to identify indistinguishable features from the 30m Landsat Scenes being processed, Validation was carried out.

Remote sensing was carried out for the last thirty years with 10-year duration intervals to determine the extent of wetland degradation. The first imagery was obtained in 1986 when the wetlands were still intact, less degradation. The rice field area reached 235 Ha at that time, as shown in Figure 11.

Encroachment later started taking place, and the wetland was turned into cropland, settlement, and forests. In the northern part of the wetland, farming activities and pockets of forest were sighted. The settlement was started on the southern part of the wetland, and equally, drainage was done using trees. In the western region, the wetland was drained for farming, and even the grassland next to it, as seen in 1986, was cultivated. Wetland declined from 235 Ha to 184.7 Ha, leading to a total loss of 50.3 Ha, as shown in Figure 12.

Degradation accelerated for the next 13 years in that wetland was reduced to 129.6 Ha. The settlement was rampant in the southern parts that divided wetland into two. All around, wetland cultivation was done, as shown in Figure 13.

Data collected on the wetland revealed that primary reasons behind wetland encroachment were: food provision (50%), generating income (25%), settlement (10%), wood fuel provision (10%), and disease control (5%), as shown in Table 9.

Table 8. The color band used in remote sensing

Ground cover type	In natural color (3,2,1), appears	In false-color: (4,3,2), appears:	In Pseudo natural color (7,4,2), appears
Trees and bushes	Olive green	Red	Shades of green
Crops	Medium to light green	Pink to red	Shades of green
Wetland vegetation	Dark green to black	Dark red	Shades of green
Water	Shades of blue to green	Shades of blue	Black to dark blue
Urban areas	White to light blue	Blue to grey	Lavender
Bare soil	White to light grey	Blue to grey	Magenta, lavender, or pale pink

Table 9. Reasons of wetland encroachment at Ruiru sub-ward, Kenya

Factor	Frequency	Percentage
Provide food	20	50%
Generate income	10	25%
Settlement	4	10%
Wood fuel provision	4	10%
Control of diseases	2	5%
Total	40	100%

The findings here are consistent with data collected on the causes of drainage of the Kisii wetlands, revealing that 70% drained wetlands for agriculture (Mironga 2005). Food sources were cited by residents as the leading cause of wetland drainage as this area can provide adequate yields all year round. The community can cultivate crops in the dry season to not limit their farming activities in the dry season. This ensures a good source of food and income throughout the year. The increase in population also forces residents to dry up wetlands to obtain the additional land they badly need for production. Farmers grow potatoes, spinach, and kale which they harvest, sell and consume locally because of the several ways wetlands increase their food security. This community also earns income by carrying out agricultural activities as excess produce is sold to nearby cities like Nairobi, Kiambu, Limuru, and Githunguri. Most of the farmers were implementing an open ditch drainage system that did not require high costs to operate during the data collection, as shown in Figure 14.

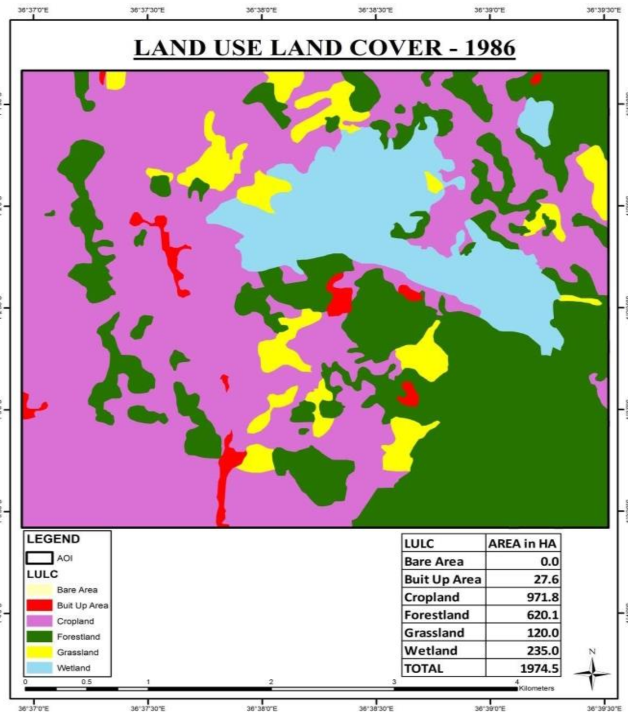

Figure 11. Landsat image of Upland Wetland 1986, Kenya (Source: Remote sensing 2016)

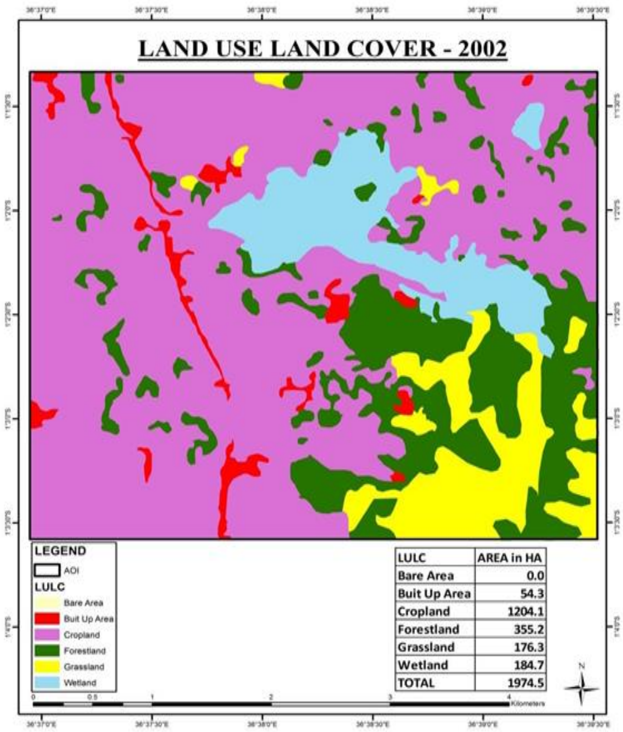

Figure 12. Landsat image of Upland Wetland 2002, Kenya (Source: Remote Sensing 2016)

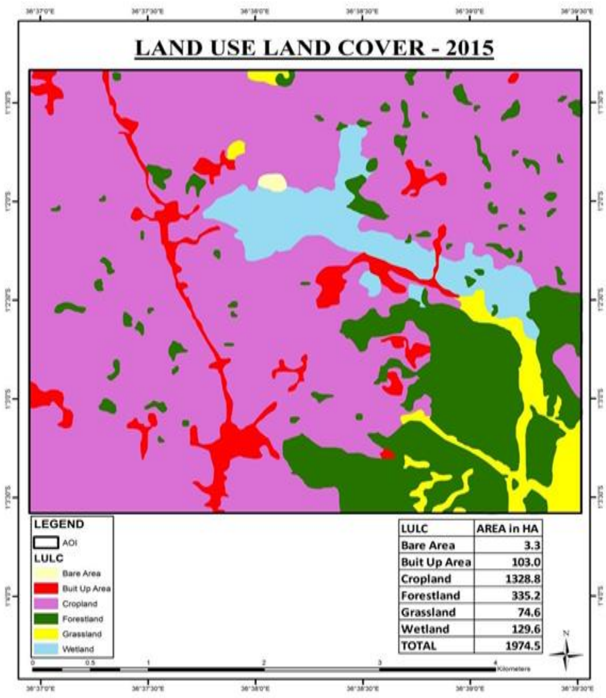

Figure 13. Landsat image of Upland Wetland 2015, Kenya (Source: Remote sensing 2016)

A source of forage is another benefit farmers get from wetland drainage. Direct grazing was not possible because the farmers claimed that pollutants killed their livestock from the factory and the upcoming town of Lari. A respondent admitted that he had lost five cows due to waste from the following factory. Farmers ended up choosing other land uses to avoid this threat. They also said that the Court case against the factory took a long time to resolve even though some farmers were compensated.

Another 10% of respondents indicated that eucalyptus tree planting was carried out due to the closure of the nearby Lari Forest to supply firewood for household needs. A nearby tea factory that wilted tea with a wood fire created a good demand for the tree and the upcoming construction activities in nearby cities. To achieve this goal, farmers intercorporate their food crops with eucalyptus to maximize their land before the trees mature, which helps drain the wetlands (Figure 15). This is more so because land-based resources are an important asset for the poor in developing countries, who rely on them to generate a large proportion of their income and living necessities (IFPRI 2013).

The study also revealed that residential houses that generate immediate income due to proximity to Lari City and future factories in this area have significantly increased. Most of the migrants who became victims of post-election violence turned Lari Subdistrict back into a residential area. Hence, the demand for cheaper housing is rising, and local people use this opportunity to build affordable housing in wetlands, as shown in Figure 16. The construction of the rental house is already alive, and this also speeds up the drainage.

The conversion of wetlands to residential areas endangers the water quality of the Ruiru river due to fecal contamination. Some of these so-called Karia has experienced eruptions of waterborne diseases such as typhus after being diverted to residential areas. Boreholes must be dug with CDF money to try to eliminate this threat. Karia- this is a Kikuyu word that means dam. Initially, the area was a dam built by Europeans to supply water to their livestock. After distinction, it was divided into 250 plots known as Scheme of Lari's Settlements 107. Each farmer was allocated a plot of land because the dam could not be divided among the members.

Farmers dry it and sell it for real estate development, especially after the PEV, which made most internally displaced people come to this area. The presence of Lari forest's encroachers driven out in 1986/1987 also accelerated this problem; they bought a plot of land in this area because it was affordable. Likewise, other rail settlers came to the wetlands after the collapse of the Kenya Railroad. Low land prices are attractive bait for large settlements.

Water-borne diseases such as upland malaria also cause drainage of wetlands. This disease outbreak led to the formation of the Running Malaria Prevention and Control Project. This project received funding from the CDF of Kshs. 200,000, which they used to buy malaria medicine and bed nets. The project also reserves the right to dig drainage ditches into assisting in draining to resolve this problem. Land-use changes should also be adapted to deal with typhus, bilharzia, and river worms that kill livestock.

The threat of accidental heart has been going on for so long that one of the tributaries is named after him, the Gethambara River. More and more people (87.5%) claim to get more benefits from wetlands due to the above activities, as shown in Figure 17. Farmers seem to be using their land to provide them with more profit. There are three central tenure systems in Kenya: public, private, and trust land. Under property rights, the owner is responsible for using the land as it seems right in one's perspective (NEMA 2012).

Figure 14. Drainage activities in Ruiru sub-ward, Kenya

Figure 15. Farming activities in Upland Wetland, Kenya

Figure 16. Settlements in Upland Wetland, Kenya

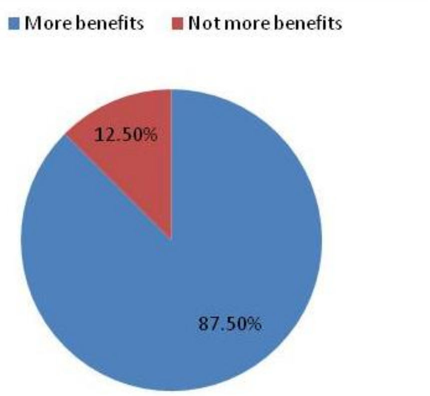

Figure 17. Responses concerning benefits accrued from Upland Wetland

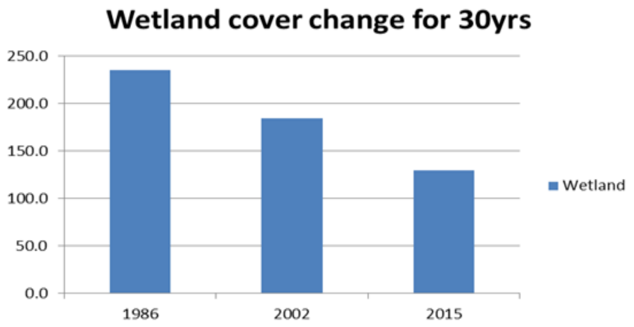

Figure 18. Wetland loss for the last 30yrs

Drainage of Upland Wetlands is mainly caused by agricultural activities, settlements, and tree farming. The findings of this study are in line with other studies conducted in the Lake Victoria wetlands, where it was found that anthropogenic activities such as reclamation for agriculture pose a significant threat to wetland conservation (Akwany 2009). The extent of community participation and their possible contribution to conservation.

The results showed that community participation in upland resource conservation was minimal; only 2.5% of respondents stated that they had participated as members of the National Environmental Management Authority and the Nairobi Water and Sewerage Company. Community members do not participate in any way at the environmental or sub-country level. No established agency like WRUA can link them to WARMA or WDC that serves community-based water conservation groups. This contrasts with the Water Act of 2002, which advocates for a bottom-up management plan that identifies and engages stakeholders in managing adjacent resources (Water Quality Group 2014).

The study found no conservation organizations represented in the area or their agents to encourage citizens to participate. Community-based participatory groups, such as WRUA as stipulated in the Water Act 2000, do not exist. The central government allocated the Lari community's resources without the residents' consent, which led to rebellion against natural resources such as encroachment of wetlands. The above can be supported because government agencies have been slow to embrace participatory wetland management, and their support for co-management may be mere lip-service. So developing techniques to increase government acceptance and commitment to co-management is one of the significant challenges facing wetland conservation (Claridge and Callaghan 1997). Using the one-sample t-test at the participation rate t-56.00, df = 39, p = 0.001, it turns out that the participation rate of the Upland Wetland management is significantly low.

Hypothesis (H3) "There is no significant effect of local community participation in the management and conservation of wetlands in the Highlands." Based on these findings; The researcher accepted this hypothesis because community participation was minimal even in cases where conservation bodies existed. Thus, a participatory approach has not been introduced and camped. Challenges and Opportunities of Participatory Management

Privatization of wetlands from pre-colonial times to the present is a significant challenge for conserving the Upland Wetlands. The farmers have official land titles issued since 1964. This is against government policies that advocate for the protection and conservation of water catchments. For example, the Water Act 2000 supports the creation of riparian lands and the repossession of similar areas for conservation. As a result, the total wetland cover area has decreased, as shown in Figure 18.

Settlements also cause the loss of wetlands, especially in the south. The current payment has divided the wetland into two equal parts. Due to continuous flooding during the long rainy season, most wetlands are drained and then abandoned, leading to loss of biota characteristics. The conversion of wetlands to cropland is also a big challenge as the area is drained from all directions. Farmers also convert some wetlands into forests, primarily eucalyptus, which dries the land faster for crop farming. Therefore, human encroachment is the greatest challenge for the Upland Wetlands as it has caused huge losses over the last thirty years, as shown in Figure 19.

The low level of community participation in managing the Upland Wetlands is also a big challenge because only 2.5% stated that they had participated. The Kiambu County sub-region has effectively engaged various stakeholders such as the Kamiti watershed and the Thiririka River to conserve water resources. However, there is no community-based conservation group on the Ruiru River. The flow of information is also insufficient because this community does not know about WRMA or WRUA. Communities living in this catchment area have not been empowered on participatory wetland management issues to form Sub-watersheds that map ahead for participatory issues.

As a result, other human activities increase at the expense of conservation activities. Changes in land cover and land use during the last thirty years show that the built-up area has increased by 74.4 Ha and agricultural land is 357 Ha. However, the decrease in the area of a conservation area on the forest land decreased by 284.9 Ha, Grassland by 45.4 Ha, and wetland by 105.4 Ha, as shown in Table 10. Therefore, human encroachment is currently threatening conservation activities in the Ruiru sub-ward.

As a sub-district settlement, Lari has a poverty problem that makes residents unable to send their children to school, considering that only 5% of the sample population has tertiary education. So there's lousy enlightenment for people as far as conservation is concerned. The local population is also not ready to be resettled. They claim that the area has good infrastructure and is very developed compared to other country regions, which poses a significant conservation challenge. Their proximity to the Nairobi District also provides good social infrastructures such as hospitals, roads, electricity, and water, giving rise to fears of losing such benefits upon resettlement. The institutional failure of the NWSC and WRMA to campaign for wetland conservation and education of local people about the importance of wetlands is also a significant challenge. These agencies do not assist with conservation issues or even help supplement low levels of education by doing extension work. Most people in this area hold KCPE certificates, so the ecological role of wetlands is unknown. No wonder those with a 50% diploma education practice conservation science. The parastatals that control natural resources in Kenya also appear to be operating at a level where the population cannot reach them.

The study results revealed opportunities for community participation, considering that 77.80% of respondents were ready to be involved in NWSC plus WRMA activities which could encourage them to carry out conservation activities. However, less than a quarter (22.20%) of the population felt that they would not allow their land conservation despite the benefits shown in Figure 20.

Those for conservation could encourage both preservation of wetland and its sustainable use. The study is inconsistent with the one carried out in Lake Victoria wetlands that revealed that raising public awareness, training, formation of conservation groups, and change of attitude can help in wetlands conservation (Akwany 2009).

Members who were ready to embrace conservation once involved suggested Community-Based projects such as fish farming, eco-tourism, and cottage industry as alternative wetland use. Such projects can create sustainable use and generate income for the residents. Irrigation projects that were seen to increase food production in the upper drier area could reduce the probability of farmers encroaching into the wetland. This is true, bearing in mind that the wetland encroachment was due to its moist soil experienced all year long. Farmers could equally be encouraged to embrace intensive farming, producing maximum yields within small areas.

Respondents also noted that while the Kenya Forest Service encourages communities to adopt resource management, such as achieving 10% tree cover on their farms, water resource conservation groups do nothing to motivate the public. Such campaigns can even entice farmers to get compensation for land and thus conserve it. By doing this, farmers can earn money to buy land elsewhere or even get funds to irrigate their highlands to produce food crops.

Table 10. Land use land cover change of Ruiru Sub-ward, Kenya for the last 30 years

LULC in Ha	1986	2002	2015
Bare area	0.0	0.0	3.3
Built-up area	27.6	54.3	103.0
Cropland	971.8	1204.1	1328.8
Forest land	620.1	355.2	335.2
Grassland	120.0	176.3	74.6
Wetland	235.0	184.7	129.6
Total area	1974.5	1974.5	1974.5

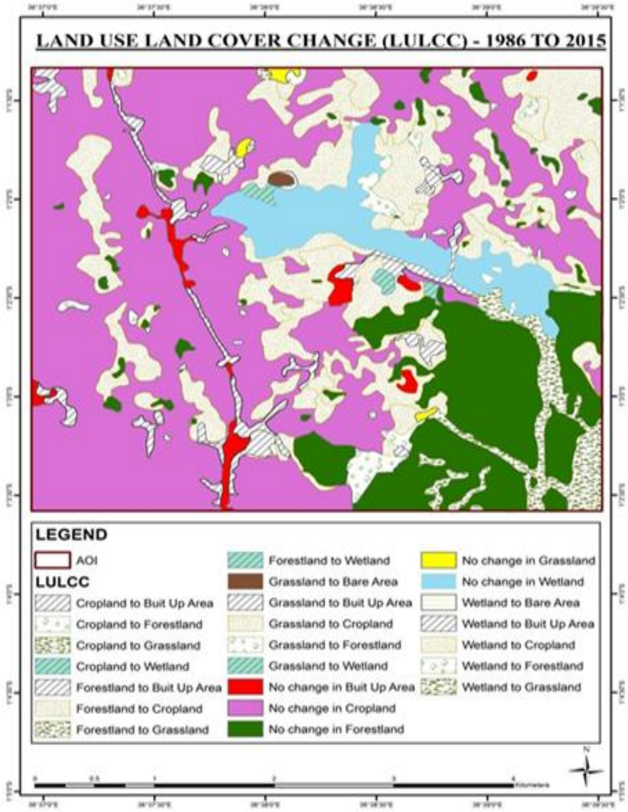

Figure 19. Summarized image of causes of Upland Wetland, Kenya loss for the last 30yrs.

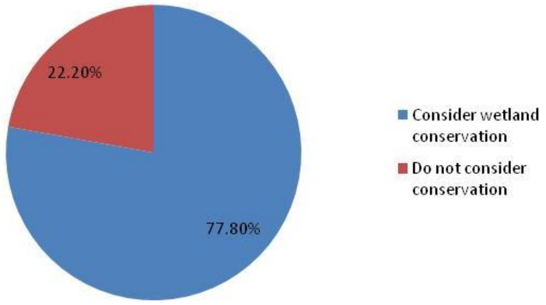

Figure 20. Respondents favoring and not favoring wetland conservation

The lack of involvement of local communities or even distribution of benefits derived from extracting water from their areas since 1935 has generated many negative attitudes in the minds of local communities with conservation. The residents had a lot of hope in the NWSC after taking over from the colonial government in river management. To date, the company has not funded any projects, employed local people, or provided any incentives to harvest and sell water to the people of Nairobi. So that the farmers feel cheated because the company takes resources that come from their land but does not provide any profit in turn. Moreover, ecosystem management is increasingly leading to collaborative management systems with indigenous peoples (Oviedo and Brown 1999).

Hypothesis (H4): "Farmer's involvement in catchment management has a positive effect on wetland management." The researcher accepts the null hypothesis that most residents were ready to conserve the wetland, i.e. (X^2=0.127, p=0.001).

Community-based management programs that advocate for bottom-up management strategies already exist in government policies such as WRUA and SCMP. Therefore, farmers can be encouraged to form community-based conservation groups such as WRUA. Community-based conservation groups can receive funding through WRMA, which can assist in wetland conservation. Therefore, the community needs enlightenment so that they can form an SCMP which can become a forum for obtaining funding from the WDC. Once this is accomplished, this will not only help provide adequate water supply to the existing Ruiru I Dam but also a sustainable water supply to the Nairobi District as well as the proposed Ruiru II Dam construction project.

Conclusions

From these findings, it was revealed that institutional failures such as the WRMA and NWSC to harvest and sell water to the citizens of the city of Nairobi were a challenge because they did not make people aware of the importance of wetlands. There are no organizations protecting wetlands in the Ruiru River catchment or their representatives. Most respondents have never heard of or encountered an organization that creates awareness about wetland issues. Lack of conservation education also contributes to wetland degradation as only 5% of the population has received tertiary education.

The study found that Uplands Wetland degradation had existed since the colonial time when a white settler was allocated this area and immediately started draining the wetland to grow wheat and oats for cattle and pig rearing. It was also found that; privatization of wetlands is a significant challenge for Upland Wetland conservation. It prevents legally mandated conservation groups such as KWF from engaging in its protection. Farmers having legal title deeds have given them rights in determining wetland use, such as settlement and farming, thus degrading the wetland further.

The study found that negative attitudes and a lack of management assistance led to the rebellion of natural resources such as encroachment of wetlands. The above can be supported by the fact that government agencies have been slow to embrace participatory wetland management, and their support for co-management may be mere lip-service. Based on these findings, it is evident that encroachment of wetlands is influenced by low community participation. In addition, community participation in the conservation of the Upland Wetlands is still minimal. Likewise, community-based participatory groups such as WRUA regulated in the Water Act 2000 also do not exist in this area.

The study revealed that wetland privatization hampered participatory efforts because there was no common ground for all communities to justify the formation of community conservation groups such as WRUA and the community missed the opportunities for establishing SCMPs that could be obtained. Funding from the WDC. The loss of wetland services and a functional role is also a major challenge as the area is currently unable to attract funding from conservation groups such as Wetland International. Chances are most residents are ready to be involved in NWSC and WRMA activities that can promote conservation. Members who are prepared to embrace conservation have been involved in suggesting Community-Based projects such as fish farming, ecotourism, and cottage industries as alternatives to wetland use. The existence of a bottom-up management strategy in the Water Act 2002 that received funding from the WDC can also increase and encourage conservation activities in Upland Wetlands through the formation of conservation groups such as WRUA.

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Parasites prevalence which infecting freshwater fishes in Mulur Reservoir of Sukoharjo District, Indonesia

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Abstract. *Iriansyah AH, Budiharjo A, Sugiyarto. 2020. Parasites prevalence infecting freshwater fishes in Mulur Reservoir of Sukoharjo District, Indonesia. Bonorowo Wetlands 10: 92-97.* Mulur Reservoir is one of the natural fish habitats and consumption fish cultivation in Sukoharjo District, Indonesia. Excessive use of the reservoir area causes decreased water quality, affecting fish life sustainability; one of them can cause the fish susceptibility to infection by parasites. This research aimed to identify the types of parasites that infect the consumption of fish in Mulur Reservoir and calculate the prevalence value. Samples were taken by purposive sampling for gourami (*Osphronemus goramy*), tilapia (*Oreochromis niloticus*), betutu fish (*Oxyeleotris marmorata*), catfish (*Clarias batrachus*), and jambal (*Pangasius djambal*) 10 fishes for each type. The parts of fish infected by ectoparasites such as body mucus, fin mucus, head mucus, and gills were taken by scrapping and observed under a microscope with magnification between 100-400x. The results showed that 5 types of ectoparasites were *Epistylis* sp., *Ichthyophthirius multifilis*, *Trichodina* sp., *Dactylogyrus* sp., and *Gyrodactylus* sp. with an average prevalence of more than 50%. There are more ectoparasites in domesticated fish than in wild fish.

Keywords: Ectoparasites, freshwater fish, consumption fish, Mulur Reservoir Sukoharjo

INTRODUCTION

Sukoharjo District, Central Java, Indonesia, is one area that develops inland aquaculture. Inland fishery production in Sukoharjo has increased yearly, both in public waters, aquaculture with ponds, and cages. Mulur Reservoir, located in Mulur Village, Bendosari Sub-district, Sukoharjo District, is a freshwater ecosystem as a natural habitat for various types of fish. Its primary function is to irrigate agricultural areas, and besides that, it is also used as a means of fisheries management (Faradiana et al., 2018).

The fishery business carried out in the Mulur reservoir is divided into two types, namely fish caught and fish cultivated through cages. Both types of fish live in the same waters and environment. If there is a change in the environment, it will affect the survival of both of them, likewise with the presence of parasitic infections in fish. Factors affecting fish distribution include DO, water flow velocity, and food sources (Muchlisin and Azizah 2009).

Parasites are organisms that live on the bodies of other organisms and generally hurt the host organism. Parasites in fish can be divided into two types, namely ectoparasites and endoparasites. Ectoparasites are parasites that live on the outer surface of the host's body and in the hosts' skin burrows (Azmi 2013). Endoparasites live in internal organs such as the digestive system, liver, blood circulation, abdominal cavity, and other body tissues. Parasite attacks on fish cause fish to lose their appetite, then slowly weaken and lead to death. Clinical symptoms caused include spots on the fish that cause itching so that the fish will rub their bodies against objects around them, loss of appetite, and excessive mucus production (Kurniawan 2012).

Parasitism is a symbiosis in which one organism lives on the sacrifice of its host, both biochemically and physiologically (Anshary 2008). Parasites that infect fish, especially consumed fish, have not affected humans. However, these parasites will affect fish life, especially in metabolism. The energy from metabolism that should be used for growth must be used for energy protection or defense from these parasites. Fish infected by parasites are likely to impact the appearance of the fish, such as slow growth, small fish size, and damage to specific organs.

Knowledge of parasites in waters needs to be known as information about the ecology of parasites and their hosts in these waters. Research on parasites that infect fish, especially in the Mulur Reservoir, has never been done before, so there is no scientific information on this matter; therefore, it is important to research to identify the types of ectoparasites that attack fish in these waters and the prevalence of ectoparasites to determine the level of parasitic infection that can cause infection occurs in consumption fish.

MATERIALS AND METHODS

The study was conducted from November 2018 to January 2019. Fish sampling was carried out in Mulur Reservoir, Mulur Village, Bendosari Sub-district, Sukoharjo District, Central Java Province, Indonesia. Parasite examination and identification were carried out at the Biology Laboratory, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Surakarta, Indonesia.

The tools used in this study were object-glass, cover glass, light microscope, surgical instruments (tweezers, scalpel, scissors), dropper, cooler box, paraffin tub, stationery, ruler, camera, and tools to measure water quality such as a thermometer, pH meter, DO meter, and Secchi disk.

The materials used in this study were distilled water and fish samples, namely goramy (*Osphronemus goramy*), tilapia (*Oreochromis niloticus*), marble goby fish (*Oxyeleotris marmorata*), catfish (*Clarias batrachus*), and pangas catfish (*Pangasius djambal*) taken from Mulur Reservoir as many as 10 individuals from each fish species. The fish samples obtained were identified using the identification book by Kottelat et al. (1993) and Saanin (1984). Sampling was carried out six times using the purposive sampling method at three predetermined points. The samples were fish that live wild in reservoirs and fish cultivated in floating net cages.

Examination of ectoparasites was carried out using macroscopic and microscopic. The macroscopic study is carried out by examining the presence or absence of clinical symptoms of parasites on the outside of the fish body, while the microscopic examination is by scrapping the surface of the body, head, fins, tail, and gills and then observed under a microscope with a magnification of 100-400x. Examination of the gills was carried out by opening the operculum and then cutting the fish gill lamellae using scissors, placing it on a glass object, dripping with distilled water, then observing it under a microscope with a magnification of 100-400x.

Each parasite found on ectoparasite examination was recorded and collected for further identification. Identification of ectoparasites using the Kabata identification book (1985).

Data analysis

The results of a quantitative examination of ectoparasites were calculated using the formula according to Margolis et al. (1982) as follows:

$$Prevalence = \frac{\sum infected\ fish}{\sum sample\ fish} \times 100\%$$

$$Intensity = \frac{\sum X\ parasite\ found}{\sum sample\ infected\ by\ parasite\ X}$$

The identification of ectoparasites that attack consumption fish in the Mulur Reservoir was analyzed descriptively, and the data was presented in the form of images. The results of calculating the prevalence and intensity of ectoparasites obtained were analyzed descriptively quantitatively, and the data were presented in tabular form (Steel and Torrie 1993).

RESULTS AND DISCUSSION

Excessive use of reservoirs will affect the condition of these waters, especially for the survival of the fish that inhabit these waters. According to Tjokrokusumo (2008), differences in environmental conditions in the inlet and outlet areas result in variations in distribution patterns, behavior, and fish composition. The community's daily activities around the reservoir, such as residential areas and rice fields, can also affect the balance of the reservoir ecosystem.

According to PP No. 82 of 2001, waters suitable for use as freshwater fishery facilities are classified into second and third water classes with specific quality standards (Table 1). The condition of the waters of the Mulur Reservoir has water quality that is not under the quality standards specified in PP No. 82 of 2001, so it can be said that the waters are not suitable for fish life. Low oxygen levels can interfere with the respiratory process in fish, and low light penetration levels can interfere with the vision of some types of fish. The temperature and acidity of the water are still within the quality standard (Table 1).

Types of ectoparasites

The parasites found were *Epistylis* sp., *Ichthyophthirius multifilis*, *Trichodina* sp. (protozoa), *Dactylogyrus* sp., and *Gyrodactylus* sp. (monogenean).

Table 1. Abiotic environmental parameters of Mulur Reservoir, Sukoharjo District, Indonesia

Variable	Unit	Sampling point			Average	Quality standards
		1	2	3		
Temperature	ºC	30	30.7	32.3	31	26-32
pH		8.5	7.9	7.9	8.1	6-9
DO	mg/L	2.8	1.1	1.6	1.8	≥ 3
Water clarity	cm	26	27	28	27	≤ 10

Epistylis sp.

Epistylis sp. is an ectoparasite of the type of protozoa with a bell-like morphology in the form of an elongated tube, translucent whitish in color. There is a small nucleus in its cells, and the cells can contract. Posteriorly there is a pair of cilia that look like stalks. *Epistylis* sp. is a protozoan measuring 45-250 m with a solitary life morphology, whitish in color, has a small macronucleus, does not contract, cells can contract, and has paired capsules (Irvansyah et al. 2012). An elongated zooid consists of a ciliated peristomial stalk, food vacuole, micronucleus, and macronucleus. These small protozoa have handles, usually in colonies composed of 2-5 individuals (Saglam and Sarieyyupoglu 2002). According to Andriyanto and Fachri (2014), this parasite is a parasite that primarily attacks freshwater fish and is generally from the Cyprinidae group and settles on the skin and fins of its host using cilia branches. This parasite has a protease enzyme secretion organ that is used to take protein from the host's skin (fish) to cause secondary infection by bacteria.

Ichthyophthirius multifilis

Ichthyophthirius multifilis is an ectoparasite of the type of protozoa with a round morphology, and there is a large macronucleus in its cells. Usually, these parasites lodge in the layers of the skin and fins and damage the epithelial tissue to cause bleeding. *I. multifilis* clusters in large numbers to form white spots on fish, so it is called white spot disease. *I. multifilis* has a round body shape where the whole body is ciliated and moves amoeba-like; inside the body, there is a transparent horseshoe-shaped macronucleus and a micronucleus attached to the macronucleus. This parasite is the most virulent protozoan parasite in fish (Nofyan et al., 2015; Rahmi. 2012).

Trichodina sp.

Trichodina sp. is an ectoparasite from the protozoa group with a transparent circular shape resembling a cup or wheel with several cilia surrounding the cell. At the center, there are three concentric circles called the adhesive plate. *Trichodina* sp. is a parasitic protozoa from the ciliates group with vibrating feathers. *Trichodina* sp. is a circular shape like a cup measuring 50-100 m with vibrating hairs strung on both sides of the cell (Irianto 2005).

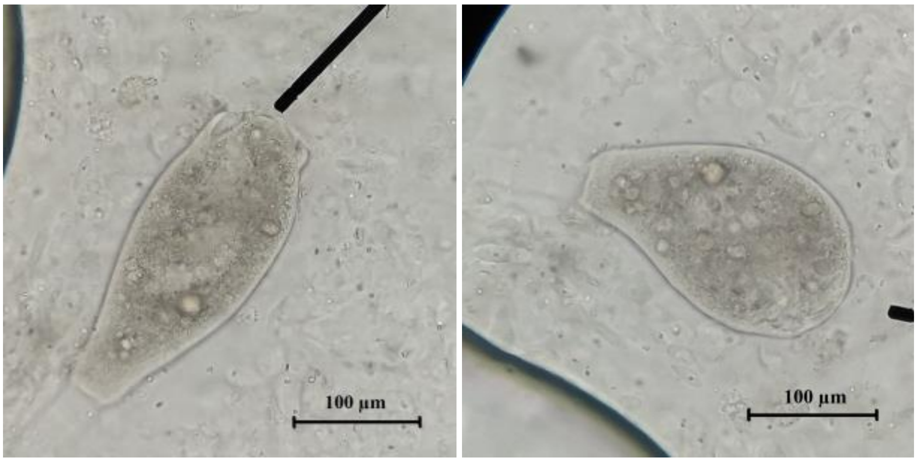

Figure 1. *Epistylis* sp. with a magnification of 100x

Figure 2. *Ichthyophthirius multifilis* with a magnification of 400x

Figure 3. *Trichodina* sp. with a magnification of 400x

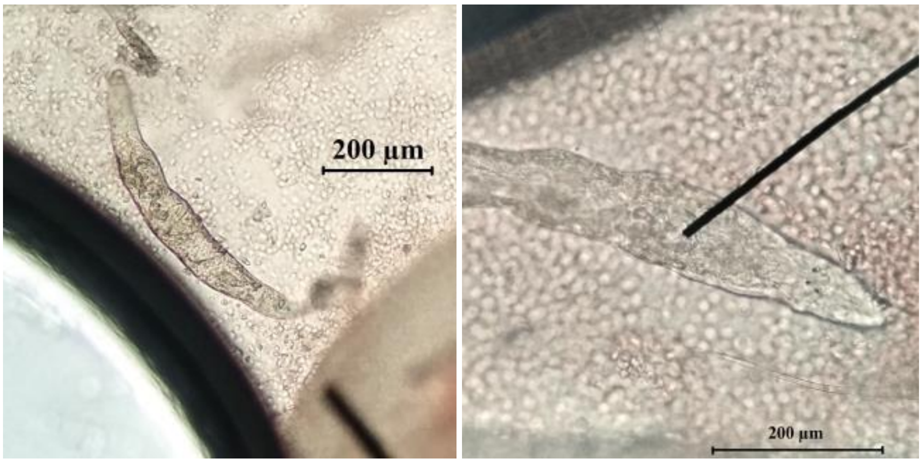

Figure 4. *Dactylogyrus* sp. with magnification of 100x and 400x

Figure 5. *Gyrodactylus* sp. with a magnification of 100x

Dactylogyrus sp.

Dactylogyrus sp. is an ectoparasite of the monogenean trematode worm group with an elongated, transparent shape with a smaller anterior end. This ectoparasite can be easily recognized by the presence of two pairs of eyespots on the anterior end of its body. The mouth is located near the anterior end of the body, with the digestive tract towards the posterior. At the posterior end of the body, an attachment apparatus consists of two pairs of large hooks surrounded by smaller hooks called opisthaptors.

Gyrodactylus sp.

Gyrodactylus sp. is an ectoparasite of the monogenean trematode worm group. Elongated transparent cylindrical parasite with a V-shaped anterior end, 2 protrusions or lobes, without eyespots or eyespots as in *Dactylogyrus* sp. This parasite has a hook-shaped anchor on the posterior, surrounded by marginal hooks that attach to the host's body tissues, namely the skin and gills.

Ectoparasite prevalence and intensity

Ichthyophthirius multifilis is the most dominant parasite because this ectoparasite infection occurs evenly in the waters, evidenced by the parasite's presence in all fish samples. *Ichthyophthirius multifilis* is also referred to as a cosmopolitan ectoparasite because it can attack almost all types of freshwater fish. Still, it is also generally found in all kinds of freshwater ecosystems.

Some parasites are only found in certain types of fish. *Trichodina* sp. is a parasite that attacks tilapia and pangas catfish. The attack of this parasite on both fish occurred with a prevalence value of 100% and a relatively high intensity, but no *Trichodina* sp. attack was found. In other types of fish. Likewise, *Epistylis* sp. was found to attack only goramy and tilapia in the least amount. *Dactylogyrus* sp. attacks catfish and pangas catfish, and *Gyrodactylus* sp. attacks tilapia and pangas catfish.

Epistylis sp. found attacking the outer surface of the body, *Ichthyophthirius multifilis* and *Trichodina* sp. found attacking the outer surface of the body and gills, *Dactylogyrus* sp. found attacking the gills, and *Gyrodactylus* sp. found attacking the gills. Species influence differences in the distribution of ectoparasites in fish body parts.

The results showed that domesticated fish were more affected by ectoparasites than wild fish, both in terms of the type and number of infections. It can happen because fish outside the cage has a place to live with a broader range so that if an infection occurs in one fish, the risk of spreading that will happen is relatively low. In contrast to domesticated fish, if an infection occurs in one fish, the risk of spreading the parasite infection is somewhat higher, supported by physical contact between one fish and another.

Table 2. Ectoparasite Prevalence and Intensity in Mulur Reservoir Sukoharjo

Type of fish	Source	Type of ectoparasites	Σ Parasite	Σ Infected sample	Σ Sample observed	Prevalence (%)	Intensity (parasite / fish)
Goramy	Domesticated	*Epistylis* sp.	5	3	10	30	1.67
		I. multifilis	23	8		80	2.87
	Average					**55**	**2.27**
	Wild				0		
	Average						
Tilapia	Domesticated	*Trichodina* sp.	151	5	5	100	30.2
		I. multifilis	11	3		60	3.67
		Epistylis sp.	1	1		20	1
		Gyrodactylus sp.	1	1		20	1
	Average					**50**	**8.96**
	Wild	*Trichodina* sp.	89	5	5	100	17.8
		I. multifilis	5	2		40	2.5
	Average					**70**	**10.15**
Marble goby	Domesticated				0		
	Average						
	Wild	*I. multifilis*	32	9	10	90	3.56
	Average					**90**	**3.56**
Catfish	Domesticated	*I. multifilis*	13	4	5	80	3.25
		Dactylogyrus sp.	1	1		20	1
	Average					**50**	**2.12**
	Wild	*I. multifilis*	6	3	5	60	2
	Average					**60**	**2**
Pangas catfish	Domesticated	*Gyrodactylus* sp.	2	1	5	20	2
		Dactylogyrus sp.	13	4		80	3.25
		I. multifilis	8	2		40	4
		Trichodina sp.	182	5		100	36.4
	Average					**60**	**11.41**
	Wild	*Dactylogyrus* sp.	1	1	5	20	1
		I. multifilis	12	3		60	4
		Trichodina sp.	44	5		100	8.8
	Average					**60**	**4.6**

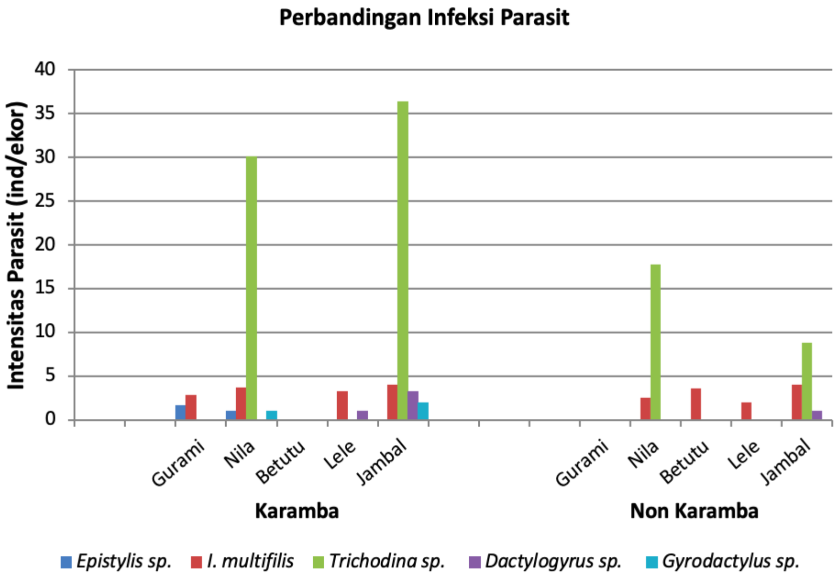

Figure 6. Comparison of parasite infections based on sampling locations

This study concludes that the types of ectoparasites that attack freshwater fish species in the Mulur reservoir are *Epistylis* sp., *Ichthyophthirius multifilis*, *Trichodina* sp., *Dactylogyrus* sp., and *Gyrodactylus* sp. The average prevalence rate of ectoparasites by type of fish, in goramy, is 55%; in domesticated tilapia by 50%; in wild tilapia by 70%; in marble goby fish by 90%; in domesticated catfish by 50%; in wild catfish by 60%; in domesticated pangas catfish by 60%; and wild pangas catfish by 60%.

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Crab diversity and crab potential as support ecotourism in Teleng Ria, Grindulu and Siwil Beaches, Pacitan, East Java, Indonesia

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Abstract. *Irwansyah RM, Azzahra SIN, Darmastuti SA, Ramadhandi AR, Firdaus O, Daeni F, Safitri N, Fajri OPA, Nugroho GN, Naim DM, Setyawan AD. 2021. Crab diversity and crab potential as support ecotourism in Teleng Ria, Grindulu and Siwil Beaches, Pacitan, East Java, Indonesia. Intl J Bonorowo Wetlands 11: 75-83.* The mangrove area in Pacitan District, Pacitan, East Java, Indonesia, is generally not polluted. Therefore, the land is suitable for growing conditions from mangrove plants and has great potential as a mangrove area with ecotourism management in Indonesia. Ecotourism activities in mangrove areas, in principle, are the use of mangrove areas while maintaining the biological/ecological functions of mangrove areas that have social and economic value for the local community. The mangrove ecosystem is a habitat of various species of Crustacea, such as the crab. Crabs are live in coastal/mangrove ecosystems and one of the key species that have a very important role in maintaining the balance of the ecosystem. The study about the diversity of crabs in the mangrove area is very important because it will improve mangrove quality and potentially support ecotourism in the mangrove ecosystem. This study aims to determine the diversity of the crab and its potential to support ecotourism if the Pacitan Beaches are ecotourism in the future. This research was conducted in Teleng Ria Beach, Grindulu Beach, and Siwil Beach, Pacitan, East Java, Indonesia, in November 2021. Plots of 10 x 10 m2 are made to record the species and the number of individual crab species. The result found five species of crab, i.e., *Austruca annulipes* (H. Milne-Edwards, 1837), *Coenobita perlatus* (H. Milne-Edwards, 1837), *Ocypode kuhlii* (De Haan, 1835), *Perisesarma guttatum* (A. Milne-Edwards, 1869), and *Scylla serrata* (Forsskål, 1775). The total crab diversity index of 1.25 is included in the medium category. The morphology, activity, number of individuals, and distribution of each crab species in an ecotourism area will increase the attractiveness of tourists to visit. For example, the morphology of *C. perlatus* that has the red color as a strawberry sometimes has a home/the shells of the Mollusca which color and unique shape so that add appeal to be seen. Then, the crab *A. annulipes* that like to dance and play the violin with the claw can also be attractions drawing tourists. Hopefully, the data can be a reference for the managers of the mangrove area in developing ecotourism and conservation of mangrove forest.

Keywords: Crab, diversity, ecotourism, mangrove, Pacitan

INTRODUCTION

Mangrove area can be defined as a forest type that grows in tidal areas, especially on protected beaches, lagoons, river mouths that are flooded and free from inundation at low tide whose plant communities tolerate salt (Kainuma et al. 2013; Junk et al. al. 2014). The benefits of mangroves in coastal areas are in the form of environmental distribution and neutralizing the presence of harmful pollutants, reducing approximately 50% of the strength of tsunami waves, and protecting coastlines. In addition, mangroves have a high productivity role compared to other ecosystems, thus making mangrove ecosystems necessary for the life of living things (Li et al., 2015). Furthermore, the mangrove ecosystem consists of organisms (plants and animals) interacting with environmental factors in a mangrove habitat (Vermeiren et al., 2015; Onyena and Sam 2020).

One of the organisms that live in the mangrove area is Crustacea. Crustacea, such as crabs, are macrobenthic animals associated with mangroves. Ecologically, mangrove areas have high productivity to support the surrounding environment because they are rich in nutrients with optimum temperature, pH, oxygen, and salinity and calm water conditions so that they are suitable for crab habitat (Sen et al. 2014; Alvareza and Leilani 2020). Crabs eat suspended matter (filter feeders), eat mangrove litter and fresh mangrove leaves, and are generally dominant on sandy and muddy substrates.

The presence of crabs is an essential indicator in the mangrove ecosystem (Freitas et al., 2021). This is because crab has an important role ecologically and economically. The ecological part of crabs in the mangrove ecosystem includes converting nutrients and enhancing mineralization, increasing the distribution of oxygen in the soil, helping the carbon life cycle, and providing natural food for various species of aquatic biota. Crab also has a high economic value because humans can sell it as a high protein food ingredient. In addition, according to Ginantra et al. (2021), the presence of crabs in the mangrove ecosystem can also be useful as an additional attraction for ecotourism activities.

Ecotourism activities in mangrove areas, in principle, are the use of mangrove areas while maintaining the biological/ecological functions of mangrove areas that have social and economic value for local communities (Duangjai et al., 2014). The conservation of mangrove areas and the ecotourism business are highly dependent on the diversity of animals and plants that live in them (Hakim et al., 2017). Ecotourism can be used as a conservation measure to protect mangrove areas and the organisms that live in them, such as crabs. A mangrove ecosystem that is used as ecotourism will increase conservation and reduce things that damage mangrove areas, such as (i) felling of mangrove trees, (ii) conversion into fish and shrimp farming pond areas, land clearing for settlements or agricultural areas, and (iii) landfills or toxic waste. The degradation of the mangrove area causes changes in the composition and structure of mangrove vegetation, destroys the balance of ecosystems and habitats (physical and chemical environmental factors), as well as the extinction of species of organisms, such as crabs (Nowak 2013).

The mangrove area in Pacitan District is quite extensive and spread over several points, such as Teleng Ria Beach, Siwil Beach, and Grindulu Beach. Research that has been conducted on the species of mangrove trees in the Pacitan mangrove area is dominated by *Rhizophora mucronata*, *Avicennia alba*, *Sonneratia alba*, *Nypa fruticans*, *Avicennia marina*, which are the result of planting (Setyawan et al. 2002). Mangrove areas in Pacitan District are generally not polluted, and the land has the potential to grow mangrove plants (Pacitan District Marine and Fisheries Service 2014). This area has a coastline of 70,709 km^2 (Central Bureau of Statistics of Pacitan District 2021), which can be a mangrove area for ecotourism management in Indonesia.

It is very important to research crab diversity in the mangrove area because it will improve the quality of mangroves and potentially support ecotourism in the Pacitan mangrove ecosystem. The diversity, abundance, morphology, activity, number of individuals, and distribution of each crab species will interest tourists. In addition, research data on crab diversity has never existed in Pacitan. Therefore, this study aims to determine the diversity of crabs and their potential to support ecotourism if Teleng Ria Beach, Grindulu Beach, and Siwil Beach, Pacitan, East Java, Indonesia, will be used as ecotourism in the future. It is hoped that this data can be a reference for managers of mangrove areas in developing ecotourism and efforts to conserve mangrove forests.

MATERIALS AND METHODS

Study area

This research was conducted on November 2021 at three coastal locations with mangrove ecosystems: Teleng Ria and Grindulu Beach in Pacitan Sub-district and Siwil Beach in Ngadirojo Sub-district, Pacitan District, East Java, Indonesia (Table 1). Apart from having a mangrove ecosystem, the three locations were chosen because of their proximity and affordable access (Figure 1).

Sampling technique

Twenty-five plots measuring 10m x 10m at each study site have been created. Plot selection was based on the different substrates in each location. After that, the species and number of crabs in each plot were counted and recorded. Then, abiotic environmental factors such as air, water and soil temperature, water and soil pH, and water salinity were made. Then, this study also recorded the dominant tree mangrove species in each research location. Finally, crab retrieval is done using a handpicking technique, a net tool, and a shovel to dig into the ground the crabs are hiding. The caught crabs were then put into bottles and given alcohol (70%) before being identified.

Crab identification and activity

Identification was carried out based on the morphological characteristics of crabs such as shell color, claw shape, body color, and body size. Identification refers to Shih and Suzuki (2016), Lapolo et al. (2018), and Ginantra et al. (2021). This identification was carried out at the Laboratory of Animal Taxonomy, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Surakarta, Indonesia.

Crab activity was observed directly by observing and documenting all activities at each research location. Each crab activity will be recorded, such as entering the water, entering the hole, walking on rocks, walking on the substrate, foraging for food, and other activities. Crab activity was observed for approximately 2 hours at each research location.

Data analysis

The data obtained were processed using the Shanon-Wiener diversity index, evenness, Simpson dominance, and the abundance of each location and the total research location. The analysis of the existence of crabs as a support ecotourism appeal refers to Rahmila and Halim (2018) and Ginantra et al. (2021).

Shanon-Wiener diversity indeks

$$H' = -\sum \mathbf{pi} \times \mathbf{ln\,pi}$$

Where:
H': Diversity index of Shannon-Winner
Pi: The number of individuals of a species divided by the total number of species.
ln: The number of individuals of the type.

The criteria for the diversity index are H'<1.5; then the species diversity is low; 1.5<H'<3.5 means that the species diversity is moderate; and H'>3.5, then the species diversity is high.

The evenness index (E)

$$E = \frac{H'}{\ln(S)}$$

Where:
E : Specific evennes index
H': diversity index of Shannon-Winner
ln: Natural logarithm
S: Number of species Found

The criteria for the diversity index are 0<E<0.4, then the evenness is low, community depressed; 0.4<E<0.6 means that the evenness is moderate, community labile; 0.6<E<1.0 then the evenness is high, and community stable.

Simpson dominance index

$$D = \Sigma_1^S \frac{ni(ni-1)}{N(N-1)}$$

Where :
D: Dominance index
ni: The number of individual species to the-i
N: The number of individuals of all species

The dominance index ranges from 0 to 1, where the smaller the value of the dominance index indicates that there are no dominant species.

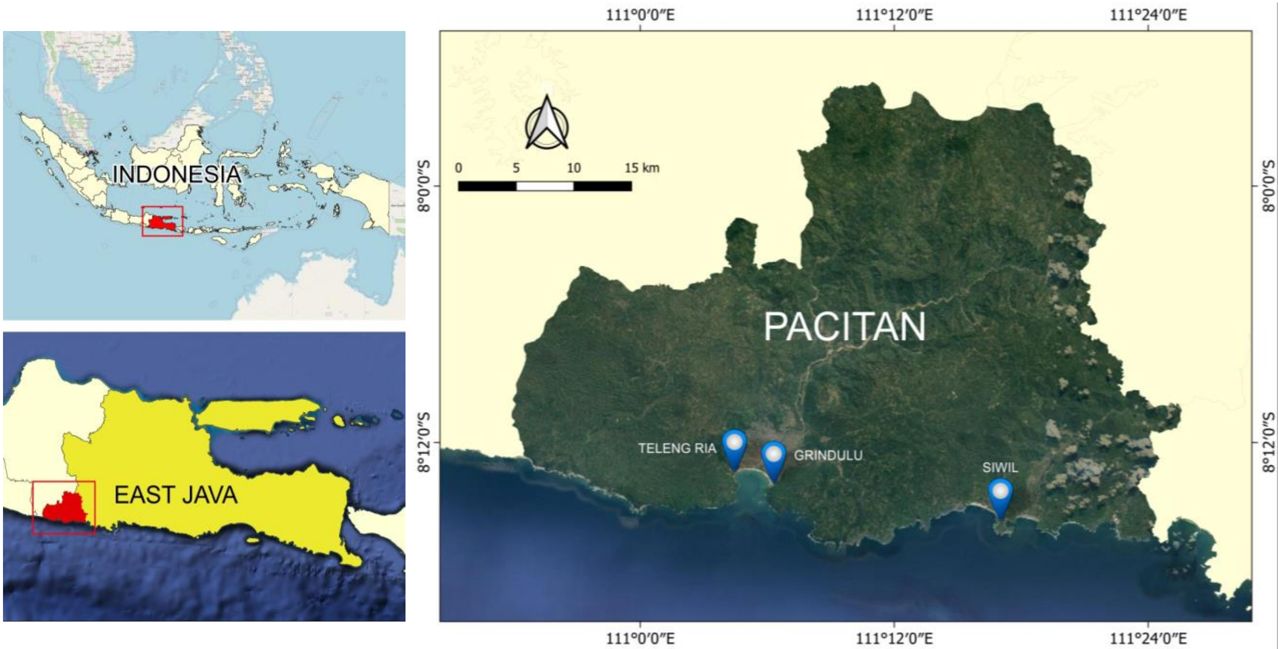

Figure 1. The location of the research crabs mangrove ecosystem in Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia

Table 1. Coordinates, type of subtracts, type of mangrove vegetation, and description of the location study (Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia)

Location	Coordinates	Type of substrate	Dominant mangrove vegetatation	Description
Teleng Ria	S 08°13'19.63" E 111°04'28.82"	Sandy, muddy	*Avicennia alba*	It is a river mouth but not too close to the beach, fishing piers, residential areas.
Grindulu	S 08°13'55.75" E 111°06'21.42"	Sandy, muddy	*Rhizophora stylosa*	Close to beach. Mangrove conservation area is still under development. It is evident from the number of mangrove plant seeds planted.
Siwil	S 08°21'49.57" E 111°07'67.15"	Sandy, rocky, muddy	*Sonneratia alba*	It is a river mouth but not too close to the beach. Tidal area with sandy, muddy and rocky substrates

RESULTS AND DISCUSSION

Crab diversity

Mangrove forests on the coast of Pacitan, such as in Teleng Ria, Grindulu, and Siwil, have a specificity: most of the substrate is white sand/quartz sand, and rocky either in the form of rocks or fragments of dead coral. Sandy beaches generally have a higher temperature than muddy sand substrates because of the larger particle size; the water will not be retained for long and dry quickly. In addition, the organic matter content of white sand is also low, so not many biotas can survive in this habitat. However, at the research site, some rivers carry food and make several points of muddy sand habitat so that organisms such as crabs can still survive (Gray and Elliot 2009). The muddy sand will make it easier for the crabs to make holes, and the abundance of organic matter carried by the river flows for crab food.

This study found 5 species of crabs (Figure 2), namely *Austruca annulipes* (H. Milne-Edwards, 1837), *Coenobita perlatus* (H. Milne-Edwards, 1837), *Ocypode kuhlii* (De Haan, 1835), *Perisesarma guttatum* (A. Milne-Edwards, 1869), and *Scylla serrata* (Forsskål, 1775). The species with the highest abundance was *O. kuhlii*, 0.33 ind./m^2, while *S. serrata* is a species with low abundance because only one individual was found in Siwil Beach. The crab diversity index was obtained for a total of three locations, including the medium category, with an index of 1.25. The family Ocypodidae is the most significant contributor to the number of species with two species (Table 2). The evenness of species is evenly distributed with a stable community structure as indicated by an evenness index of 0.78 and a low dominance index of 0.32 (Figure 3).

As for the diversity index at each location, the Siwil Beach research location has the highest diversity index, 1.3 (medium). The lowest diversity index is Grindulu Beach, 0.18 (lower). The number of species in a community and the abundance of each species will affect the diversity in an ecosystem. Diversity species in an ecosystem will decrease if there are fewer species and variations in the number of individuals of a species or several species with a more significant number of individuals. Compared to other locations, all species in this study can be found in Siwil Beach. This is related to the more diverse habitats in the Siwil Beach, whose habitat has a quartz/white sand substrate mixed with mud, sand with rocks, and sand with fragments of dead coral (Table 1).

The highest evenness index of crabs in Teleng Ria is 0.91, and Siwil, which is 0.77, is in the high category, indicating that the distribution of crabs in the area is relatively equal or even (Figure 2). The results of the dominance index in both places are the same, which is 0.32. This indicates that the dominance of crab species in the area is low. The Grindulu area has a diversity index of 0.18 and an evenness index of 0.91. Both values are low because only two species of crab were found. The crab *O. kuhlii* was dominant against *P. guttatum* in Grindulu. Compared to the other two locations, Grindulu does have a low and young mangrove tree density and size because the mangrove area is used as a mangrove nursery (Table 1). This condition will affect the canopy cover area and the organic matter produced. A wide and dense canopy cover will protect crabs from direct sunlight and predators' wave action and increase the production of organic matter produced (Ravichandran et al., 2011). The better vegetation from mangrove trees, the more diverse the crab species found.

Factor abiotic

A suitable living environment for crabs will make them survive and carry out their role as important organisms in the mangrove ecosystem. The environmental parameter values measured included temperature (°C), acidity (pH), and salinity (Table 3). The measurement of environmental parameters at the research site has average air, water, and soil temperature of 28-33 °C. Compared with research in the Mangroves of Purworejo District, Central Java (Rahayu et al. 2018) and Kuala Langsa, Aceh (Putriningtias et al. 2019), the temperature parameters there are quite different, which is around 26-30 ºC. However, the temperature of this study is not much different from research conducted in the mangrove forests of Alas Purwo National Park, East Java, 29-33 °C (Gita et al. 2015) and Segara Anakan Mangrove Forest Ecosystem, Cilacap, Central Java, 27-33 °C (Redjeki et al. 2017). According to Saparinto (2010), a suitable temperature for mangroves is not less than 20°C, and in general, crabs that live in mangrove ecosystems can survive at temperatures of 23-33°C. It is assumed that the difference in the average temperature of each location is influenced by the mangrove vegetation cover around it, the type of sediment, and the sampling time of the study.

Table 3. Abiotic factors in Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia

Location study	Temperature ºC			pH		Salinity
	Air	Water	Soil	Water	Soil	
Teleng Ria	33	32,6	33	7,6	6	5
Grindulu	32	32,5	33	8	7	10
Siwil	32	28,2	31	7,6	6,1	5

Table 2. Diversity and abundance of crabs crustaceans (ind./m^2) in three location studies (Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia)

Class/Family	Species	Location			Total
		Teleng Ria	Grindulu	Siwil	
Malacostraca/Ocypodidae	*Austruca annulipes*	0.01	0	0.19	0.2
Malacostraca/Coenobitidae	*Coenobita perlatus*	0.02	0	0.03	0.05
Malacostraca/Ocypodidae	*Ocypode kuhlii*	0.04	0.13	0.16	0.33
Malacostraca/Sesarmidae	*Perisesarma guttatum*	0.02	0.01	0.09	0.12
Malacostraca/Portunidae	*Scylla serrata*	0	0	0.001	0.001

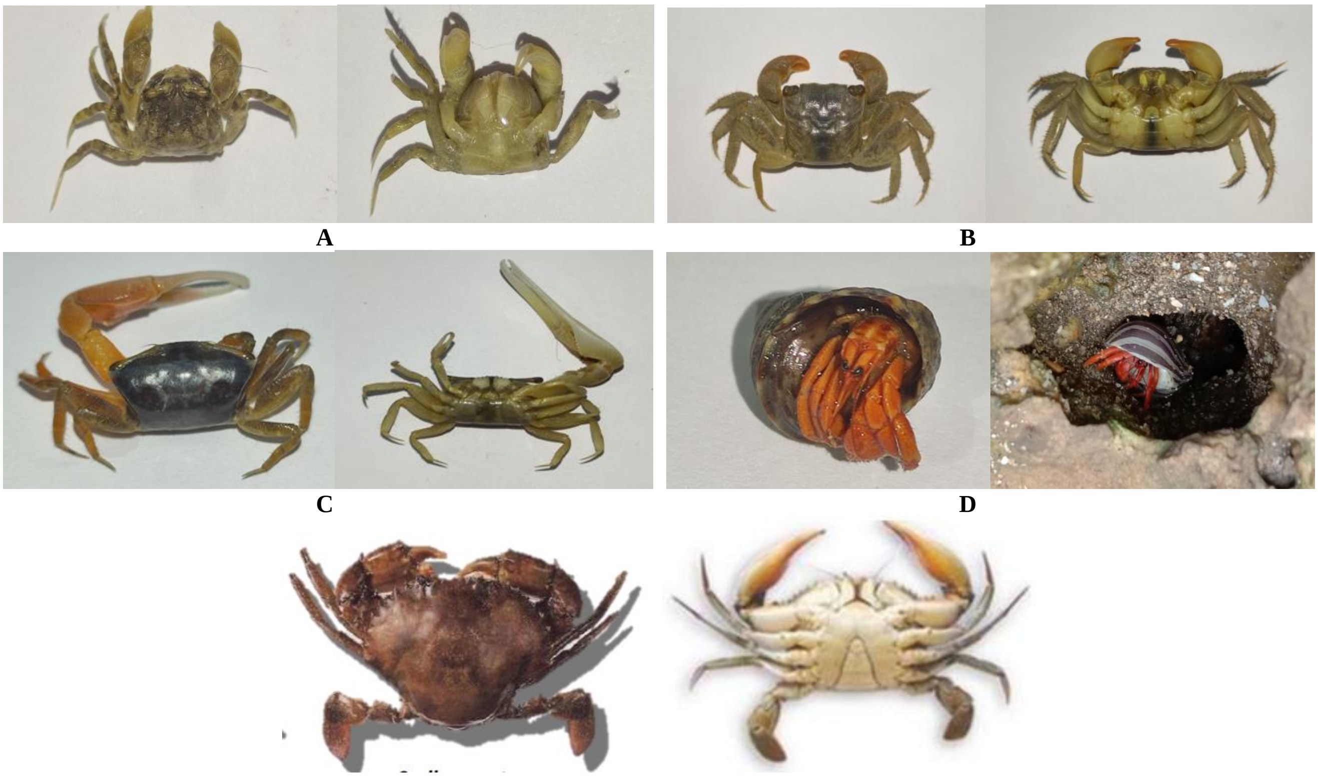

Figure 3. Species of Crustaceans in three location study (Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia): A. *Ocypode kuhlii*; B. *Perisesarma guttatum*; C. *Austruca annulipes*; D. *Coenobita perlatus*; E. *Scylla serrata*

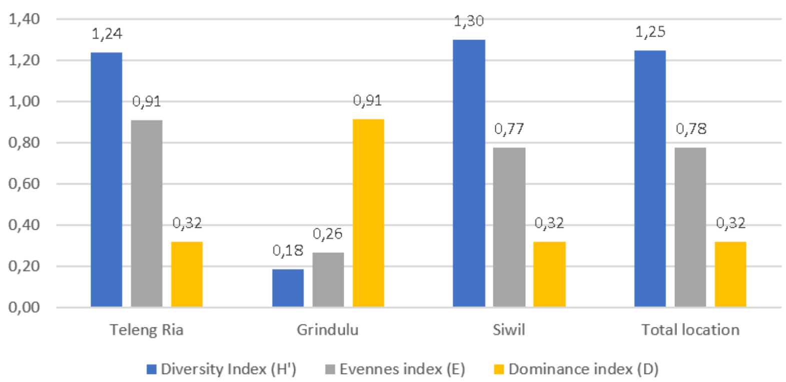

Figure 2. Diversity index, evenness index, and crab dominance index in three location studies (Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia)

The water and soil pH values at each location ranged from 6-8. This is still considered normal because, according to Gillikin et al. (2004), the normal pH value for brackish waters of mangrove ecosystems with animals and plants in them has a pH between 6-9. According to Pratiwi (2010), pH <5 and >9 will create unfavorable conditions for macrozoobenthos life. This means that each research location is at a good pH for crab life and development. The pH value describes the balance between acid and base, which will affect the growth of mangroves. Good mangrove growth in the composition of the mangrove ecosystem will make the litter produced to meet the needs of crab food. The pH results in the crab habitat in this study were also the same as the pH results in the crab habitat by Gita et al. (2015), Redjeki et al. (2017), Rahayu et al. (2018), and Putriningtias et al. (2019).

Based on observational data, the average salinity obtained in the observation area is in the range of 5-10 ppt. According to Rahayu et al. (2018), the range is still in the range of oligohaline (0.5-5 ppt) to mesohaline (5-18 ppt) and can still support crab life. The highest salinity of around 10 ppt is found in Grindulu. This is because Grindulu is closer to the coast, so seawater has more influence than freshwater (Table 1). Meanwhile, the lowest salinity range of 5 ppt was found in Siwil and Teleng Ria. This is because the location is far from the beach, so the seawater has less direct effect. On the other hand, freshwater has more influence because the mangrove areas in both locations receive more freshwater input from water channels, resulting in water dilution resulting in relatively lower salinity than in Grindulu. Based on the research, the water's salinity in the mangrove area's study area fluctuates and is influenced by freshwater runoff from the mainland and the entry of seawater from river mouths.

Crab potential as a support ecotourism attraction

According to Ginantra et al. (2021), information about the species of crabs found their status of existence, whether protected or not, rare or common, is important information to support the attractiveness of ecotourism. In addition, the morphology, activity, number, and distribution of each crab species in an ecotourism area has its own uniqueness and will increase the attractiveness of tourists to visit.

Unique activities of crabs as supporting ecotourism attractions

Activities in the habitat by crabs were observed, such as walking on rocks, sand/gravel, entering and exiting hiding holes, getting into mud, foraging for food, and walking on mudflats. The behavioral observations must be made carefully, because they perfectly camouflage with their environment (Figure 4). This activity is an attraction crab's that tourists can see. *Ocypode kuhlii* and *P. guttatum* will be easy to find and see by tourists because they often walk on sand or rocks. Then, the hermit crab C. perlatus runs slower than *O. kuhlii* and *P. guttatum* to be held and observed for longer by tourists. The most exciting activity of the crabs encountered was the activity of *A. annulipes*. *Austruca annulipes* have activities such as dancing and playing the violin, where the male often moves his giant claw in the air while one of the smaller claws picks up food on the substrate. In the observations made, this activity was carried out at low tide during the day while looking for food (see the youtube video of this research https://youtu.be/QNFR0hKYPZ8). The results of observations of other activities regarding the crab *A. annulipes* that this crab is very sensitive to vibration, if there is a vibration around this crab, then this crab quickly goes into its hiding hole. As long as when seeing this crab, do not make vibration around its hiding hole, then this crab will come out and dance again so the tourists can see this crab dance closely and clearly. In many plots in Siwil Beach, this dance activity is carried out by dozens of individuals of *A. annulipes* under the shade of *Rhizophora stylosa* and *Sonneratia alba* trees. Then, the activity of *S. serrata* crabs is rather difficult to observe during the day because these crabs are nocturnal (Febriyani 2018) and always hide in their hiding holes.

Unique morphology of crabs as supporting ecotourism attractions

Austruca annulipes. Morphologically, according to Rahayu et al. (2018) the crab *A. annulipes* has a body size of 25-60 mm, has a trapezoidal carapace shape with white spots that cross close to the anterior and is black, orbits are not visible, cerpus, merus, and manus are red, smooth dactyl and pollex are white. The carapace has 1 or 2 dark bands on the back. Pollex's large claws have a tubercle along the underside. The upper side of the dactyl is completely convex, especially the mid-flat. Gonopod with less torque. The posterior flange is longer and wider than the anterior. In males, this crab has a characteristic claw that is larger than other claws. The paws are red-orange or yellow and the carapace is black with blue spots. Based on their small size, a pair of claws that are very different in size and attractive colors make these crabs very attractive to tourists.

Coenobita perlatus. The *C. perlatus* is a species of land hermit crab. According to Pavia (2006), this crab is known as the strawberry hermit crab because of its reddish-orange color in the body. In addition, the entire body of this type of hermit crab is also filled with white granules (pores) which is the reason why it is also called "strawberry". The adults can grow to a typical length of 80 mm (3.1 in) and weigh 80 g. Eye color is generally clear brown, but sometimes found black, moss green, or gray eyes. The abdomen of this hermit crab is always pure white and the carapace on the back tends to widen. The *C. perlatus* utilize empty shells of Mollusca to protect its abdomen (Jeremy and Patria 2020). The third left leg, which is usually called the shield leg is useful for closing the shell with the slightly fat left pincer, while the left pin is round and flat. Because *C. perlatus* which has a reddish-orange color also filled with white granules (pores) in the body like a strawberry and has a house/shell of a Mollusca that is attractively colored and has a unique shape so that it can be an attraction for tourists to see.

Ocypode kuhlii. According to Sakai and Türkay (2013) and Amin et al. (2021), this crab is small in stature and the carapace is 33×43 mm. Carapace is wider than long; convex in the direction of its length; fine nodules. This crab has a square eye shape with a pair of eyes that rise upwards. The first limb is calf-shaped, which is unequal in size between the right and left; the surface texture is speckled. The head of the calf (palm) with a rounded top side and rough nodules; inner side with middle (8-10) nodules lined crosswise, bidirectional, stiff scraper to produce a whooshing sound. The morphology of this crab is small, has fine nodules, not large claws and unique eyes make this crab very adorable for tourists to see.

Perisesarma guttatum. This crab has a body shape (carapace) that is almost square. Carapace is about 3 cm in length. This crab has a pair of claws that are reddish in color with bright orange internal palms. The body surface also has protrusions like that of *P. darwinensis*, but does not have a striped pattern on the legs (Fauzan et al. 2020). In the present study, different types of pectinated crests (on the dorsal face of chelar palm) were recognized among the selected species of the family Sesarmidae. Males of this species have two rows of transverse crests with elevated teeth, each row (crest) being framed by a high and large tubercle on the inner side (Shahdadi and Schubart 2017). The morphological characteristics of the carapace shape and the color of the claws of this crab make this crab attractive for tourists to see.

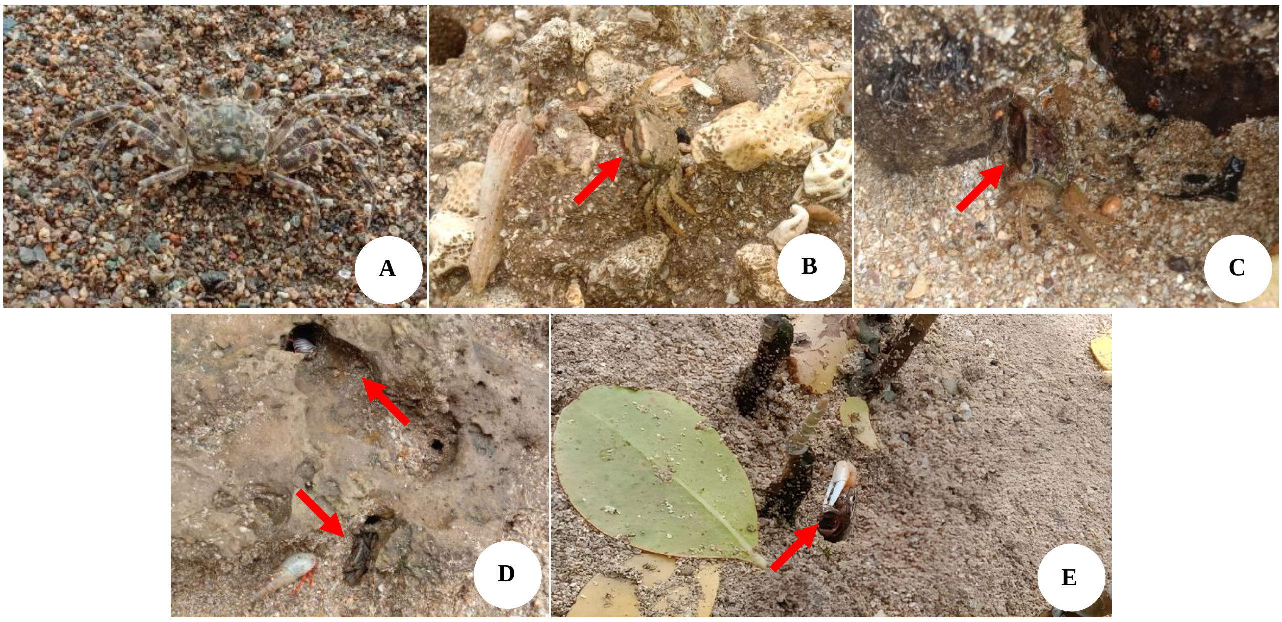

Figure 4. Some crabs activity in three location studies (Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia): A. *Ocypode kuhlii* walking on sand; B and C. *Perisarma guttatum* walking on the rocks; D. *Coenobita perlatus* and *Perisesarma guttatum* walking towards hiding in a rock crevice; E. *Austruca annulipes* to a hiding hole in the sand

***Scylla serrata*.** According to Febriyani (2018), the characteristics of *S. serrata* crabs are that they have a slightly greenish, olive-green to almost black carapace, while the outer side of the claws is green, often with a spotted pattern or spots. On the frontal side, there are 4 sharp spines, the outer palm (claws) is green with a round pattern, has three pairs of walking legs and one swimmer's leg which is located at the end of the abdomen with the ends equipped with a rower. The last pair of legs (swimming legs) have spots, both in males and females. These crabs are large to very large, the maximum carapace width is between 25-28 cm and the weight reaches 2-3 kg. Compared to other crabs found in this study, this crab has a large body size, carapace and claws that make this crab have special characteristics that attract tourists to see it.

Number of individuals and distribution of crabs in research study as supporting ecotourism attractions

Twenty-five plots spread over three research sites, found 5 species of crab with a total of 613 individuals (Table 4). From the number of individuals, it is evidence that the three locations are suitable habitats for several species of crabs. Crabs are one of the Crustacea that live in coastal/mangrove ecosystems and are one of the key species that have a very important role in maintaining the balance of the ecosystem. Therefore, the presence of crabs in the mangrove ecosystem can be used to indicate whether the mangrove ecosystem is still functioning properly or not. According to Kristensen et al. (2012), Saher and Qureshi (2014), and Kalor et al. (2018) crab is a key species in mangrove forests that functions to convert nutrients and enhance mineralization, increase oxygen distribution in the soil, assist in the carbon cycle, and provide natural food for various species of biota in the waters.

Table 4. Total individual crabs in Teleng Ria, Grindulu and Siwil Beach, Pacitan, East Java, Indonesia

Species	Location			Total individul spesies
	Teleng Ria	Grindulu	Siwil	
Austruca annulipes	9	0	189	198
Coenobita perlatus	18	0	33	51
Ocypode kuhlii	38	64	156	258
Perisesarma guttatum	17	3	85	105
Scylla serrata	0	0	1	1
				613

In this study, *O. kuhlii* were found in all study sites with the highest abundance (Table 2). According to Elfandi et al. (2018) *O. kuhlii* spread in many parts of Indonesia such as Sumatra, Java, Madura, Bali, Lombok, Flores, and Papua. The existence of this crab population is strongly influenced by the condition of the beach which is its habitat. Unspoiled beaches are usually found in an abundance of these crabs because the food chain process is still maintained. Polluted beaches will rarely be found *O. kuhlii* (Schlacher et al. 2011).

Besides *O. kuhlii*, *P. guttatum* can also be found in all research sites, this species likes muddy sand habitats in each research location, eating vascular plants including mangrove litter and young sprouts. These crabs can live on the surface of the mud, or mangrove trees can tolerate a wide range of salinity, which causes this crab to dominate in mangrove forests. This is also in accordance with the research conducted by Shih et al. (2016), Lapolo et al. (2018) and Rosenberg (2019) that crabs from the Ocypodidae (*O. kuhlii* and *A. annulipes)* and Sesarmidae

(*P. guttatum*) groups are commonly found in inhabiting shorelines worldwide across the tropics and well into the temperate zones mangrove forests in Indonesia. These three species are often found in vents with stable temperatures and can adapt to their surrounding environment even in damaged or extreme conditions.

Coenobita perlatus lives in a wide swathe of the Indo-Pacific, like Indonesia (Mckenzie 1999). From the research conducted, it was found that most *C. perlatus* individuals were found in Siwil Beach. *Ceonobita perlatus* likes substrate conditions that are dominated by sandy and rocky substrates (Ingle 1993). Hermit crab can be used as an environmental bioindicator. If there are hermit crabs, the environment is still good and far from environmental pollution (McKenzie 1999). In addition, *C. perlatus* can be eaten by people, however, they are more usually found as home pets. Because they are scavengers, they also play an important part in beach cleanup. Hermit crabs are important in keeping the beach clean and creating a healthy environment for humans and other aquatic and coastal species by removing dead sea matter and other detritus that collects on the shore (McKenzie 1999).

In this study, *S. serrata* is a species that has few individuals and is only found on Siwil Beach. According to Ginanthra et al. (2021) several factors that can cause the low population of this crab include substrate, mangrove plants, seagrass, and human disturbance. In addition, according to Febriyani (2018), the *S. serrata* crab is a typical species in the mangrove area. These crabs only come out of hiding some time after sunset and move throughout the night mainly in search of food. When the sun is about to rise, these crabs immerse themselves again, so these crabs are classified as nocturnal animals. This species is edible and susceptible to hunting by humans. Crabs have a relatively stable habitat. Li et al. (2015) showed that the distribution of crabs has a significant correlation with energy flow and species because each crab responds to feed on different mangrove vegetation. This species was found in the white sand substrate with *R. stylosa* and *S. alba* vegetation. Mangrove vegetation that grows will provide nutrition and food for crabs. Kamaruddin et al. (2019) also found that the crab *S. serrata* is found on the sandy substrate in mangrove habitat in Sungai Pinang Village, Lingga and this species also were found in muddy sediments, Cibako mangrove forest, Garut, West Java by Avianto et al. (2013) and in the mangrove forests of Alas Purwo National Park, East Java by Gita et al. (2015).

The conclusion of this study was found 5 species of crabs, namely *A. annulipes*, *C. perlatus*, *O. kuhlii*, *P. guttatum*, and *S. serrata*. The crab diversity index was obtained for a total of three locations including the medium category with an index of 1.25 (medium). Morphology, activity, number of individuals, and distribution of each crabs species in an ecotourism area will increase the attractiveness of tourists to visit. It is hoped that this data can be a reference for managers of mangrove areas in developing ecotourism and efforts to conserve mangrove forests.

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Review:
Biogeochemical process in mangrove ecosystem

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Abstract. *Aprilia DA, Dianti, Arifiani KN, Cahyaningsih AP, Kusumaningrum L, Sarno, Rahim KAA, Setyawan AD. 2020. Review: Biogeochemical process in mangrove ecosystem. Intl J Bonorowo Wetlands 10: 126-141.* The mangrove ecosystem, one of the unique and distinctive aquatic ecosystems, is located in the tidal areas of the coast coastal areas in the tropics and subtropics. Mangrove ecosystems have many ecological, environmental, and social benefits. Mangrove forests have the potential to become a potential resource. This review aims to determine the process and function of the biogeochemical cycle in the mangrove ecosystem. The research method used in this research is descriptive qualitative research methods and tends to use inductive analysis. The biogeochemical cycle acts as a cycle that cannot be separated from the mangrove ecosystem. Biogeochemistry is the process of circulating chemical elements or compounds that occur repeatedly and continuously. Biogeochemistry plays a role in maintaining environmental stability and maintaining life on earth. The biogeochemical cycle consists of energy flow and nutrient cycling. Energy flows consist of food chains and food webs. The nutrient cycles include water, carbon, nitrogen, phosphorus, and sulfur. Various chemical elements resulting from the cycle process are needed to survive living things in the mangrove ecosystem.

Keywords: Biogeochemistry, energy flow, mangrove ecosystems, nutrient cycling

INTRODUCTION

The mangrove ecosystem is also one of the wetland ecosystems (Moudingo et al. 2020). Based on ecological parameters, namely mangrove density mangrove type, it can determine whether an area is suitable or not suitable for ecotourism (Malik et al. 2019 et). Nugroho et al. (2013) stated that mangrove forests are a nutrient contributor to organisms living in and around them. Mangrove species must be able to adapt to salinity conditions (Liang et al. 2008) and also drought during periods of receding seawater. The food chain plays a role in the formation of ecosystem biomass; the food chain explains the relationships within the ecosystem (Yonvitner et al., 2019). With all their potential, mangrove forests are very vulnerable to damage (Takarendehang et al., 2018). Good knowledge and skills will significantly assist in optimizing mangrove ecosystems by maintaining and preserving mangrove forests to benefit the community (Alongi 2002) greatly. The carbon cycle is one of the biogeochemical cycles (Alongi 2020). The characteristics of mangrove habitat factors are different for each region (Poedjirahajoe et al., 2017). Mangrove forest is the richest forest in carbon with a high organic matter content (Donato et al., 2012). The low diversity and vegetation of mangroves can be caused by artificial or unnatural ecosystems (Rudianto et al. 2020). The life cycle of mangroves is determined by water flow, sprouts, depth, and bottom substrate (Saru 2019). Biogeochemistry affects the substrate of mangrove land, which characterizes mangrove habitats (Djamaluddin 2018).

The carbon content in mangrove ecosystems is related to the biogeochemical cycle, namely the carbon cycle (Husalin et al. 2020). Organic matter plays a major role in the biogeochemical cycle (Dittmar et al. 2006). The biogeochemical processes on earth have been developing for three billion years (Hulth et al., 2010). Mangrove forest vegetation has the potential to absorb carbon which is quite large and better than other tropical forest types (Donato et al. 2011). Mangroves have the ability to absorb most of the carbon from the atmosphere stored in stems, leaves, roots, soil which is called carbon stock or carbon sequestration (Abino et al. 2014). Mangrove species density and tree circumference affect the biomass value (Njana et al. 2016). The addition of biomass content affects the addition of carbon content (Chanan 2012). Coastal ecosystems have the potential for carbon absorption; one of the coastal ecosystems is the mangrove (Stringer et al., 2015). With the presence of mangrove ecosystems in Indonesia, Indonesia has great potential for carbon sequestration and storage (Adame et al., 2013). CO_2 reduction and management of carbon sequestration ecosystems can significantly impact global climate change and be used as practical mitigation efforts (Martuti et al., 2018). The nitrogen cycle in the balance in the oceans includes the biogeochemical cycle (Meirinawati 2017). The biogeochemical process of mangroves causes metal and sediment bonds, thereby reducing the transfer of metals to the water (Machado et al., 2002). In these areas, high organic matter content is much more abundant (Setiawan 2013). To determine the stored carbon content, the total tree biomass is calculated by considering the value of the wood density factor, carbon fraction, and biomass expansion (Senoaji and Hidayat 2016). The mangrove ecosystem has service providers (utilization of wood, crabs, and fish), regulatory services (breakwater and prevention of seawater intrusion, cultural services (mangrove ecotourism) with a very high total economic value (Idrus 2017).

The energy flow in mangrove ecosystems includes food chains and food webs involving organic matter (Karimah 2017). Manengki (2010) states that the content of organic matter in sediments in areas with river estuaries tends to be higher due to input from upstream (upstream) land (Sari et al. 2014). Various series of ecological researches on mangrove forests are needed to ensure the ecological function and sustainability of mangrove ecosystem production, ecological data as basic data for mangrove resource management (Julaikha and Sumiyati 2017). In some mangrove ecosystems, there are still those containing heavy metals Cu and Hg that exceed the threshold value (Ernawati et al., 2018). According to the mangrove tourism index, biophysical mangrove ecosystems can be managed (Prihadi et al., 2018). The conversion of mangrove land to other lands, such as agriculture, can damage the mangrove land; mangrove land improvement requires a long time, and costs are high (Putra 2014). Anthropogenic activities that cause mangrove forest degradation are agriculture, plantation, fishery, industry, logging, mining, settlements, and salt ponds (Eddy et al., 2015). The location of mangroves affects the types of mangroves that grow, for example, namely; *Avicennia,* which usually grows in mangrove areas directly facing the open sea; the substrate that is getting muddy and thicker usually has a high genus frequency value (Sunarni et al. 2019). Mangrove fruit is currently increasing food security (Pardede 2013). Several environmental parameters can determine the growth and viability of mangroves; these parameters include freshwater supply and salinity (Sunarto 2008). The carbon cycle is related to carbon sequestration in organic matter (vegetation) and carbon storage (carbon burial) in sediments and soil (Wen Qiu et al., 2011). In the carbon cycle or mangrove biogeochemistry, carbon absorption occurs by the mangrove ecosystem and is stored in the soil (Wang et al. 2013). The biosphere's living and non-living components are related to the biogeochemical cycle (Nasprianto et al., 2016). The biogeochemical cycle can also be associated with the cycles of mercury and other materials in the sea; this cycle affects the resistance of organisms (Budiyanto 2012). The aim of this review was to determine the process and function of the biogeochemical cycle in the mangrove ecosystem.

ENERGY FLOW IN MANGROVE ECOSYSTEM

Energy flow occurs due to interactions in the ecosystem that cause energy transfer between organisms. The flow of energy in the mangrove ecosystem starts from sunlight energy and other organic materials such as phosphate, nitrogen, and organic carbon that enter the mangrove forest environment. Mangrove trees in the photosynthesis process use the energy of sunlight. After solar energy is used for photosynthesis, mangrove trees produce chemical energy obtained from changing light energy. Chemical energy is stored in mangrove trees, so mangrove trees can be called producers. Furthermore, mangrove tree litter such as twigs, flowers, and mangroves fall into the water. Small particles of litter are eaten by surrounding organisms such as shrimp and other herbivores. There is a transfer of energy from producers to consumers I (primary consumers) in this process. The energy stored by level I consumers is about 10 percent of the producers' energy. The next energy transfer occurs when fish or other carnivorous organisms eat the shrimp. The energy of consumer I move to consumer II, with the amount of energy 10 percent of the energy of level I consumers. If mangrove trees are not eaten by level I consumers, the energy is passed on to detrivores or released from the mangrove ecosystem to other ecosystems such as seawater ecosystems as organic matter. Energy can go out because the ecosystem is open.

There are various kinds of energy flows; examples of energy flow in mangrove ecosystems include food chains and food webs. The energy flow runs due to the interaction between components in the mangrove ecosystem. Plant Mangroves that can exercise control over energy flow are called dominant ecological types, such as *Rhizophora apiculata* (Randongkir et al. 2019). Mangrove trees require the breakdown of energy into nutrients. Litter is influenced by altitude, fertility, climate, density, soil moisture, season, plant base area, plant age, and annual variation. The rate of decomposition in mangroves is influenced by forest type, abundance and herbivorous fauna, temperature microbial activity (Friesen et al. 2018), and weather conditions (Loría-Naranjo et al. 2018). Macrobenthos in the structure of energy flows has an important role due to acting as primary and secondary consumers (Achsan 2019).

The food chain is the transfer of energy that occurs from one organism to another due to the process of eating and being eaten in one direction, which forms a food chain. The number of organisms or populations influences the balance of the food populations in an ecosystem. The reduction of one population will affect the population of other organisms. For example, if the shrimp population decreases, it will reduce the shrimp-eating fish population in the mangrove ecosystem. It will also affect the reduction in the fish-eating bird population. Threatening one organism can cause other organisms to be endangered. The food chain in the mangrove ecosystem is divided into 2 types, namely the direct food chain and the detritus food chain. The direct food chain cycle includes mangrove tree litter in the form of flowers, leaves, or twigs falling into the water. Then the litter falls into the water, is carried by the water currents, and is eaten by level I consumers, shrimp, and small fish in coral reefs. Consumer I is preyed on by level II consumers such as fish-eating birds and big fish. When level II consumers die, the decomposer breaks them down into organic compounds, which mangrove trees or plants reuse. The detritus chain is an indirect food chain. One difference from the direct food chain is that in the number of organisms involved, there are more organisms involved in the indirect food chain than in the direct food chain. The detritus food chain cycle begins with mangrove litter falling into the water being broken down by the detritivore. The detritivores are eaten by aquatic organisms such as mollusks, algae, and crabs (crustaceans). Level I consumers are then eaten by level II consumers, namely protozoa. Level II consumers are eaten by level III consumers, amphipods. Then these organisms, such as amphipods, are eaten by small fish, which act as consumers IV. Consumer IV is preyed on by large fish and seabirds belonging to consumer V. Consumer V, or the detritivore will break down the last consumer to die again to produce organic compounds that mangroves can reuse.

Various complex food chains form food webs. In the food web, prey and prey interactions occur, which involve two organisms and multiple types of organisms that eat and eat each other. The food web cycle includes producers eaten by different consumers I. Each consumer I is eaten by a different consumer II. This can give rise to many food chains that interact with each other to form food webs. For example, shrimp and small fish eat litter from mangrove trees. Shrimp are then eaten by other fish, while seabirds eat small fish. According to Kamaruddin (2015), most of the litter or organic material is not directly used by mangrove organisms; litter or organic material will enter the food web in the form of dissolved organic material.

The energy flow process must continue to run to create a balance in the mangrove ecosystem. Energy imbalance can trigger various dangerous things, one of which is global climate change. Mangrove forests that carry out photosynthesis and respiration are very beneficial for humans and the environment as a sink for excess carbon in the atmosphere (Purnobasuki 2012). According to (Hazmi 2017), the average yield of organic carbon in leaf litter, leaf, and sediment can be different; the amount of organic carbon in biomass affects the absorption of CO^2 in leaf litter, leaves, and mangrove sediments. The flow of biomass productivity is calculated starting from the biomass detritus that is available every month (Noer 2009). Methane gas in mangrove ecosystems is related to mangrove biogeochemistry; disturbed mangrove ecosystems have the potential to have high methane gas fluxes (Ulumuddin 2019). According to (Hanifah 2019), one of the mangrove forest organisms important in controlling energy flow is decapods. These animals are influenced by the content of organic matter, pH, salinity, and water temperature. The biogeochemical process makes mangrove ecosystems have bonds between metals and sediments to maintain metal movement (Martuti et al., 2019).

NUTRIENT CYCLE

Living and non-living organisms are composed of several materials that originated within the earth. This material forms the basis for inanimate and living organisms, which are elements consisting of chemical compounds. All living things on earth require matter in both organic and inorganic forms. The material will undergo a recycling cycle through water, soil, and air in an ecosystem. This recycling of material is called the biogeochemical cycle, which involves living things and rocks to maintain and stabilize their survival. A cycle is a series of events repeatedly within a certain period. There will be a cycle of substances or materials with similar events or circumstances in the cycle. Cycles can occur over a long or short period. Cycles are formed in both abiotic and biotic environments. At the same time, a nutrient is a substance needed by organisms to grow, develop and live. The nutrient is a substance that plays an important role for organisms because plants use it to support primary productivity (Alongi 2018). Nutrients are needed and essential for an organism. Nutrients participate in forming the body of an organism in a certain ecosystem. Living things require a minimum of 30 to 40 chemical elements from about 92 known elements in order to live and develop. According to Parsons et al. (1984), nutrients are grouped into two, namely macro and micronutrients, macronutrients are needed in large quantities such as C, H, N, P, Mg, and Ca, while micronutrients required in small amounts include Fe, Mn, Cu, Si, Zn, Na, Mo, Cl, V, and Co. Therefore, nutrients are the essential elements for organisms to meet their needs.

The nutrient cycle is a series of circulating substances needed by organisms in an ecosystem repeatedly. The nutrient cycle runs consistently at all times so that the sustainability of an ecosystem can run well. All organisms need both organic and inorganic material to live. Phosphorus is an essential element in the formation of ATP and nucleotides. Nitrogen is a crucial component in the body, making up proteins and nucleic acids. Meanwhile, according to (Karil et al. 2015), the source of nutrients (phosphate) in the waters in the cycle places sediment as one of the sources. The sediment around the mangrove is mixed with the fallen litter and deposited in the sediment. This condition makes the mangrove forest a nutrient contributor to other ecosystems around it (Indrawati et al., 2013). Nitrogen, phosphorus, and silica are nutrients that have an essential role in the growth and development of organisms (Patriquin 1972; Dennison 1987 in Muchtar 2012). The existence of living things in this world depends on the flow of energy and the cycle of matter in the ecosystem. The nutrient cycle is an example of environmental ecosystem services that provide welfare for living things. In the process of the nutrient cycle, organic and inorganic components are mutually related and influence one another. The existence of living things in this world depends on the flow of energy and the cycle of matter in the ecosystem. The nutrient cycle is an example of environmental ecosystem services that provide welfare for living things. In the process of the nutrient cycle, organic and inorganic components are mutually related and influence one another.

Mangroves derive nutrients from inorganic mineral ions and organic matter and nutrient recycling internally through the detrital-based food web (Strauch et al., 2012). Reef et al. (2010) revealed that it is possible for nutrients in coastal waters to come from the land. Macronutrients can be produced from chemical processes that occur in plants. Observation of the content of limiting nutrients can help identify the relationship between nutrient availability and plant growth (Caubey et al., 2007). According to (Syah et al. 2018), mangrove ecosystems have an important role in ecological and economic cycles because they consist of elements such as the accumulation of dissolved phosphorus, nitrogen, primary and secondary production. Mangroves produce nutrients that can nourish marine waters, mangroves help in the rotation of carbon, nitrogen, and sulfur, and mangrove waters are rich in nutrients, both organic and inorganic nutrients. (Ramdani 2015) also suggests the function of mangroves, namely as a source of nutrient production that is useful for fertilizing marine waters. In contrast, there are nutrients such as phosphorus, carbon, nitrogen, potassium, calcium, and magnesium in mangrove leaves. With a high average primary production, mangroves can maintain the sustainability of fish, shellfish, and other populations (Siegers 2015).

Essential nutrient elements are essential and needed by an organism, namely nitrate and phosphate because other elements cannot replace these two elements. Nitrate (NO3) and phosphate (PO4) are nutrients that determine the stability of vegetation growth (Hartoko 2013). Nitrate is a form of the central nitrogen that is in natural waters which comes from ammonium (Mustofa 2015). Phosphate is an essential element second only to nitrogen which can play a critical role in the development and photosynthesis of roots (Supriharyono 2015). The high nutrient content caused by the continuous decay will result in the waters experiencing a too fertile state or often referred to as eutrophication (Rahajeng 2018). Several nutrient cycles occur on earth, including the water cycle, the carbon cycle, the nitrogen cycle, the sulfur cycle, and the phosphorus cycle.

Water cycle

Water is a compound that is very important and necessary for life. Every individual definitely needs water. With water, the circulation process in the body becomes smooth. Water on earth always experiences movement and rotation continuously. According to (Soewarno 2000 in Sallata 2015), water is a natural resource found above and below the earth's surface and as a non-living natural resource. Water above the earth's surface, such as rivers, lakes, oceans, and so on. Meanwhile, water on the surface of the ground is usually called groundwater. Water is needed for the livelihood of many people, even by all living things (Widiyanto et al., 2015). Water is one of the natural resources that can be renewed and has regenerative power, which is always in circulation called the water cycle/hydrological cycle (Sallata 2015).

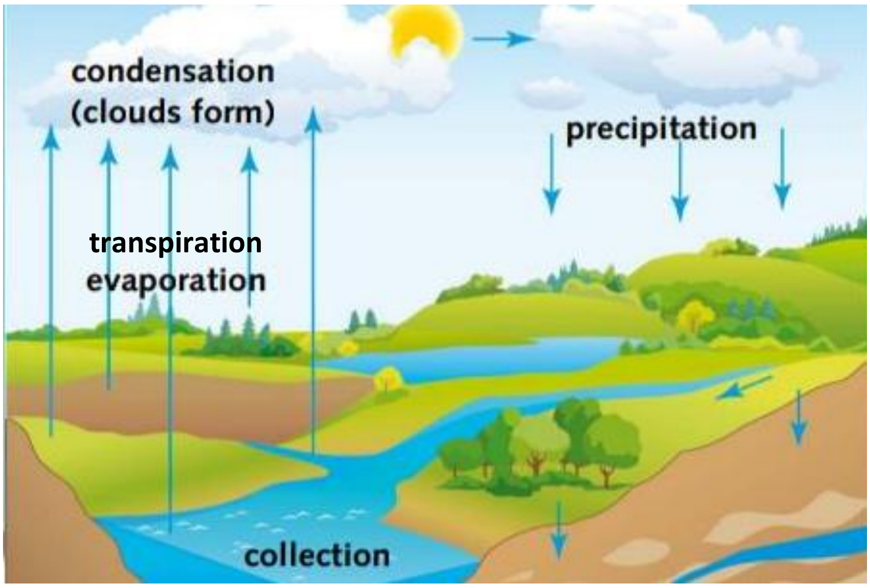

Figure 1. Water cycle (Source: Hutmacher 2013)

The hydrological cycle is water circulation from the atmosphere to the earth then back to the atmosphere and never stops. Water in nature is not static but constantly rotates and moves so that the water available in nature always experiences long-term displacement (Lisnawati 2012). According to (Pynkyawati and Wahadamaputera 2015), the hydrological cycle starts from the evaporation of sea and land water to the air. The hydrological cycle is the movement of seawater into the air, which then falls to the ground again as rain or some other form of precipitation, and finally flows into the sea again. Arrangement cyclically, the event is not simple. First, the cycle can be a short cycle: namely rain that falls on the sea, lake, or river that can immediately flow back to the sea. Second, there is no uniformity of time required by a cycle. It seems the cycle stops in-season dry while the monsoons cycle is running again. Third, the intensity and frequency of the cycle depend on geographical and climatic conditions, which is the result the sun changes its location towards the earth's meridian throughout the year. Fourth, various parts of the cycle can become a complex river, so we can only observe the final part of rain falling above the ground and then find its way back to the sea (Talumepa et al., 2017).

In fact, the availability of water sources in nature is relatively constant. The problem is the changing time of availability and quality because water actually only changes its shape and moves from one place to another. Therefore, it is known that the processes of precipitation (rain), evaporation, and transpiration are the main factors in the occurrence of the hydrological cycle. The heat source from the sun will make surface water mainly in the sea, and lakes/reservoirs will experience evaporation into clouds which by the wind clouds will be carried to the mainland. In their time, the accumulation of these clouds will experience condensation caused by physical processes and altitude to turn into rain. Furthermore, the rain will fall on the earth, which fills the system of lakes, rivers, groundwater, and in the end, it will return to the sea, and there will be a cycle process again (Adi 2018). The process of traveling water on land will form a watershed (DAS) system (Syarifudin 2017).

Mangrove ecosystems play an essential role in the water cycle or hydrological cycle. Mangrove ecosystems provide regulatory/regulatory services in the form of an ecosystem's ability to regulate climate, water and biochemical cycles, soil surface processes, and various biological processes (Dewha 2009 in Anggraini and Marfai 2017). Mangroves are ecosystems that have high productivity for other living things, including fish spawning, nutrient supply and regeneration, water cycles, and carbon storage (Rahmadi et al. 2020). The water cycle process occurs in several stages, including evaporation, transpiration, precipitation, and condensation. The water cycle will continue to move and rotate through the land, water, and air. In mangrove ecosystems, the water cycle begins with the process of transpiration and evaporation from the existing environment, namely the biotic and abiotic environment. Transpiration is a process of evaporation originating from plants (Suparmoko 1997). Meanwhile, evaporation is water from the sea surface that experiences evaporation (Lisnawati 2012). From the evaporation and transpiration process, water in the form of steam will move into the atmosphere and experience condensation in the clouds. The water collected in the clouds will then descend to earth through a process of precipitation to land or return to the sea. Water that falls on land will seep into the ground and flow out to sea. And the transpiration and evaporation process occurs again. This process will continue to repeat itself, forming a cycle. In the water cycle, gravity and sunlight will continuously influence water's movement on the earth's surface (Indriyanto 2006).

Mangroves usually live in muddy and watery places. Mangroves cannot live in dry or waterless ecosystems. (Watson 1928 in Saefurahman 2008) argues that mangrove vegetation cannot live well along with dry coastal areas and does not contain mud or sediment. From the research results in the Cangring Village area, Cantigi District, Indramayu Regency, the substrate types of mangrove sediments are the clay, clay sand, and dusty clay (Darmadi et al. 2012). Therefore, in the mangrove ecosystem, the water cycle can run well. The water cycle can move repeatedly and regularly. According to (Ruitenbeek 1994), mangrove ecosystems have environmental functions, including nutrient supply and regeneration, pollutant recycling, water cycling, and maintaining water quality around the ecosystem. With the water cycle, water availability on earth will not run out; there will only be partial displacement caused by human activity as the inability to maintain this cycle (Smith and Stopp 2004).

Carbon cycle

Carbon is a key element of life and is the fourth most abundant element in the universe after hydrogen (H), helium (He), and oxygen (O). The carbon cycle is the process of exchanging carbon elements between the biosphere, pedosphere, hydrosphere, and atmosphere. The carbon cycle, nitrogen cycle, and water cycle are formed from the sequence of processes that make the earth's key capable supports life - describes the movement of carbon in the biosphere where there are reused and recycled processes. Carbon is an essential element for life on earth as a major component of biological compounds or DNA and a major component of most minerals (Botkin and Keller 2011). This carbon exchange through four main carbon reservoirs: the atmosphere, terrestrial biosphere, oceans, and sediments. The carbon cycle is a biogeochemical cycle that includes chemical, physical, geological, and biological processes and reactions that make up the composition of the natural environment (including the biosphere, hydrosphere, pedosphere, atmosphere, and lithosphere), as well as the cycle of substances and energy that carry the chemical components of the earth in space and time.

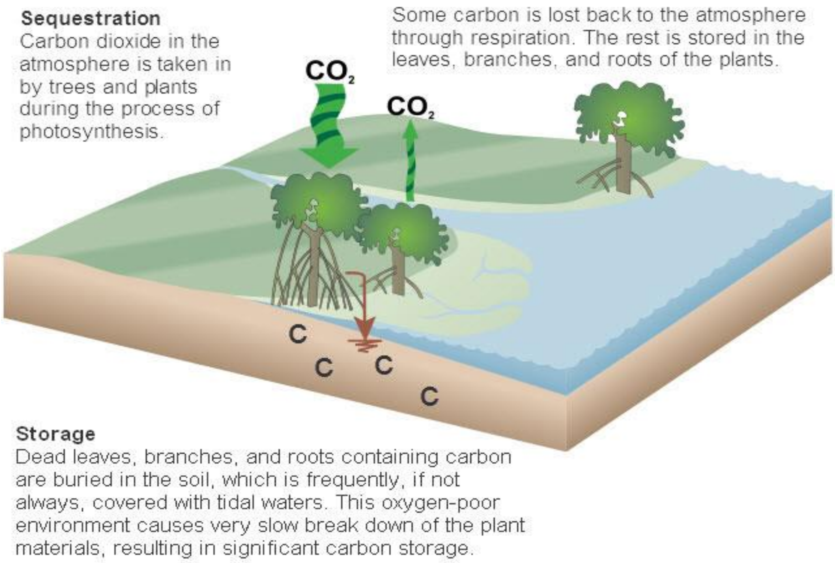

Figure 2. Carbon sequestration and storage in a mangrove wetland (Source: Sutton-Grier et al. 2014)

Forests and seas are natural places on earth that function to absorb CO_2 gas. Carbon dioxide gas is absorbed by growing plants and stored in their wooden stalks. In the oceans, carbon dioxide gas, which is used by phytoplankton for photosynthesis, sinks to the ocean floor along with the feces of living things that eat phytoplankton and other high-level predators. (Daniel and Edward 2011) stated that the ecosystem with the highest carbon absorption capacity is the mangrove ecosystem because it has a high-density value. (Murdiyarso et al. 2015) stated that the ability of mangroves to store carbon stocks makes them an important ecosystem in climate change mitigation efforts. Forest vegetation biomass can be stored above or below the soil surface (Kotowska 2015).

The global carbon cycle can be explained based on the process of displacing and storing carbon in main components. Following are the main components of the carbon cycle according to (Kurniawan 2013): 1) Atmosphere carbon in the Earth's atmosphere can be found in the form of carbon dioxide (CO_2) and methane (CH), both of which are greenhouse gases. Although methane gas has a larger than greenhouse gas effect carbon dioxide, it is in the atmosphere in concentration and a smaller timeframe than carbon dioxide - making carbon dioxide is the leading cause of the greenhouse effect or global warming—the terrestrial biosphere. Carbon in the terrestrial biosphere is found and stored in the form of organic carbon in the form of living and dead living things and stored in the soil in the form of carbon soil. Carbon cycle on the land biosphere, starting from the photosynthesis process in green plants and the process of displacement or transfer through the food chain cycle ends in the decomposition or decomposition of living things; 2) Ocean, the ocean has the largest content of activated carbon in nature, where its storage capacity is second only to the lithosphere. The sea surface stores large amounts of organic carbon, subject to a rapid and direct exchange process with the atmosphere.

Naturally, the release of forest carbon into the atmosphere, or emissions, occurs through various mechanisms such as respiration of living things, decomposition of organic matter, and biomass burning. In addition to the photosynthesis process to convert carbon dioxide (CO_2) into oxygen (O_2), plants also carry out the process of respiration, which releases CO_2. However, this process tends to be insignificant because the CO_2 released can still be reabsorbed during the photosynthesis process. When a forest plant or animal dies, a decomposition process will occur by bacteria and microbes that release CO_2 into the atmosphere. The carbon element is essential in human life, in everyday life, every time the breathing process, humans contribute to the release of carbon in nature in the form of carbon dioxide (CO_2), tree cutting, burning, industrial activities, and motorized vehicles also contribute to the release of carbon in nature (Purnobasuki 2012). The amount of carbon stored for each land varies, depending on the diversity and density of existing plants, soil types, and management methods (Gurung et al., 2015).

The area of mangrove forests in the world is only 0.4% of the world's forest area. However, mangrove forests have a major role as a carbon sink and storage, from more than 4 gigatonnes C/year to 112 gigatonnes C/year. Mangrove forests are forests with the densest carbon content in the tropics. This land stores more than three times the average carbon per hectare of mainland tropical forest (Donato et al., 2011). Indonesia's mangrove forests store five times more carbon per hectare than upland tropical forests (Murdiyarso et al., 2015). Mangroves contribute 10-15% of coastal sediment carbon storage, while global coastal areas only contribute 0.5% (Alongi 2014). Indonesia's mangroves store 3.14 billion metric tons of carbon (PgC) (Murdiyarso et al., 2015). This amount includes one-third of global coastal carbon stocks (Pendleton et al., 2012). The lower surface of Indonesia's mangrove ecosystems stores a large amount of carbon: 78% carbon is stored in the soil, 20% is stored in living trees, roots, or biomass, and 2% is stored in dead or fallen trees (Murdiyarso et al. 2015). Carbon storage in natural forest, swamp forest, and agroforestry, namely 37.2846 tonnes/ha respectively; 39.2875 tonnes/ha; and 36.8416 tonnes/ha. Deposits from these three forests are not much different, while mangrove forests have the largest carbon storage, which is 51.5031 tonnes/ha (Sugirahayu and Rusdiana 2011).

The dynamics of carbon in nature can be explained simply by the carbon cycle. The carbon cycle is a biogeochemical cycle that includes the exchange or transfer of carbon in the biosphere, pedosphere, geosphere, hydrosphere, and Earth's atmosphere. The carbon cycle is actually a complex process, and each process influences one another. According to (Alongi 2012), the carbon cycle has 3 stages: absorption, storage, and expenditure. The absorption process is that mangroves absorb CO_2 in the air and form C6H12O6 (glucose) stored in roots, stems, leaves, flowers, fruit, and seeds. Most carbon storage in plants is found in stems. The process of removing carbon in mangrove plants is caused by several things such as cutting down trees, burning mangrove forests, clearing land, and decomposing dead plant parts by bacteria and fungi.

The process of accumulating carbon (C) in living plant bodies is called the sequestration process (C-sequestration) (Larasati 2012). Thus, measuring the amount of C stored in the living plant body (biomass) inland can describe CO_2 in the atmosphere that plants absorb. Meanwhile, the measurement of C, which is still stored in the dead plant part (necromass), indirectly describes the CO_2 that is not released into the air through combustion. Plants will reduce carbon in the atmosphere through photosynthesis and store it in plant tissues. Until such time as carbon is recycled back into the atmosphere, it occupies one of several carbon pools or pools. All vegetation components, including trees, shrubs, lianas, and epiphytes, are part of the aboveground biomass. Below the soil surface, plant roots also store carbon and the soil itself. On peat soils, the amount of carbon stored may be more significant than the carbon stored above the surface. Carbon storage is more excellent if good soil fertility conditions (Hairiah 2007). Carbon is also stored in debris and biomass-based products such as wood, both surface and stockpiles. Carbon can be stored in a carbon pocket or pool for an extended period or only briefly. The increase in the amount of carbon stored in this carbon pool represents the amount of carbon absorbed from the atmosphere (Sutaryo 2009).

Nitrogen cycle

The biogeochemical cycle describes the process of oxidation and reduction of one inorganic nitrogen compound to another inorganic nitrogen compound. The nitrogen cycle describes changes in the form of nitrogen ions and nitrogen compounds in nature (Reece et al., 2014). Plants use nitrogen to help the photosynthesis process, which is for survival and maintains the food chain in the ecosystem around these plants (Yulma et al. 2018). The primary nitrogen source for plants is free nitrogen gas from the air. Plants cannot utilize nitrogen in the form of elements; nitrogen will undergo several decomposition processes used by plants. Soil microorganisms such as *Rhizobium* will develop symbiosis with plants to help nitrogen availability. Nitrogen is a limiting factor that affects plant growth, including mangroves (Chrisyariati et al. 2014).

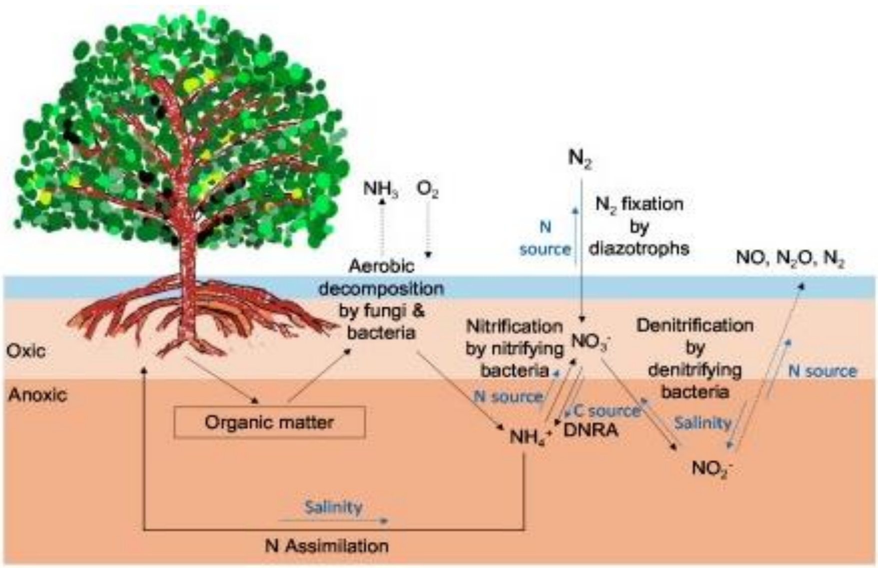

Figure 3. The nitrogen cycle in mangroves (Source: Shiau and Chiu 2020)

Nitrogen stored in soil or sediment is in the form of organic nitrogen (proteins, amino acids) and inorganic nitrogen. Nitrogen in the soil can be lost through volatilization (evaporation), denitrification, and absorption by plants (Oktavia 2006). Nainggolan et al. (2009) stated that nitrogen is an essential nutrient for plants, so there is a lack of nitrogen which causes the plant not to grow optimally. Suharno et al. (2007) stated that the presence of nitrogen is very important, especially about the formation of chlorophyll in plant leaves. The presence of nitrogen in the soil determines vegetation quality (Patti et al., 2013). Nitrogen is needed by plants in large quantities, absorbed by plants in the form of ammonium and nitrate. The nitrogen source is not obtained from aid and minerals. Still, it comes from the weathering of organic matter from the air through nitrogen fixation by microorganisms in symbiosis with plant roots. Another source of nitrogen in the soil is through rainwater and through the addition of artificial fertilizers (Fauzi 2008). The presence of nitrogen in the plant structure is influenced by several factors, especially water availability, nutrients in the soil, especially nitrogen. Three things cause nitrogen loss from the soil: washed with drainage water, evaporation, and plants' absorption.

In the atmosphere, there is ±80% nitrogen in the form of free nitrogen (N2). Some bacteria can absorb nitrogen in the form of N2. The nitrogen bound by the bacteria is converted into ammonia (NH3). This process of forming ammonia is called ammonification. Nitrite bacteria then break down ammonia into nitrite ions (NO_{2-}). Then the nitrite ion is broken down into nitrate ions (NO_{3-}). The process of preparing nitrate compounds from ammonia is called nitrification. New plants can absorb nitrogen in the form of nitrate ions. Nitrate is one of the essential elements that make up protein, nucleic acid, and chlorophyll needed for plant growth. Apart from plants, soil bacteria also utilize nitrate ions to obtain oxygen in the denitrification process (the process of reducing nitrate to nitrogen gas). The nitrification and denitrification processes influence the concentration of ammonium and nitrate compounds in sediments and waters. Nitrogen produced from the denitrification process right is returned to the atmosphere.

A nitrogen cycle process is quite dynamic in the mangrove ecosystem. Nitrogen concentrations in mangrove forest waters are more influenced by mangrove litter decomposition, transfer of nutrients from land, and sediment types (Ramdani et al., 2015). Litter production is an integral part of transferring organic matter from vegetation to the soil (Wahyuni et al., 2016). Analysis of nutrient composition in litter production shows limiting nutrients, and the efficiency of the nutrients used to maintain the nutrient cycle in the mangrove forest ecosystem (Vitousek 1982; Rahajoe et al. 2004). The nitrogen source in the waters comes from the decomposition of dead living things. This is because protein is found in all living things. At the same time, sources caused by human activities are industrial waste and runoff from agricultural areas, fishery activities, and domestic waste (Effendi 2003). Ecological conditions indirectly affect nitrogen content in mangrove ecosystems (Kaseng 2018).

Plants use nitrogen to help the photosynthesis process, which is for survival and maintains the food chain in the ecosystem around these plants (Yulma et al. 2018). The nitrate content in coastal waters is used to measure water fertility because the more optimal the nitrate content of water is, the more abundant marine phytoplankton will be (Wisha et al., 2018). The nitrogen stock in natural mangrove forest sediments is, on average higher than in artificial mangrove forests (Fikri 2017). Natural mangrove forests have denser and older trees and are exposed to tides in the pond area. Dense mangrove forests will result in many tree litter or branches breaking down into sediment. The denser the roots are factors that influence nitrogen storage in sediments. According to Chrisyariati et al. (2014), the older the mangroves, the more nitrogen content will be. Based on the research of Alongi (2011), an increase in N content also occurs along with the increase in tree height and diameter in the mangrove species *Rhizophora* sp. The increase in nitrogen also impacts the development of stem diameter, height, and the number of stands which is better for mangroves (Hermiyanti et al. 2014). The high ammonia content can be caused by the density of the mangrove ecosystem and the influence of agricultural and aquaculture activities resulting from fish feed, which contains a lot of protein from feed residue, fertilization, and metabolic activity of aquatic organisms (Ridwan et al. 2018).

On average, the decomposition process on the mangrove sediment surface is more effective than in the sediment. Surface sediment is an area that is very effective at donating nutrients. Sediment characteristics in mangrove forests can also affect nitrogen stores. The completely decomposed litter can cause an increase in nitrogen stock at depth, but it can also be influenced by the release of organic compounds from the roots. Critical processes in the nitrogen cycle are: but they can also be affected by the release of organic compounds from the roots (Fatih 2008). Fundamental processes of the nitrogen cycle are nitrogen fixation, ammonification, nitrification, assimilation, and denitrification (the process of releasing nitrogen back into the air) (Darjamuni 2003). The nitrogen cycle can be illustrated in Figure 3.

Sulfur cycle

The sulfur cycle occurs among the various biogeochemical cycles in coastal sediments, such as mangrove sediments rich in detritus. From an ecological point of view, mangrove forests can stabilize coastal areas, develop and improve the condition of delta areas, protect coastal areas from waves and storms, protect beaches and rivers as essential sources of the sulfur cycle (Amal et al. 2020). The sulfur cycle is used as a structural and functional role in the amino acid cysteine and methionine and vitamins such as biotin, thiamine, lipoic acid, and coenzyme A (Behera et al. 2014). The existence of sulfur is essential for living things on earth, both plants and animals. Lack of elemental S can cause chlorosis in various plant organs, especially leaves (Yudana 2008). Sulfur is also part of the amino acid Methionine; it is absolutely necessary. The amino acid cysteine also contains sulfur (Siregar et al., 2018). In mangrove ecosystems, sulfur is a factor that affects the percentage of life propagules in mangrove species (Wu et al., 2015). Other functions of the sulfur cycle are to make plant leaves greener, increase the protein and vitamin content in plants, play an essential role in the sugar-turning process.

Sulfurized is the change of sulfur from hydrogen sulfide to sulfur dioxides and then into sulfates and back into hydrogen sulfide again. On earth, sulfur is present in the form of inorganic sulfate. Sulfur in nature is found in various forms. In the soil, sulfur is found in the form of minerals, in the air in the form of sulfur dioxide gas, and in the body of organisms as a building block of protein. Sulfur is reduced by bacteria to sulfides and is sometimes present in the form of sulfur dioxide or hydrogen sulfide (H_2S). Hydrogen sulfide is often deadly to aquatic life and is generally produced from the decomposition dead organic matter. Partially decomposed hydrogen sulfide remains in the soil and is partially released as hydrogen sulfide gas into the air. Hydrogen sulfide gas in the air then combines with oxygen to form sulfur dioxide. Meanwhile, hydrogen sulfide left in the soil with the help of bacteria will be converted into sulfate ions and sulfur oxide compounds. Plants absorb sulfur in the form of sulfate ions ($SO4^-$). The transfer of sulfate occurs through the process of the food chain. All living things die, and their organic components will be broken down by bacteria or decomposers, organisms that feed on dead organisms, and waste products from other organisms. In the sulfur cycle or sulfur cycle, at least two types of processes occur to convert sulfur into other sulfur compounds, namely, through the reaction between sulfur, oxygen, and water and by the microorganism activity of several microorganisms that play a role in the sulfur cycle, including *Desulfomaculum* bacteria and *Desulfibrio* bacteria which will reduce sulfate to sulfide in the form of hydrogen sulfide (H2S). Then H2S is used by anaerobic photoautotrophic bacteria (Chromatium) and releases sulfur and oxygen.

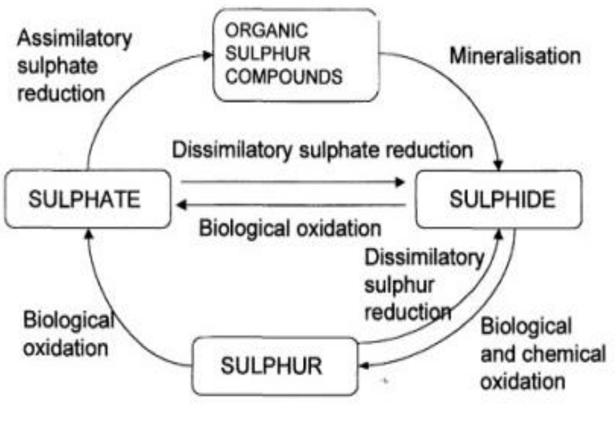

Figure 4. Sulfur cycle in mangroves (Source: Janssen et al. 1999)

Mangrove soils are generally neutral to slightly acidic due to the activity of sulfur-reducing bacteria and the presence of acidic clay sedimentation. The action of sulfur-reducing bacteria is shown by dark, acidic, and foul-smelling soil (Akhrianti et al., 2019). Mangrove sediments are anaerobic and have high levels of organic matter and salinity. Mangrove sediments also act as a source of sulfur (Lopez et al., 2013). So, in order for a nutritional cycle, including the sulfur cycle in a mangrove ecosystem, to remain sound, the quality of the mangrove sediment must be maintained. One of them is by keeping sediment from excessive chemicals. The use of chemicals on the sediment or soil will affect the quality of the sediment because their chemical properties cannot be easily degraded. The direct impact is that H2S or hydrogen sulfide, ammonia, nitrite, nitrate, and carbon compounds can be toxic in shrimp farming systems. This causes the ecological balance of microorganisms in the ponds to be no longer normal (Hastuti 2011). Mangroves are a source of life for marine or coastal fauna, so various fauna live in the mangrove ecosystem. Taqwa (2010) suggests that substrate excavation carried out by mangrove fauna such as crabs, nematodes, Polychaeta, and mudfish is known to have a significant effect on the sulfur cycle in sediments, and sediment has a substantial impact on nutrient cycling and the physical and chemical environment of mangrove forests. The holes made by crabs can increase aeration, facilitate drying of the soil, and support nutrient exchange between sediment and tidal waters (Rizal et al. 2014)

Phosphorus cycle

Phosphorus (P) is a structural and functional component of all organisms, so it is an essential element for all life. Phosphorus is almost undetectable at most sea levels. According to Kolliopoulos et al. (2015), the phosphorus element is not found in free form as an element but in the form of dissolved organic compounds (orthophosphates and polyphosphates) and particulate organic compounds. Phosphorus forms iron and calcium ions complexes in aerobic conditions, soluble and deposited in sediments. Orthophosphates are a form of phosphorus that aquatic plants can directly exploit, while polyphosphates must be reduced to orthophosphate before use. Phosphorus in the form of phosphate is a necessary micronutrient in small amounts but is essential for aquatic organisms. Phosphate in waters naturally comes from weathering rocks and the decomposition of organic matter (Gadd 2010). As reported by Vicente, organic matter in sediments also contributes to the retention of phosphorus by sediment (Vicente et al. 2016). In some marine and estuarine environments, the availability of P is considered a macronutrient that affects the productivity rate of water or is also known as a limiting factor.

According to Hidayat (2001), the phosphorus content in water is characteristic of the waters' fertility. The phosphate content of coastal waters is used to measure water fertility. The more optimal the phosphate content of water is, the more abundant living phytoplankton will be (Takarina et al., 2019). Phosphorus, especially in the form of orthophosphate as a limiting nutrient, has been found in many of them in the eastern Mediterranean Sea. In the form of orthophosphate, phosphorus plays a key role in photosynthesis (primary productivity) (Meirinawatil 2015). Phosphorus comes from various sources, phosphorus from fertilizers and human activities such as waste, erosion, livestock, and paper mills enter rivers, groundwater, and estuaries, causing an increase in anthropogenic P to the sea. Suspended materials may also carry the phosphate absorbed there (Zhuang and Xuelu 2015).

The primary source of phosphorus is in sediments. The sediment source is from decomposed terrestrial sediment carried by river flows towards the sea. The source of phosphorus in mangrove sediments comes from falling mangrove leaves, which are then decomposed into organic material with the help of bacteria. In sediments, these minerals are absorbed by hydrolyzed sediments, especially clay. The increase in phosphorus is proportional to the increase in sediment concentration (Yulma et al., 2018). The high phosphorus content in the sediments is also thought to be due to differences in the number of mangroves standing. This illustrates that the high and low organic matter content is directly affected by the difference in the volume of mangrove leaf litter, which falls into the sediment and finally decomposes into organic matter (Yulma et al., 2018). Sediment is the main storage area in the phosphorus cycle in the ocean. The phosphorus and phosphate content in sediments is influenced by the type of substrate (Supriyantini et al., 2018). P in marine sediments is in the form of particulate matter, bound to metal oxides and hydroxides, estimates of total P in open ocean sediments range from 9.3 x 1010 mol/year to 34x1010 mol/year (Paytan and McLaughlin 2007). The oxygen-containing (oxic) sediments on the surface rich in iron and manganese absorb phosphate and form minerals. In anoxic (oxygen-free) sediments, the phosphate is bound to calcium minerals. The organic P associated with plankton also depends on the redox conditions of the sediments. Phosphorus in sediments can be transferred when degrading organic matter and reducing iron oxides. The phosphate ion concentration in the ocean increases with depth. In response to P-limiting, some phytoplankton species produce enzymes that catalyze the hydrolytic cleavage of phosphate from organic matter. In particular, alkaline phosphates limit P response in many species (Labry et al., 2005).

Most of the phosphorus compounds on earth are stored in rocks. These rocks will experience erosion and free phosphate compounds (PO_4) needed by living things. Phosphorus compounds will be returned to the soil and water by decomposers (decomposing microorganisms). The phosphorus cycle in the environment is relatively simpler when compared to the cycle of other chemicals. Still, this phosphorus cycle has a very important role as an energy carrier in the form of ATP (Adenosine Triphosphate). This cycle of elements is a chemical cycle that produces a precipitate like the calcium cycle. Most phosphorus is present in igneous rock and soil parent material as apatite compounds. Fluoroapatite is one of the known apatite minerals. In the environment, there are no gaseous phosphorus compounds found; in general, the phosphorus elements found in the environment are solid particles. Phosphate is an essential nutrient for the growth of an aquatic organism. However, the high concentration of phosphate in the waters indicates a pollutant. Phosphate compounds generally come from industrial waste, fertilizers, domestic waste, and the decomposition of other organic matter (Makmur et al., 2012). The phosphorus cycle can be illustrated in Figure 5.

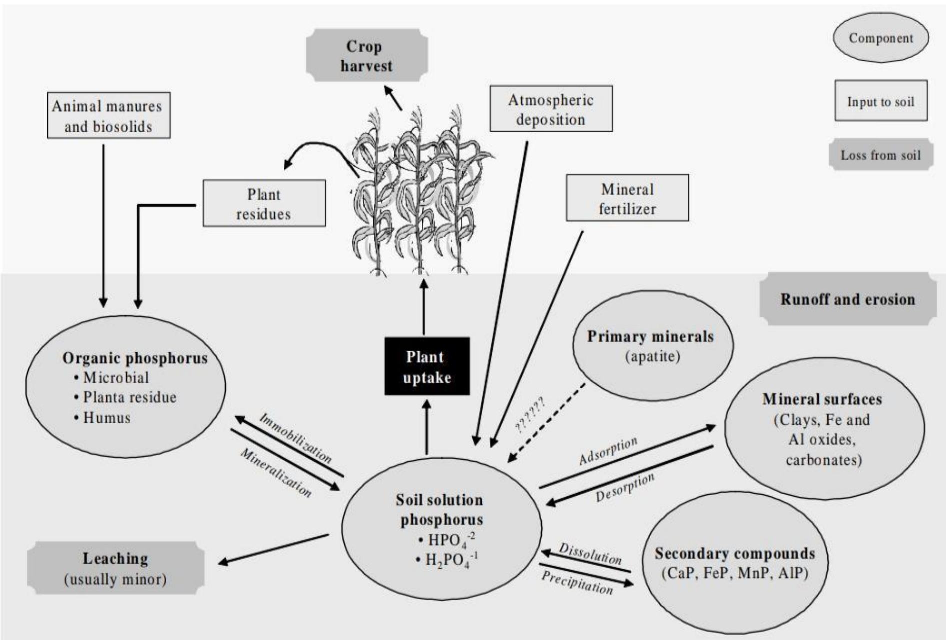

Figure 5. Phosphorus cycle (Source: Vendramini et al. 2007)

Phosphorus is an essential element in life because all living things need phosphorus in the form of ATP (Adenosine Tri Phosphate), a source of energy for cellular metabolism. Phosphorus occurs in nature in the form of the phosphate ion (PO_4^{3-}). The source of phosphate in water comes from various sources. One of them comes from the degradation of organic matter or the weathering of mineral rocks from the land (Maulana et al., 2014). Hutasoit (2014) states that high organic matter content in sediments is directly proportional to the high phosphate content in an ecosystem area. The occurrence of erosion and weathering causes phosphate to be carried to rivers to the sea to form sediments. The input of soil erosion from land carried by the river will be a source of phosphate in the waters. Phosphate compounds play a significant role in the process of eutrophication so that it has the potential to cause blooming algae (explosion of aquatic plant populations such as water hyacinth) if the phosphate content is too high in the water (Ngatia and Taylor 2018). The movement of the earth's base causes phosphate-containing sediments to emerge to the surface.

In the mangrove ecosystem, there is a phosphorus cycle. The presence of phosphorus is important for mangroves. Mangrove growth and structure correlate with the physical and chemical conditions of the soil and the ratio of phosphate, soil water content, sedimentation rate, and soil quality (Hossain and Nuruddin 2016). Phosphate is a limiting factor that affects the growth of mangrove plants (Chrisyariati et al., 2014). Phosphate (PO_4) is one of the major nutrients that determine the stability of vegetation growth, such as mangroves (Reef et al., 2010). It can help the process of photosynthesis, which is for survival, and maintain the food chain in the ecosystem around these plants (Yulma et al., 2018). The condition of mangrove waters which tend to be calm and not much influenced by tides, can cause the phosphate content in the sediment to tend to be high (Supriyantini et al. 2018). The high phosphate content in the mangrove location is influenced by the absence of mangrove vegetation growing at the site so that most of the phosphate is not utilized and settles in the sediment. Muddy coastal waters and river estuary waters contain less phosphate than the waters near mangroves. The mud content is soil material that enters the sea and fresh water and settles because marine energy holds it back. This sediment material contains a small number of macrobenthos which can break down minerals and decompose organic materials into nitrates and phosphates. As a result, the nitrate and phosphate content is less than the waters close to mangroves. The phosphate content in mangrove ecosystems can also be influenced by soil content; there is a relationship between sediment particles (sand, mud, and clay) and phosphate (Amelia et al., 2014).

Nitrogen (N) and phosphorus (P) are critical nutrients that regulate the magnitude and spatial distribution of mangrove forest productivity and structural properties. N transformations are generally slow in mangrove wetlands. N rates vary among mangrove ecotypes and depend on local (nutrient gradients, salinity), regional (geomorphology), and anthropogenic impacts (Kristensen et al., 2017). The use of fertilization experiments under field conditions has advanced understanding of the complex interaction and relative role of N and P availability for mangrove structural development and productivity. The response of ecological processes to nutrient enrichment depends on site characteristics, species composition and dominance, and the nature of nutrient limitation. For example, the resorption of P from senescent tissue by *R. mangle* is under P-limited conditions much higher than that for N. N fertilization does not change this pattern. Still, P fertilization decreases P resorption, whereas N resorption increases: scrub mangrove forests (R. mangle and A. germinans) growing in P limited carbonate sediments always respond to P fertilization, surrounding fringing mangroves (R. mangle) respond primarily to N fertilization. Those exposed to intermediate tidal influence respond to both N and P fertilization as the hydroperiod interacts with nutrient availability (Rivera-Monroy et al., 2017).

P availability within mangrove wetlands is in contrast to N, strongly dependent on the dynamic interactions of P with Fe and S cycling: phosphate (PO_4^{3-}) is readily adsorbed and then retained by Fe (III) oxyhydroxides in near-surface sediments, around crab burrows, and around rhizospheres, then limiting plant production (Nóbrega et al. 2014). However, the adsorbed PO_4^{3-} can be released back to dissolved form and be available again for primary producers when Fe (III) oxyhydroxides are reduced in anoxic sediment. This oxidation-reduction cycle depends on either: the transport of particles between oxic and anoxic zones, typically mediated by crabs when they rework surface and subsurface sediments, or temporal expansion and contraction of oxic zones, primarily due to tidal and seasonal changes in redox conditions.

Interaction between biogeochemical process and flora and fauna in mangrove

The cycle of elements in the mangrove sediment can be influenced by various factors such as land function change, sediment pH, tides, the intensity of sunlight, the life activities of living things, decomposing bacteria. Land-use change can affect the cycle of elements in the mangrove sediment. For example, mangrove land was initially used as aquaculture land, changing its function to mangrove forest or vice versa. Then the land-use change can affect the element cycle. Sediment pH, too high or low, can affect the element cycle. The tides of seawater cause sediment movement, which later affects the element cycle. Sunlight plays a role as the most influential factor in the process of the elemental cycle because sunlight plays a role as a provider of life on this earth. Living things act as life objects on earth influence the element cycle. Bacteria play a role in breaking down all types of inorganic and organic materials. Decomposing bacteria release the phosphorus captured by plants which occur in the elemental cycle.

Sources of sediment in mangrove areas come from land and sea (allochthonous) and from the mangrove area itself (autochtonous) in the form of heaps of leaf, twigs, or dead vegetation and organisms deposited in the mangrove area and contain a lot of organic and mineral (N, P, K, Fe, and

Mg) (Matsui et al. 2015). Mangrove density can affect the level of soil organic matter content. Soil organic carbon content in the mangrove stand habitat varies widely and depends on vegetation type. The diversity of soil organic carbon (SOC) content at soil depth occurs because each vegetation type is different in its vertical root distribution and leaves a distinct footprint on the SOC depth distribution. The amount and dynamics of SOC in the soil are very different in different mangrove species, mainly influenced by tidal gradients, mangrove forest age, biomass, and productivity. The greater the value of the organic matter content, the greater the stored organic carbon content, while the low carbon content in the soil can be due to the low content of organic matter in the soil. And organic matter in the soil is influenced by litter, leaf fall, and existing vegetation. As a manifestation of sediment conditions, the pH and Eh gradients are important factors affecting OC or organic carbon stocks and mobility/absorption of chemical elements. The P and Mg content in leaves increases with increasing pH. Mangrove species show a preference for absorbing certain elements. The organic carbon in the mangrove mud layer is characterized by high aliphatic content, indicating that the soil is not yet moisturized and susceptible to decomposition.

Benthos is an organism that lives on the surface or in the bottom substrate of waters, including plants (phytobenthos) and animals (zoobenthos). Benthos plays several critical roles in waters, such as decomposition and mineralization of organic material, and occupies several trophic levels in the food chain. Macrozoobenthos has a very important role in the nutrient cycle at the bottom of the water. In aquatic ecosystems, macrozoobenthos act as a link in the energy flow and cycle from planktonic algae to high-level consumers (Kaiser et al., 2015). Many benthic live or eat in the mangrove sediments. The vast majority are invertebrates, including crustaceans, polychaetes, sipunculids, mollusks, and fish. The dominant crabs living in mangroves are Brachyuran crabs, which are very dominant because of their speed and ability to move and their way of taking refuge in the mangrove environment (Rivera-Monroy et al. 2017).

The mud and sand substrate were the most preferred habitat for macrozoobenthos (Kumar and Khan 2013). Benthic animals prefer bottom waters with mud, sand, gravel, and waste substrates. Bentos does not like the bottom of the water in the form of rocks, but if the rock bed has high organic material, the habitat will be rich in benthic animals. The type of substrate is related to the oxygen content and availability of nutrients in the sediment. In the sandy substrate, the oxygen content is relatively greater than the fine substrate because, in the sandy substrate, there are air pores that allow for more intensive mixing with the above water. However, nutrients are not much present in the sandy substrate. In contrast to a smooth substrate, oxygen is not the case.

In conclusion, the mangrove ecosystem is a habitat to find food for various marine life, and a biogeochemical process occurs. Biogeochemistry of the organic-inorganic cycle is the process of circulating chemical elements or compounds that flow from the abiotic component to the biotic component and back again to the abiotic component. The cycle of these elements is not only through organisms but also involves chemical reactions in an abiotic environment that occur repeatedly and are not limited. Biogeochemistry plays a role in maintaining environmental stability and maintaining survival on earth. The biogeochemical cycle consists of an energy flow, a series of sequences in which one form of energy is transferred to another form of energy, and a nutrient cycle that describes the use, movement, and recycling of nutrients in the environment. Energy flows consist of food chains and food webs. The nutrient cycle consists of the water, carbon, nitrogen, phosphorus, and sulfur cycles. Various chemical elements resulting from the cycle process are needed to survive both flora and fauna in the mangrove ecosystem. The presence of organic matter in the mangrove environment, especially in the mangrove sediments, affects the elements of the nutrient cycle, movement, and recycling of nutrients in the environment. There is an influence from the presence of vegetation and fauna on mangrove sediments. Vegetation and litter are sources of organic matter in mangrove sediments. Benthos plays a role in the decomposition and mineralization of organic material in mangrove sediments.

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