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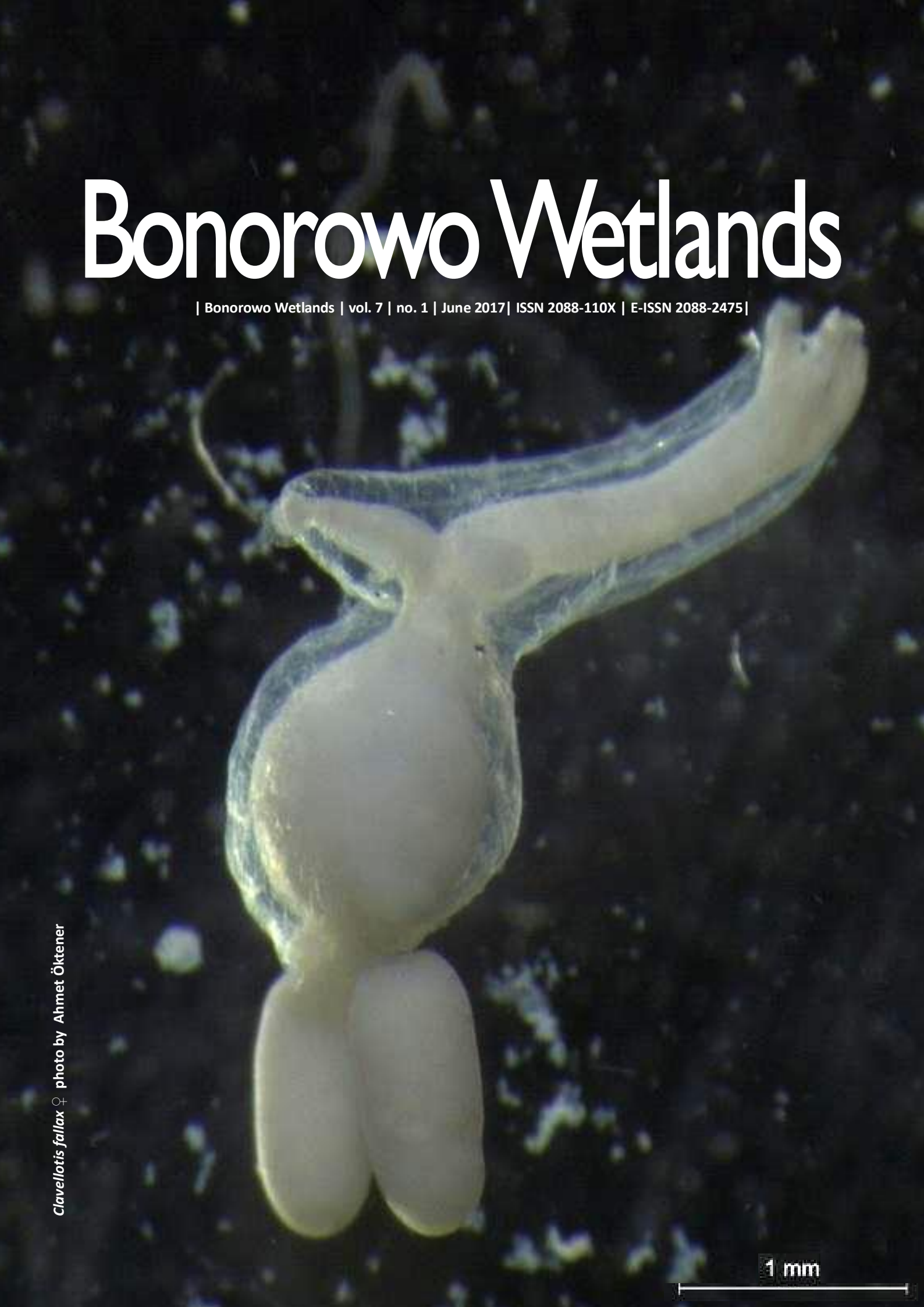

Clavellotis fallax ♀ photo by Ahmet Öktener

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Two new hosts for *Caligus bonito* Wilson C.B., 1905 (Copepoda, Siphonostomatoida, Caligidae) from Turkey

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Abstract. *Öktener A, Alaş A, Türker D. 2017. Two new hosts for* Caligus bonito *Wilson C.B., 1905 (Copepoda, Siphonostomatoida, Caligidae) from Turkey. Bonorowo Wetlands 7: 1-3. Caligus bonito* Wilson C.B., 1905 (Copepoda, Siphonostomatoida, Caligidae) was reported for the first time on the gill filaments of *Sarda sarda* (Bloch, 1793), *Auxis rochei* (Risso, 1810) from Turkish marine waters. The morphological characters of this cosmopolitan parasitic copepod are given using photographs. This study presents two new host species and a new geographic distribution of *Caligus bonito* in Turkey.

Keywords: Copepod, *Caligus bonito*, Sarda, Auxis, Turkey

INTRODUCTION

Copepods of the family Caligidae (Siphonostomatoida) are commonly known as sea lice among the fish culturists. It is the largest family of marine copepods comprising over 450 species. The members of this family are characteristic in possessing a flattened body, which is well adapted for life on a moving object - the fish. They feed on their host's blood, mucus, and epithelial cells (Ho 2004). This family has been responsible for most documented disease outbreaks (Johnson et al., 2004).

Hitherto, only ten species of the Caligidae family have been recorded parasitizing fishes in Turkish marine habitats. They are *Caligus apodus* (Brian 1924), *Caligus bonito* Wilson C.B., 1905, *Caligus brevicaudatus* Scott, 1901, *Caligus lagocephali* Pillai, 1961, *Caligus minimus* Otto, 1821, *Caligus pageti* Russel, 1925, *Caligus pelamydis* Krøyer, 1863, *Caligus solea* Demirkale, Özak, Yanar, Boxshall, 2014, *Caligus temnodontis* Brian, 1924, and *Lepeophtheirus europaensis* Zeddam, Berrebi, Renaud, Raibaut, Gabrion, 1988 (Alaş et al. 2016). In this paper, we present a second report of the male of *Caligus bonito* Wilson C.B., 1905, with morphological characters from Turkey.

MATERIAL AND METHODS

Thirty-three of Atlantic bonito, *Sarda sarda* (Bloch, 1793) (Scombridae) and forty-two of bullet tuna, *Auxis rochei* (Risso, 1810) (Scombridae) were collected by local gears from the Sea of Marmara, the Aegean Sea Coasts of Turkey) in 2014. The collected parasitic copepods were preserved in 70% ethanol. Some specimens were cleared in lactic acid before dissection of the appendages of copepods. The drawings of appendages were carried with the aid of camera lucida (Olympus BH-DA). The photos were taken with Canon EOS 1100D connected to a microscope. Measurements were taken in millimeters (mm) with a micrometric program (Pro-way). The scientific names and synonyms of parasite and host were checked with WoRMS Editorial Board (2016) and Froese and Pauly (2016). The identification, scientific names, their synonyms of the parasite were checked with Wilson (1905), Brian (1935), Kabata (1979), Cressey and Cressey (1980), Cressey (1991), Ho and Lin (2004). The parasite (MNHN-IU-2013-18732) was deposited in the Museum National d'Histoire Naturelle (MNHN), Paris, France.

RESULTS AND DISCUSSION

***Caligus bonito* Wilson, 1905 (Copepoda, Siphonostomatoida, Caligidae)**

Host: *Sarda sarda*, *Auxis rochei*

Locality: Bandırma Bay, Babakale Port

Total parasite: 5 males; **Dissected material:** 2 males

All parasites were firmly attached to the gill filaments of the host. The prevalence of parasite was 6% for *Sarda sarda* and 7.1% for *Auxis rochei*

Malemorphology (Figure 1-2): Body length varies from 4.5 to 5 mm. Maxilliped 3-segmented; proximal segment with ornamentation has four small tubercules, a distal segment comprising claw with a short seta. The setae on the exopod of the first leg carry teeth. The first segment of the second leg endopod carries four teeth, while the second segment with teeth in two slightly alternating rows.

Distribution: *Caligus bonito* was cosmopolitan, found in all waters inhabited by its wide-ranging hosts. It was reported from the Mediterranean Sea, the Black Sea, The Atlantic Ocean, the Pacific Ocean (Kabata 1979).

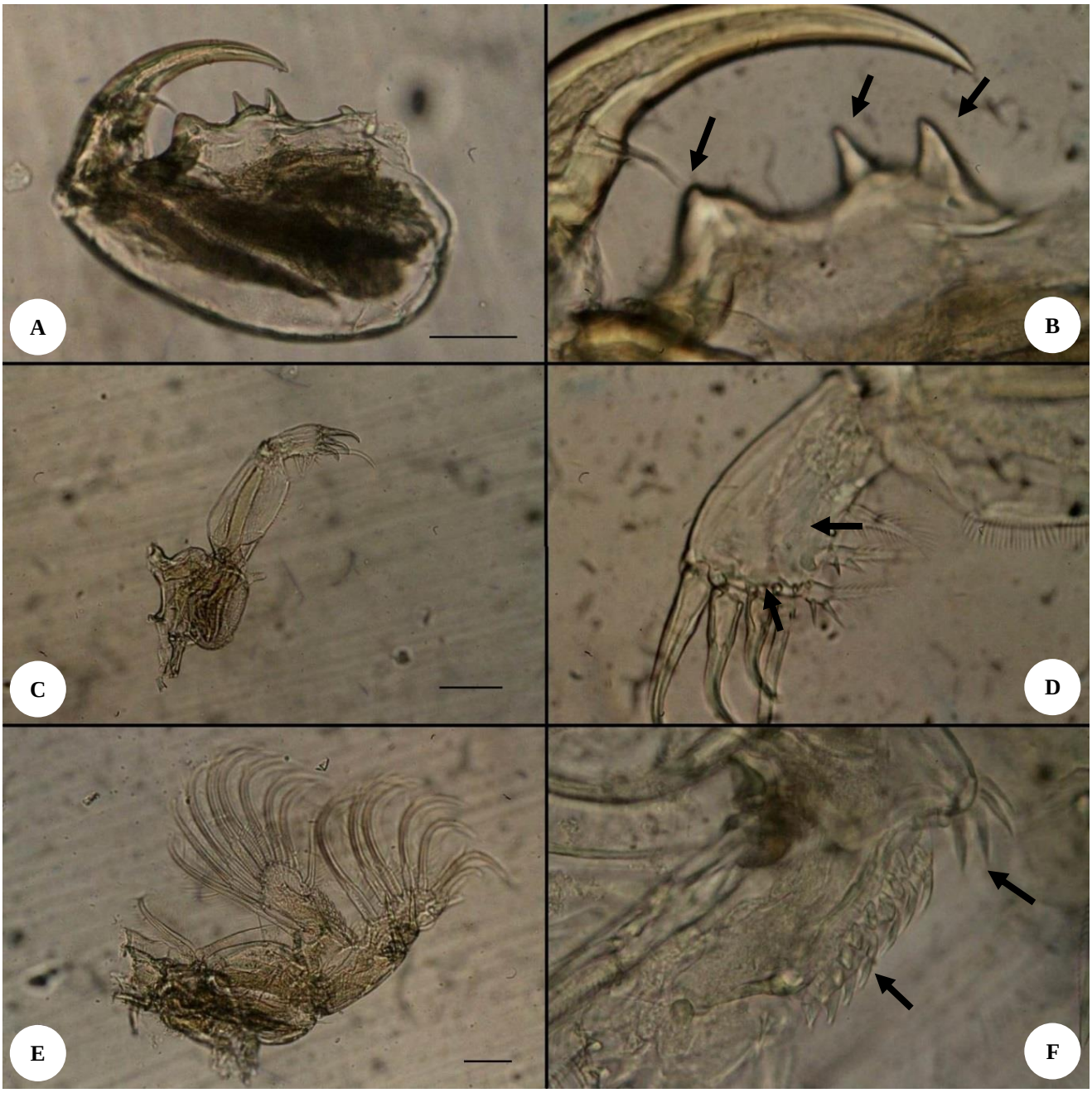

Figure 1. *Caligus bonito* ♂. A. Maxilliped (Bar = 0.075 mm), B. Four small tubercules on proximal segment of maxilliped, C. First leg (Bar = 0.10 mm), D. Setae on exopod of the first leg, E. Second leg (Bar = 0.08 mm), F. Four teeth and teeth in two slightly alternating rows on the first and second segment of second leg endopod

Hosts: *Caligus bonito* parasitizes several teleost species belonging to the family Scombridae, such as *Euthynnus affinis*, *Euthynnus alletteratus*, *Katsuwonus pelamis*, *Sarda sarda*, *Sarda orientalis*, *Sarda australis*, *Sarda chilensis chilensis*, *Scomberomorus regalis*, *Thunnus thynnus*, *Euthynnus lineatus*, *Gymnosardaunicolor* (Walter and Boxshall 2008), *Scomberomorus carvalla*, *Scomberomorus maculatus* (Bere 1936). However, it has been collected on hosts from other families (Mugilidae, Carangidae, Lutjanidae, Sciaenidae, Pomatomidae, Serranidae, Coryphaenidae), including *Mugil cephalus*, *Oligoplites saurus*, *Lutjanus griseus*, *Pomatomus saltatrix* (Bere 1936), *Mugil platanus* (Knoff et al. 1994), *Mugil curema* (Cavalcanti et al. 2006), *Oligoplites palometa* (Takemoto and Luque 2002), *Cynoscion nebulosus* (Blanchet et al. 2001), *Cratinus agassizii*, *Lutjanus novemfasciatus*, *Trachurus murphyi* (Ho and Lin 2004), *and Coryphaena hippurus* (Ho and Lin 2004; Öktener and Trilles 2009).

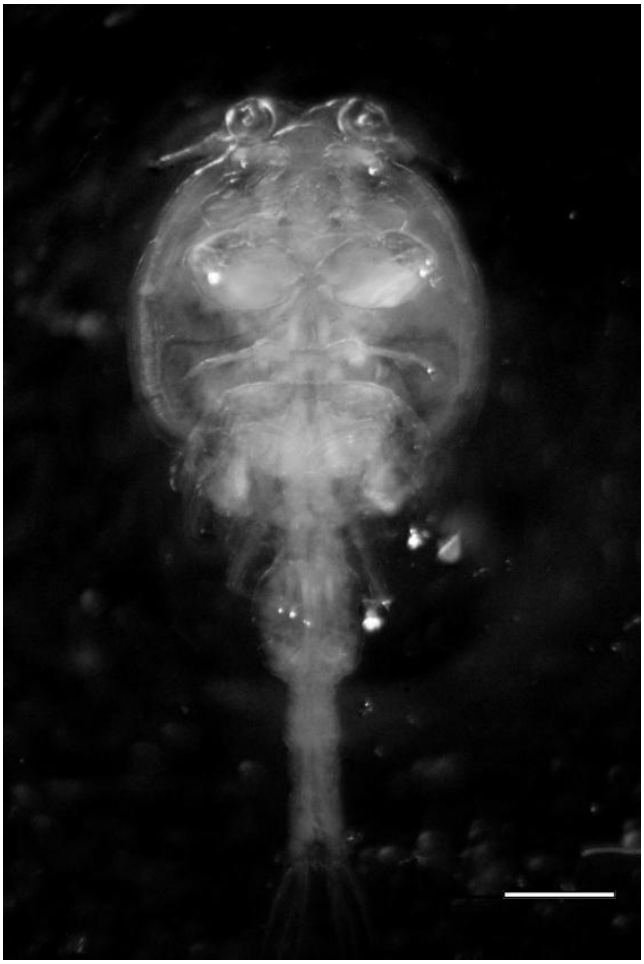

Figure 2. *Caligus bonito*♂ (Bar = 1 mm)

Discussion

Significantly, the Scombridae family fishes are the host of *Caligus bonito*. This parasite selects carnivorous and pelagic fishes as hosts for habitat and feeding habits. This study examined *Sarda sarda* ve *Auxis rochei*, carnivorous and pelagic fish. It is fit for host preferring of *Caligus bonito*.

Concerning the studies about the prevalence values of *Caligus bonito*, Takemoto and Luque (2002) found 3.57% prevalence on *Oligoplites palometa*; Knoff et al. (1994) found 13.33% prevalence on *Mugil platanus*; Cavalcanti et al. (2011), 3.23% prevalence on *Mugil curema*. The low prevalence values on *Sarda sarda* (6%) and *Auxis rochei* (7.1%) show the similarity with Takemoto and Luque (2002), Cavalcanti et al. (2011). Both differences in the infestation values and morphology of the parasite can result from the parasite-host interactions and host species that have migratory character.

The morphological characters found in this study are compared with mainly (Wilson 1905; Brian 1935; Lewis 1967; Pillai 1969; Kabata 1979; Cressey and Cressey 1980; Cressey 1991; Ho and Lin, 2004). The general morphology, three adhesion pads on the antenna, teeth on three setae of exopod of the first leg, four teeth and teeth in two slightly alternating rows on the first and second segment of second leg endopod, maxilliped proximal segment with four small tubercules, the setal and spinal formula of from the first leg to the fourth leg in this study are compatible according to this literature. The morphologic features of all dissected parasites permitted identification of this copepod as *Caligus bonito* Wilson, 1905. This study was aimed to present two new host species and a new geographic distribution of *Caligus bonito* in Turkey.

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Confirmed record of *Clavellotis fallax* (Heller) (Siphonostomatoida; Lernaeopodidae) from *Dentex dentex* (Linnaeus) with morphological characters in Turkey

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Abstract. *Öktener A, Alaş A, Türker D. 2017. Confirmed record of* Clavellotis fallax *(Heller) (Siphonostomatoida; Lernaeopodidae) from* Dentex dentex *(Linnaeus) with morphological characters in Turkey. Bonorowo Wetlands 7: 4-7. Clavellotis fallax* (Heller, 1865) (Copepoda, Siphonostomatoida; Lernaeopodidae) was reported for the first time on *Dentex dentex* (Linnaeus, 1758) from the North Aegean Sea Coasts. This species was reported from different sparid species in Turkey but not *Dentex dentex*. This paper aims to present some morphological characters with photographs and drawings of *Clavellotis fallax* from Turkey.

Keywords: *Clavellotis, Dentex, Copepoda*, Lernaeopodidae, Turkey

INTRODUCTION

Lernaeopodidae is a diverse and large family of highly specialized parasitic copepods, currently comprising 48 genera (Boxshall and Halsey 2004). Lernaeopodids are found everywhere in the world's oceans on teleosts and chondrichthyans. As a group, they may infect all external surfaces of the host's body, including the gills, spiracles, and olfactory sacs (Benz 1993). The pathology associated with lernaeopodid copepods depends on the tissue infected, the parasite species, its size, and the type of bulla (Lester and Hayward 2006). *Salmincola edwardsii* in brook trout caused a severe diffuse exuberant proliferation of gill epithelium, resulting in severe lamellar fusion and aneurysms (Duston and Cusack 2002).

Fifteen species of *the* Lernaeopodidae family are reported from Turkish waters, namely *Clavellotis fallax* (Heller, 1865), *Clavellotis briani* Benmansour, Ben Hassine, Diebakate & Raibaut, 2001; Clavellotis *strumosa* (Brian, 1906), *Clavella alata* Brian, 1909; Clavellisa *scombri* (Kurz, 1877), *Lernaeopoda galei* Krøyer, 1837, *Thysanote impudica* (Nordmann, 1832), *Parabrachiella bispinosa* (Nordmann, 1832), *Parabrachiella exigua* (Brian, 1906), *Parabrachiella insidiosa* (Heller, 1865), *Parabrachiella hostilis* (Heller, 1868), *Tracheliastes polycolpus* Nordmann, 1832, *Naobranchia cygniformis* Hesse, 1863, *Pseudotracheliastes stellifer* (Kollar, 1835) (Alaş et al. 2014).

The morphological characters in the study obtain a possibility to compare the other countries' findings next time. This study aims to confirm the occurrence of *C. fallax* with the morphological characters especially including mouthparts from Turkey. It also aims to present the host preferences according to family characteristics, habitat selections, feeding habits for *C. fallax*.

MATERIAL AND METHODS

The host was obtained with the local fishing gears in North Aegean Sea in 2014. The collected parasites were fixed in 70% ethanol. Parasites were dissected using a Wild M5 stereo microscope. The dissected parts were mounted on slides in a glycerin-gelatine mounting medium. The appendages were drawn with the aid of a camera lucida (Olympus BH-DA). The photos were taken with the assistance of the Canon EOS 1100D camera attached to the microscope. The measurements were taken in millimeters (mm) with a micrometric program (Pro-way). The scientific names synonyms of parasite and host were checked with the WoRMS Editorial Board (2015). The information of feeding habits habitat characteristics of the host was prepared according to Froese and Pauly (2015). *C. fallax* (MNHN-IU-2013-18739) was deposited in the collections of the Muséum National d'Histoire Naturelle (MNHN), Paris, France.

RESULTS AND DISCUSSION

Clavellotis fallax (Heller, 1865) (Figure 1, 2, 3)

Host: *D. dentex* (Linnaeus, 1758) (Pisces; Sparidae) (the common dentex); Locality: Babakale Port; Total parasite: 14; Dissected parasite: 10.

All parasites were firmly attached to the gill rakers of the host. The prevalence means the intensity of parasites was 40.

Description-female: Body length varies from 4 to 5 mm. The cephalothorax is longer than the trunk. The trunk is ovate or pyriform, with a truncated posterior margin. Ovisac is stout, cylindrical, apically rounded. Second maxillae shorter than trunk and cephalothorax. Second maxillae short, about one-third of cephalothorax length, fused at tip; bulla small, mushroom-shaped. First antenna 4-segmented; basal segment unarmed; third segment armed with seta whip on anterior margin; the apical segment with terminal armature consisting of one tubercule, two short setae, three long setae. Second antenna typical biramous, bulbous exopod more prominent and longer than endopod, covered with robust spinules on the rounded tip. Endopod two-segmented, armed apically with two setae, one tubercule. Exopod with 6-9 spines and much more spinules. First maxilla biramous with small endopod and prominent tripartite exopod. Endopod is composed of a short digitiform process surmounted with one long, short setae. Exopod tripartite with two big and one short setae. Mandible with dental formula P1, S1, P1, S1, P1, S1, B5. Maxilliped with a strong corpus, moderately elongated, with 1 with a strong terminal spine in its m area. subchela bearing a spine on its side. A sturdy barb reaches close to the middle of the claw.

Figure 1. *Clavellotis fallax* ♀ (Bar = 1 mm)

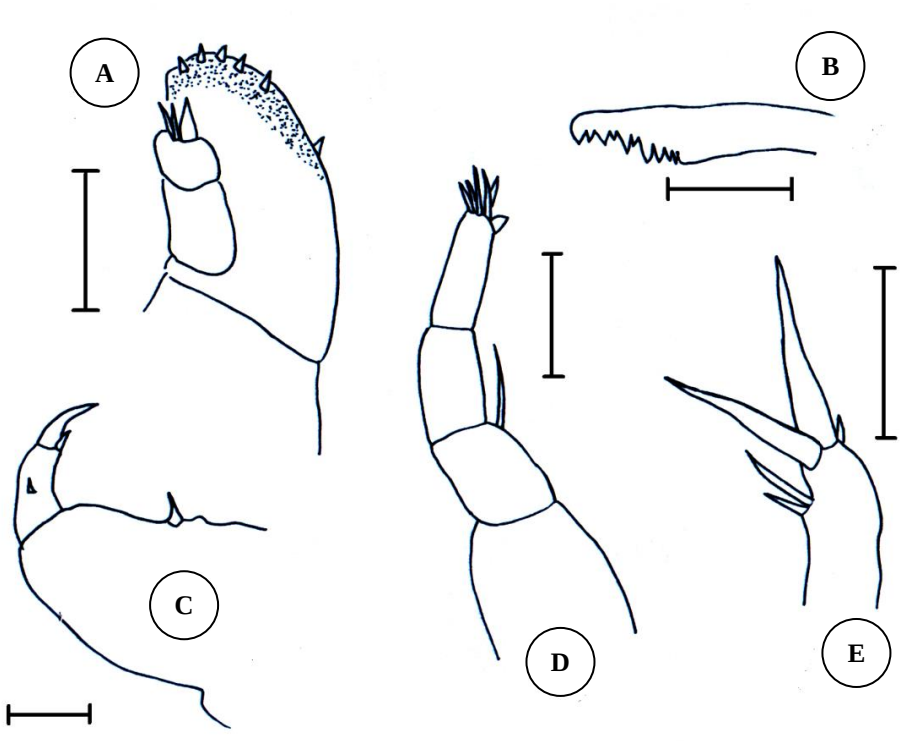

Figure 3. *Clavellotis fallax* ♀. A. Second antenna (Bar = 0.05mm), B. Mandible (Bar = 0.03mm), C. Maxilliped (Bar = 0.06mm), D. First antenna (Bar = 0.03mm), E. First maxilla (Bar = 0.05mm)

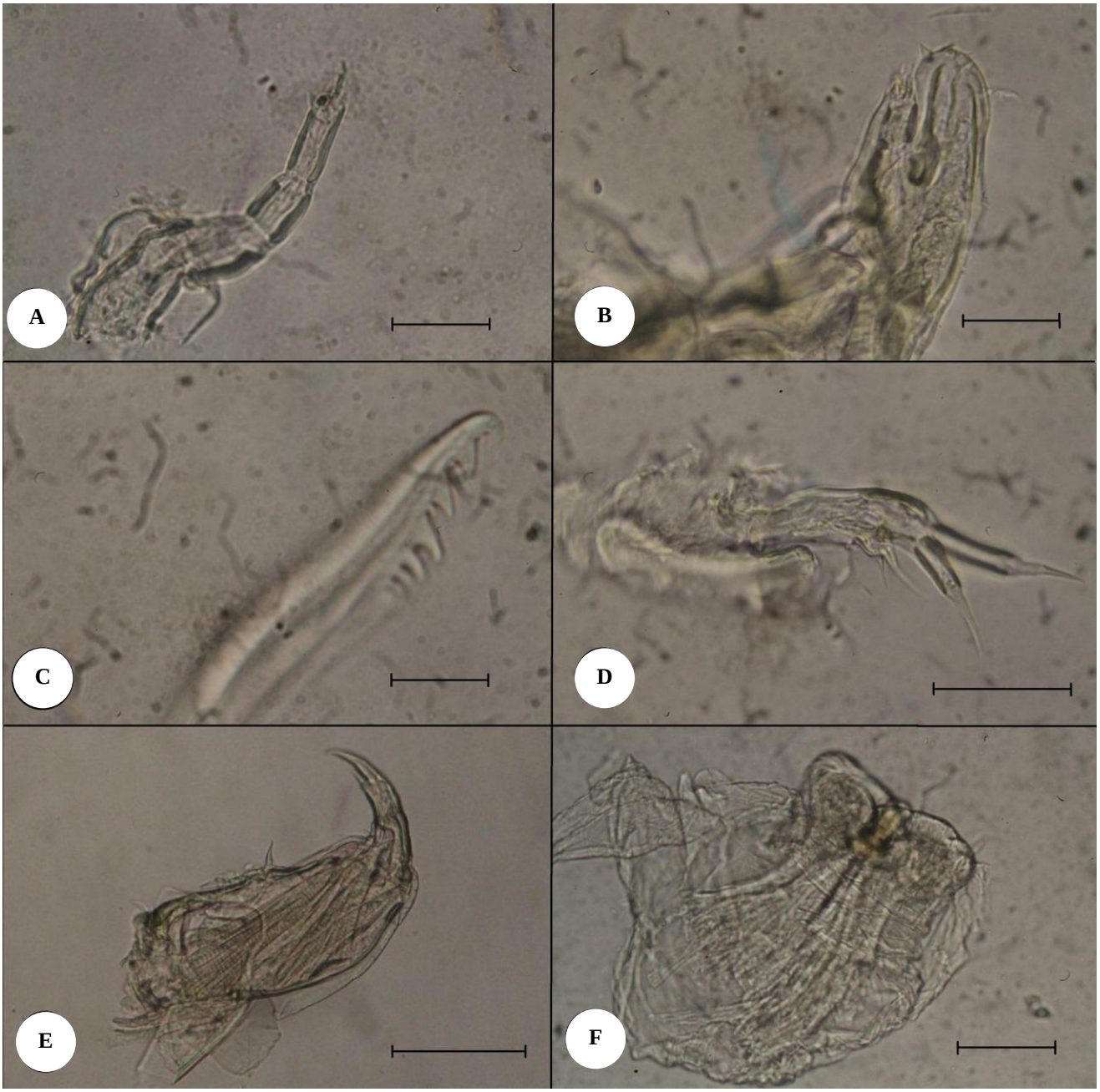

Figure 2. *Clavellotis fallax* ♀. A. First antenna (Bar = 0.03mm), B. Second antenna (Bar = 0.05mm), C. Mandible (Bar = 0.015mm), D. First maxilla (Bar = 0.05mm), E. Maxilliped (Bar = 0.06mm), F. Bulla (Bar = 0.15mm).

Discussion

Clavellotis fallax has been reported from North Atlantic Ocean, Mediterranean Sea, Adriatic Sea (Radujkovic and Raibaut, 1989). It was reported on *D. dentex* (Brian 1906; Raibaut et al. 1971; Papoutsoglou 1976; Ben Hassine et al. 1978; Essafi et al. 1984; Radujkovic and Raibaut 1989; Benmansour and Ben Hassine 1997; Raibaut et al. 1998; Benkirane et al. 1999; Gonzalez et al. 2004; Martorell 2004), *Dentex gibbosus* (Brian 1924), *Lithognathus lithognathus*, *Cymatoceps nasutus* (Barnard 1955), *Lithognathus mormyrus* (Ben Hassine et al. 1978; Raibaut et al. 1998; Martorell 2004), *Sparus aurata* (Ben Hassine et al. 1978; Essafi et al. 1984; Benmansour and Ben Hassine 1997; Raibaut et al. 1998; Martorell 2004; Souidenne 2010), *Spondyliosoma cantharus* (Ben Hassine et al. 1978; Essafi et al. 1984; Benmansour and Ben Hassine 1997; Raibaut et al. 1998; Martorell 2004; Boualleg et al. 2010), and *Pagellus erythrinus* (Essafi et al. 1984)

The host parasitism with *C. fallax* was examined according to family characteristics; all 8 hosts belong to the Sparidae family. The host parasitism with *C. fallax* was examined according to habitat selections of host fish; 5 of 8 host species are benthopelagic; 3 are demersal. The host parasitism with *C. fallax* according to feeding habits of host fish; 6 of 8 host species are carnivorous, 2 are omnivorous. It may say that this parasite selects fishes with carnivorous

and benthopelagic character. *D. dentex* examined in this study is carnivorous and benthopelagic character fish. It is fit as preferring host for *C. fallax*.

The cephalothorax, trunk, second maxilla proportions; the segment number on the first antenna; the status exopod/endopod on the second antenna, first maxilla; the myxal area, barb, spine on maxilliped of *C. fallax* agree with findings of Barnard (1955), Ben Hassine et al. (1978), Brian (1924), Martorell (2004).

C. fallax was reported on the gill rakers of *Sarpa salpa*, *Diplodus sargus*, *Spondyliosoma cantharus*, *Pagellus erythrinus* from the Aegean Sea by Akmirza (2000). A parasitic copepod belonging to Clavellotis at the genus level was reported on *D. dentex* by Çilli (2012). This study confirms the occurrence of *Clavellotis fallax* on *Dentex dentex* in Turkey.

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Recent record of Masked Finfoot (*Heliopais personata*) in Indonesia after 17 years

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Abstract. *Nurza A, Husnurrizal, Iqbal M. 2017. Recent record of Masked Finfoot (*Heliopais personata*) in Indonesia after 17 years. Bonorowo Wetlands 7: 8-10.* Masked Finfoot (*Heliopais personata*) is currently listed as Endangered based having a tiny and rapidly declining population caused by ongoing loss and degradation of wetlands and especially riverine lowland forest in Asia. Indonesia is one important habitat for this species during the migration period. However, information on Masked Finfoot in Indonesia is very little known. Since October 1992, there has been no further information on the Masked Finfoot in Indonesia. The Recent record of Masked Finfoot in Bangko Lake (Aceh Province, Indonesia) on 31 December 2009 is the only recent record of Masked Finfoot in Indonesia after 17 years break.

Keywords: Aceh, endangered, *Heliopais personata*, Masked Finfoot

INTRODUCTION

The Masked Finfoot, *Heliopais personata* (Gray, 1849), is recorded in Bangladesh and northeast India (Assam) through Myanmar and Thailand to Cambodia and Vietnam with uncertain status in Malaysia and Sumatra (Bertram 1996). This species is scarce winter visitor and passage migrant (probably also a resident) in southern Thailand, Peninsular Malaysia, and vagrant in Singapore (Robson 2011). In Indonesia, the bird is a winter visitor to Sumatra and Java (MacKinnon and Phillips 1993). The complete distribution of this species includes South Bangladesh (Sundarbans) and Northeast India (East Arunachal Pradesh, East Assam, South Assam Hills), Myanmar, Laos, Cambodia, and Vietnam; status is uncertain in South Thailand, Malaysia, and Sumatra (Figure 1) (Bertram and Boesman 2017).

Currently, the status is listed as Endangered based on having a tiny and rapidly declining population caused by ongoing loss and degradation of wetlands and especially riverine lowland forest in Asia (BirdLife International 2014). The world population is estimated at fewer than 10,000 birds (Bertram 1996). However, other updated population numbers may now number as low as 1,000 individuals, so is placed in the band 1,000-2,499 individuals; this equates to 667-1,666 mature individuals, rounded here to 600-1,700 mature individuals (BirdLife International 2014).

Since October 1992, there has been no further information on the Masked Finfoot in Indonesia (Birdlife International 2001). To our knowledge, this paper describes the recent record of the Masked Finfoot in Indonesian after a break of 17 years.

Figure 1. The distribution of Masked Finfoot in South Asia and Southeast Asia (Bertram and Boesman 2017). Note: Green = Extant (resident), Yellow = Extant (breeding) , Blue = Extant (non-breeding)

MATERIALS AND METHODS

The study site is located in Danau Laut Bangko or Bangko Lake (03°13.2"N, 97°27.6"E), Ujung Mangki Village, Bakongan Subdistrict, Aceh Selatan District, Aceh Province, Indonesia. This is a salt lake located at Leuser National Park. The area consists of hilly forests, settlements, and agriculture. The incident of Masked Finfoot in Bangko Lake was recorded on 31 December 2009, during a bird-watching trip. The bird was observed

and photographed for identification and documentation (Figure 2).

RESULTS AND DISCUSSION

On 31 December 2009, an incidental observation of an adult Masked Finfoot was taken place. The birds were observed swimming and searching for food for approximately one minute and identified as adults. Masked Finfoot by its gray hind crown and neck, black face and upper fore neck with a white border, thick yellow bill, body mostly brown above. These are fitted well with characters of Masked Finfoot in various references (MacKinnon and Phillips 1993; Bertram 1996; Robson 2011).

Figure 1. A. Masked Finfoot swims and searching for food in Bangko Lake (Danau Laut Bangko), Aceh Selatan District, Aceh Province, Sumatra, Indonesia on 31 December 2009 (Photo: Agus Nurza). B. Location of Bangko Lake in Sumatra.

This recent record of Masked Finfoot in Bangko Lake (Danau Laut Bangko, Aceh Selatan) on 31 December 2009 is unexpected. There are previous few records of Masked Finfoot in Sumatra, including Aceh (Alas river, Ketambe) in 1974 and 1978 (Marle and Voous 1988). The latest record of Masked Finfoot in Indonesia is in October 1992, when one adult and one immature were seen at different localities in a dense mangrove in Riau (Burn and Brickle 1992; Birdlife International 2001). The record of Masked Finfoot in Bangko Lake is the only recent record of Masked Finfoot in Indonesia after 17 years break.

We hope that researchers and birdwatchers in Indonesia will pay more attention to Masked Finfoot to determine the status and support its conservation in Indonesia. It looks like the bird is a possible regular visitor in a small number in Sumatra, but the limited number of birdwatchers could have it overlooked in the past.

To conclude, the recent record of Endangered Masked Finfoot in Sumatra after 17 years break is unexpected. The status in Sumatra or Indonesia is uncertain, but it is presumed Indonesia is an essential wintering habitat for this species during the migration period. A further survey is needed to determine the status of this species in Indonesia.

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Distribution and abundance of aquatic plants of Oyan Lake, Ogun State, Nigeria

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Abstract. *Dienye HE, Olopade OA, 2017. Distribution and abundance of aquatic plants of Oyan Lake, Ogun State, Nigeria. Bonorowo Wetlands 7: 11-15.* The distribution and abundance of aquatic plants from Oyan Lake were assessed bi-monthly between October 2012 and January 2013. In total, 20 species of aquatic plants were recorded, representing 13 families. Cyperaceae and Poaceae families had the highest species with four species each. A further study showed that *Azolla africana* had the highest abundance (richness), followed by *Salvinia nymphellula,* while the species with the lowest abundance (richness) was *Ceratophyllum demersum. Ludwigia decurrens* and *Rhynchospora corymbosa* had the lowest evenness (distribution), followed by *Nymphaea lotus. Fimbristylis ferruginea* had the highest evenness, followed by *Echinochloa stagnina*. The three most prominent species found at the Stations in order of prominence were: *Azolla africana, Salvinia nymphellula, and Polygonum lanigerum* occupying 42.33% of the area covered by aquatic plants. The biotic indices of species richness, Shannon - Wiener information function, evenness, and Simpson's Dominance were fairly distributed in the study area.

Keywords: Aquatic plants, distribution, classification, distribution, Oyan Lake

INTRODUCTION

Macrophytes are important components of the freshwater (aquatic) ecosystem because they enhance habitats' biological complexity and physical structure, increasing biodiversity within the littoral zones (Esteves 1998; Wetzel 2001; Pelicice et al. 2008). In addition, both live and dead materials (detritus) from aquatic macrophytes may serve as food resources for aquatic and terrestrial organisms (Lope et al., 2007). Macrophytes play a significant role in the hydro ecosystem by providing a breeding substrate for organisms, including fish, aquatic insects, and zooplankton. Many of them serve as food for fish (Ratusshnyale 2008). However, in most rivers and lakes, the excessive growth of macrophytes may provoke some negative effects (Bini et al. 2005), and it develops into an explosively large population only when the environment is altered

Nigerian inland water bodies serve as an important refuge for numerous animals and vascular plants that have sustained their communities. But in recent times, both natural and human-induced environmental problems have either destroyed or altered the associated ecosystem with consequent impact on the endowed natural resources. And yet little is presently known about Nigerian inland water bodies associated with flora and fauna, including their inventories, socio-economic values, and overall management (Daddy et al. 1993).

Among the least understood and least studied components of urban streams and rivers biota are aquatic macrophytes. This is rather unfortunate since changes in macrophytes communities may be especially indicative of major categories of urban stress. The health and structure of macrophytes communities are likely to be important determinants of water quality (Gregg and Rose 1982; Suren 2000; Balanson et al. 2005). There is very little information on aquatic plants, particularly the freshwater ecosystem. In this present study, an attempt has been made to analyze the pattern of species diversity and distribution of the aquatic macrophytes of the Oyan Lake, Ogun State, Nigeria.

MATERIALS AND METHODS

Description of the Study area

Oyan Lake is situated at about 26km North-West of Abeokuta, Ogun State, Nigeria (Figure 1) that lies on latitudes between 7^0 15^1 and 7^0 25^1 and longitude 3^0 5^1 and 3^0 15^1. It is a gated spillway lake and covers an area of 40km^2 with a normal reservoir capacity of 140million m^3. The Lake was constructed on the Oyan River, a significant tributary to Ogun River with a catchment area of 9,000km^2; it is an artificial lake in Ogun State. It is the second-largest lake in the southern part of Nigeria (Adekoya 1991).

The lake has a tributary where the water flows in from the Oyan River and meets with the Ofiki River; the Hausas are predominantly the inhabitants of Ofiki while the Ilajes dominate the Oyan River. The climate of the study area is warm and humid. Two distinct seasons are felt during the year: rainy (March-October) and dry (November-February). The range of rainfall was between 1600mm and

2900mm to provide all-year-round pictures of the aquatic plants of the study area.

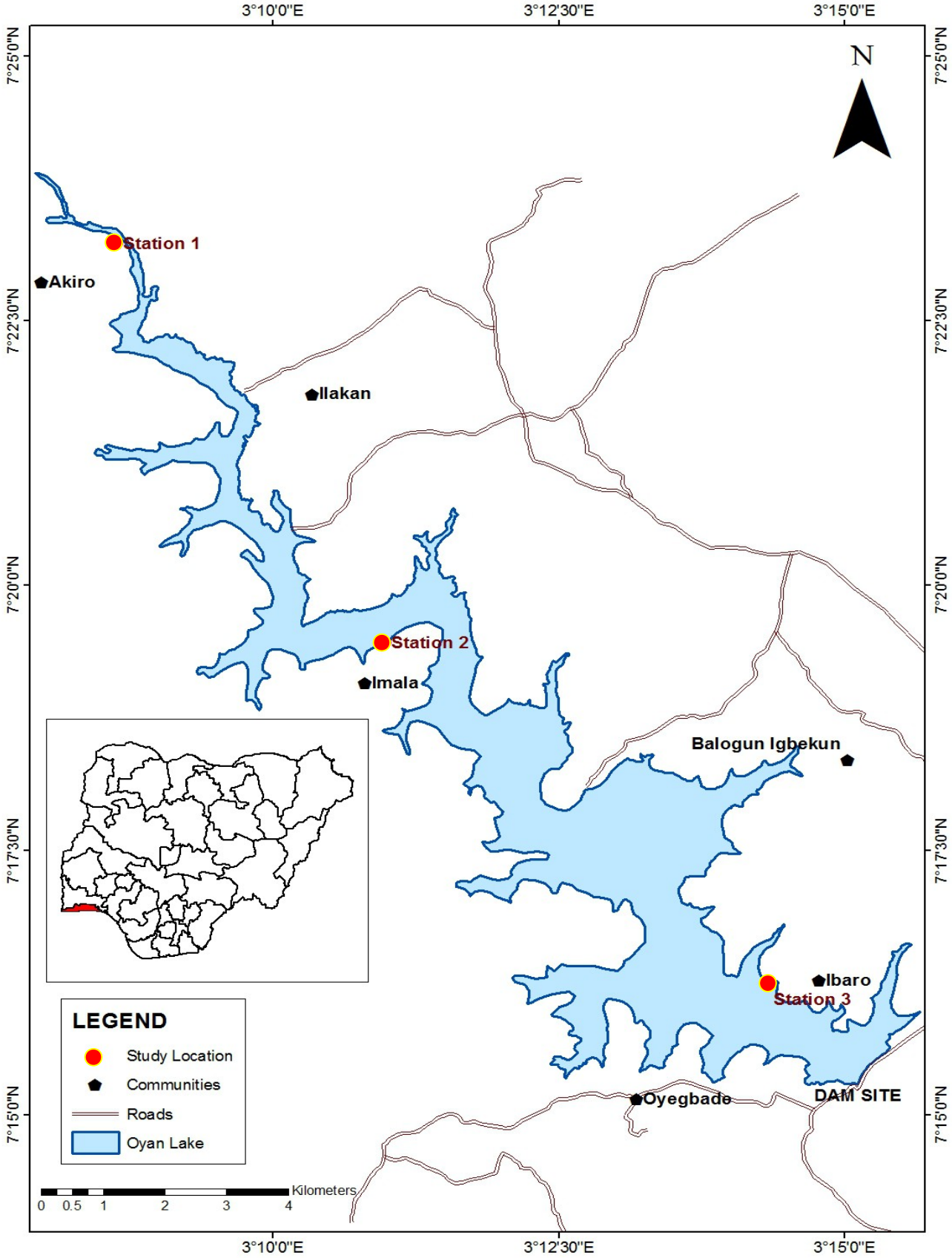

Figure 1. Study area showing the different sampling Stations in Oyan Dam, Ogun State, Nigeria

Table 1. Morphometry of Oyan Dam, Ogun State, Nigeria (Adekoya 1991)

Morphometry	
Dam	
Length of the crest	1.1km
Maximum height of the crest	32.5m
1st service spillway capacity	2271m3per second
2nd Service spillway capacity	3340m3 per second
Reservoir	
Length	27km
Maximum width	6km
Water storage capacity	270 million cubic meters
Surface area	40km2

Collection of samples

The study was conducted on Oyan Lake from October 2012 to January 2013, and sampling was done twice a month. A general survey of the Oyan Lake was made at three different study sites (Inlet of the Lake, Centre of the Lake, and dam site). In each field visit, aquatic plants from each of the three studies were collected following a standard approach (Janauer, 2003). Aquatic plants found at the edge of the Lake were easily collected, while the ones in the lake were collected with a paddled boat to the different zones through the assistance of a fisherman. A wooden square quadrat of $1m^2$ was placed on the vegetation at random bearings at each zone, and counting was also carried out per square meter. These samples were respectively tagged for ease in identification following Akobundu and Agyakwa (1987).

Data analysis

The data generated were statistically analyzed using means and some ecological indices. These were:

Shannon-Weiner diversity index (H^1) = -E [(ni/N) x In (ni/N)] (Shannon and Weaver 1963)

Where:

H^1=Diversity index, ni=the total number of individuals belonging to the ith species=total number of individuals for the site, and ln=the natural log of the number.

Simpson diversity (1-Δ) =1-E n (n-1)/N (N-1)

Where:

N=the total number of organisms of all species, and n=the total number of organisms of a particular species

Margalef-value is the measure of species richness. It is expressed as

d=S-1/lnN,

Where:

d=Margalef value, S=number of species collected in a sample, and N=total number of individuals in the sample.

Menhinicks Index (D) =S/√N

Where:

S=Number of species in a population and N=Total number of individuals in S species

Pielou index measures how evenly the species are distributed in a sample community. It is expressed as:

J=1/Hmax (Pielou 1969)

Where:

J=Diversity evenness or Equitability Index. H1 = calculated Shannon-Weiner diversity index. (Shannon-Weiner) Hmax+inS S=total number of species in a population in=natural log of the number

Simpson dominance index(C) =Σ (n/N) 2 (Ogbeibu 2005)

Where:

N=the number of species in the ith species and N=total number of individuals.

RESULTS AND DISCUSSION

The samples collected during the survey were classified into 20 aquatic macrophytes species representing 13 families. Cyperaceae and Poaceae families had the highest species of four each, followed by Mimosaceae with two species. At the same time, the other ten families recorded one species each, respectively, as shown in Table 1. Bini et al. (1999) reported that Poaceae and Cyperaceae are among the best-represented families and the most important families in other freshwater ecosystems. Daddy et al. (1993) reported that in the herbarium of Kainji and Jebba Lake, 13 different aquatic plants families constituted thirty-one species. Family Poaceae ranked the commonest with fourteen species, representing another family. Ikenweiwe (2005) also classified macrophytes of Oyan Lake into 10 Families and 9 species, respectively. Family Poaceae and Cyperaceae ranked the commonest with 2 species each.In comparison, other families were represented by 1 species each Dienye (2015) classified macrophytes of the New Calabar River into ten families made up of 12 different species. The resulting family Cyperaceae recorded the highest number of species with 3 species, while the other nine families recorded one species each. According to Obot (1987), in the classification of aquatic plants of Nigeria, the family Poaceae has the highest number of species of 12, according to the results of this study.

The species samples were zoned into floating, submerged, and emergent groups. Table 2 shows that 15 out of twenty identified species were grouped as emergent,

two as submerged, and the remaining three as floating aquatic plants. Obot and Ayeni (1987) grouped aquatic plants of Kainji Lake, marginal flora species (31), submerged species (15), and floating and marginal species (4). Dienye (2015) reported that the zonation of the different species of macrophytes in the New Calabar River into floating, submerged and emergent. Among the 12 species samples, 10 were grouped as emergent,2 as floating, and none were grouped as submerged during the sampling period. This finding shows that emergent species ranked the highest in the zonation of macrophytes, which is in line with this result.

The evenness is the distribution of species sampled among species in the community. *Fimbristylis ferruginea* had the highest distribution, followed by *Echinochloa stagnina,* while *Ludwiga decurrens* recorded the lowest distribution. In the study of the ecology of macrophytes of Jebba Lake carried out by Adesina et al. (1993), *Vossia cuspidata* has the highest calculated value while *Ceratophyllum demersum*, *Tephrosia bracteolata*, *Nymphaea lotus,* and *Setaria pumila* had the lowest in distribution.

The richness is the number of species present in a community Table 3 shows the abundance in each zone and the mean abundance of the community. The species *Azolla africana* had the highest richness, followed by *Echinochloa stagnina* and *Oryza longistaminata* with the same level of richness. *Ceratophyllum demersum* recorded the lowest richness among the species sampled in the community.

The similarity index shows the similarity between the different zones,i.e., the presence and absence of other species in each Station. The comparison of the stations and the respective percentages are shown in Table 4. The Stations compared, which has the highest percentage of 73.68%, had the highest similarity of all the sampled stations, i.e., Station 2 and 3, followed by Station 1 and 3 with 31.58%, with the slightest similarity.

Table 1. Checklist of aquatic plants species in Oyan Lake, Ogun State, Nigeria

Family	Species	Common name
Cyperaceae	*Rynchospora corymbosa*	
	Mariscus longibracteatus	
	Cyperus esculentus	Yellow Nutsedge
	Fimbristylis ferruginea	
Poaceae	*Echinochloa pyramidalis*	
	Echinochloa stagnina	
	Sacciolepsis africana	
	Oryza longistaminata	Wild rice
Onagraceae	*Ludwigia decurrens*	Water primrose
Araceae	*Pistia stratiotes*	Water lettuce
Polygonaceae	*Polygonium lanigerum*	Smartweed
Curcubitaceae	*Luffa aegyptiaca*	Loofah, Loofah gourd
Azollaceae	*Azolla africana*	Water velvet
Hydrophyllaceae	*Hydrolea glabra*	
Mimosaceae	*Mimosa pigra*	Giant sensitive plant
	Neptunia oleracea	
Salviniaceae	*Salvina nymphellula*	Salvinia
Convolvulaceae	*Ipomea triloba*	
Nymphaeaceae	*Nymphaea lotus*	
Ceratophyllaceae	*Ceratophyllum demersum*	Water lily

Table 2. Zonation of aquatic plants in Oyan Lake, Ogun State, Nigeria

Species	Floating	Submerged	Emergent
Ludwigia decurrens			+
Pistia stratiotes	+		
Polygonium lanigerum		+	
Echinochloa pyramidalis			+
Neptunia oleracea			
Rynchospora corymbosa			+
Echinochloa stagnina			+
Oryza longistaminata			+
Luffa aegyptiaca			+
Azolla africana	+		
Fimbristylis ferruginea			+
Mariscus longibracteatus			+
Cyperus esculentus			+
Hydrolea glabra			+
Sacciolepsis africana			+
Mimosa pigra			+
Salvina nymphellula	+		
Ipomea triloba			+
Nymphaea lotus			+
Ceratophyllum demersum		+	

Table 3. Distribution of aquatic plants in Oyan Lake, Ogun State, Nigeria

Species	Akiro	Imala	Ibaro	Total	ValueMean
Ludwigia decurrens	0.06	0.12	0.11	0.29	0.10
Pistia stratiotes	0.05	0.10	0.09	0.24	0.08
Polygonium lanigerum	0.03	0.06	0.06	0.15	0.05
Echinochloa pyramidalis	0.05	0.09	0.08	0.22	0.07
Neptunia oleracea	0.08	0.14	0.14	0.36	0.13
Rynchospora corymbosa	0.08	0.14	0.14	0.36	0.12
Echinochloa stagnina	0.03	0.06	0.06	0.15	0.05***
Oryza longistaminata	0.03	0.07	0.06	0.16	0.05***
Luffa aegyptiaca	0.06	0.12	0.11	0.29	0.10
Azolla africana	0.02	0.04	0.04	0.10	0.03**
Fimbristlysis ferruginea	0.06	0.11	0.11	0.28	0.09
Mariscus longibracteatus	0.08	0.15	0.14	0.37	0.12
Cyperus esculentus	0.08	0.15	0.14	0.37	0.12
Hydrolea glabra	0.06	0.11	0.10	0.27	0.09
Sacciolepsis africana	0.05	0.09	0.09	0.23	0.08
Mimosa pigra	0.05	0.10	0.09	0.24	0.08
Salvina nymphellula	0.03	0.06	0.05	0.14	0.05
Ipomea triloba	0.05	0.10	0.09	0.24	0.08
Nymphea lotus	0.05	0.09	0.08	0.22	0.07
Ceratophyllum demersum	0.10	0.18	0.17	0.45	0.15*

Note: *Highest, ** Lowest, *** Same calculated mean value

Table 4. Percentage of similarity index between species of different stations in Oyan Lake, Ogun State, Nigeria

Station	1 and 2	1 and 3	2 and 3
Percentage	36.84	31.58	73.6

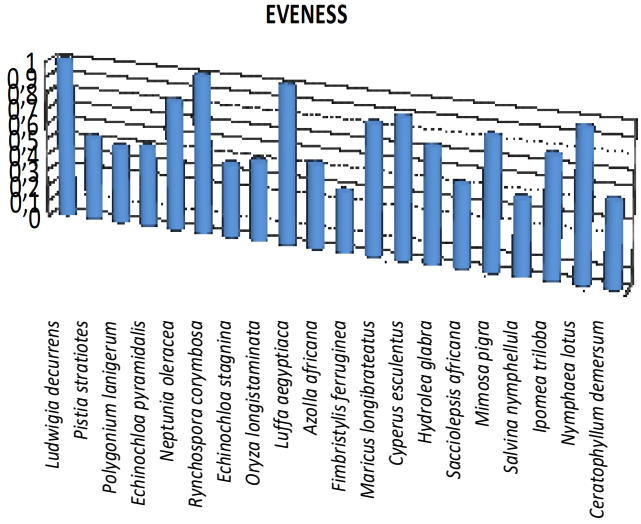

Figure 2. The evenness (distribution) of aquatic plants of Oyan Lake, Ogun State, Nigeria

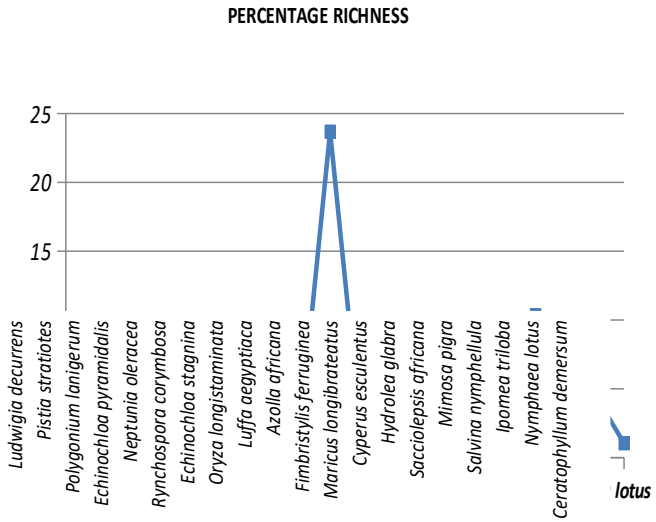

Figure 3. The percentage richness (abundance) of aquatic plants of Oyan Lake, Ogun State, Nigeria

In conclusion, the aquatic plants of Oyan Lake constitute different species with different families. A total of 20 species of aquatic plants representing 13 families were encountered; the family Cyperaceae and Poaceae had the highest species. *Azolla africana* dominated the area and is evenly distributed. The species is of high economic importance, while *Ceratophyllum demersum,* a submerged plant, was the least species in the study area. From most research carried out on aquatic plants of Lakes and dams, it has been observed that the families Cyperaceae and Poaceae dominated the water body with the highest corresponding species.

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Phytoplankton distribution in Mikawa Bay of Japan in relation to temperature and salinity variables

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Abstract. *Djumanto, Rasul E, InoueT, Aoki S. 2017. Phytoplankton distribution in Mikawa Bay of Japan in relation to temperature and salinity variables.Bonorowo Wetlands 1: 16-25.* Species composition and horizontal distribution of phytoplankton in relation to temperature and salinity variables were investigated in Mikawa Bay of Japan. Surface seawater was filtered with a 30 cm diameter conical plankton net with a mesh size of 53 µm weekly from mid-August to late September 2011. Surface layer temperature and salinity were measured with a CTD sensor. Phytoplankton samples were observed with an inverted microscope with phase contrast at 100-400 magnification. The salinity and surface temperature data and the density of the phytoplankton horizontally were made contour maps by connecting the location of each sampling station having the same value. Contour maps were created using surfer software. The result showed that the average temperature at the 1 m surface layer ranged from 22.7 to 28.7ºC. Meanwhile, salinity was ranged from 11.8 psu to 30.0 psu. Phytoplankton was abundant in the area with high temperatures and low salinity. The most abundant species among sampling stations in Bacillariophyceae was *Chaetoceros* sp(p). (52.2%) followed by *Pseudo-Nitzschia* sp(p) (27,7%), and then *Coscinodiscus* sp(p). (6.3%). On the other hand, the most abundant in Dinophyceae was *Dinophysis* sp(p). (1.1%) followed by *Ceratium fusus* (0.9%) and then *Ceratium furca* (0.8%), which was most dominant in the off-river mouth area. The phytoplankton population's density center and contour lines were changed and moved depending on salinity or temperature profiles.

Keywords: Abundance, phytoplankton, Mikawa Bay, Japan

INTRODUCTION

In aquatic ecosystems, phytoplankton plays an important role in the biogeochemical cycles of elements due to their role as primary producers and a major supplier of organic matter for heterotrophic organisms. It is a fundamental biological property and governs productivity, carbon transformation within the food webs, nutrient utilization, and a quality element for determining the ecological status of water ecosystems. Phytoplankton is responsible for about 40% of global primary production and forms the aquatic food web base. They are essential mediators of carbon and energy (Falkowski 1994). Quantitative measures of phytoplankton biomass, size distribution, and community composition are important indicators of the trophic state of aquatic systems and provide insight into the environmental forcing that affects phytoplankton dynamics. Phytoplankton growth is affected by the availability of nutrients and other limiting factors such as light and temperature. In many estuarine systems, primary production is considered high (Mann 2000) due to increased nutrient input from adjacent land or river runoff. It hence often serves as nursery grounds for commercially important finfish and shellfish species.

Mikawa Bay is a coastal water system in which freshwater runoff from some rivers supplies nutrient influx, and circulation in the bay induces nutrient transport off wards and backward into the water system. This affects the nutrient level, phytoplankton growth, and biomass distribution. Mikawa Bay is characterized by fluctuations in hydrographic and chemical conditions within the water system, driven by the wind, freshwater input, tides, and hurricanes. Wind strength and direction, precipitation, and waves may vary substantially quickly and affect the hydrographic conditions. Such bay can, therefore, often be considered as highly dynamic systems. Periodically, increases and decreases in primary production may be triggered by alternating periods of mixing and changing nutrient cycling. Phytoplankton distribution in the bay systems is affected either directly through alternating periods of mixing and stratification or indirectly through subsequent variability in nutrient concentrations and forms of nutrients.

Previous researchers have conducted several studies regarding plankton bloom in Mikawa Bay. The characteristic features of the bay ecosystem, such as the distribution of salinity, dissolved total nitrogen, and dissolved oxygen during the stratified period, were studied by Suzuki and Matsukawa (1987). There were two layers of circulation, and the upper layer of the river mouth region has higher production of particulate organic nitrogen due to strong upwelling and river inflow. In contrast, the lower layer of the bay mouth region has a higher deposition of particulate organic nitrogen caused by weak upwelling and downwelling. On the one hand, a study about a massive coccolithophorid bloom found that blooming initiated by

the poorer standing crops during spring resulted in relatively rich nutrients through the bay. The influx of oceanic water into Mikawa Bay with higher salinity and temperature leads to bloom (Kai et al. 1999). Yamamoto and Okai (2000) found that diatoms with a low growth rate cannot form red tides in a heavily diffusive environment, while species with a high growth rate can form red tides even in a robust and diffusive environment. However, the flagellates will develop red tides in severe diffusive conditions through their swimming ability. In contrast, diatoms form red waves through their high growth rates with vertical diffusion and upwelling movement of water.

However, no one has studied the phytoplankton distribution in the Mikawa Bay in relation to temperature and salinity variables. It is interesting to investigate the phytoplankton distribution and occurrence of nutrient concentration in environmental conditions. Nutrient levels in Mikawa Bay are stirred by water discharged from the river; sediment absorption and nutrient uptake ultimately affect increased phytoplankton distribution.

Although the intensive use of the bay and its ecological importance for much marine living, relatively little is known about basic features, such as hydrographic conditions, phytoplankton distribution, primary production, and processes in the estuary environment, this knowledge is essential in the sustainable use of the bay systems, maintaining optimal water quality conditions, and the welfare of farmed fish. This study investigates the variable environmental influences on a typical bay's phytoplankton distribution, dynamics, and processes.

MATERIALS AND METHODS

Study site

Mikawa Bay is a partially mixed estuary composed of Kinu-ura Bay, the estuary of the Yahagi River (37 m^3s^{-1} the annual mean) in the northwest, and Atsumi Bay, the estuary of Toyo River (35 m^3s^{-1}) in the east (Suzuki and Matsukawa 1987). The Bay is a semi-enclosed estuary located in mid-Japan, has a surface area of 604 km^2 with an average depth of 9.2 m. The Yahagi and Toyo Rivers are two major rivers empty into the bay from the northwest and northeast, respectively. Mikawa Bay is a rich fishery area because of inorganic and organic loadings from these rivers. This bay is the most eutrophicated in Japan because of high economic growth during the last two decades (Yamamoto and Okai 2000).

Field survey

Field sampling was conducted in 18 stations once a week from mid-August to last September 2011, as shown in Figure 1. The position of stations 1 to 8 formed a straight line west-east towards Toyo rivers, while stations 9 to 15 formed a straight line north-south towards Tahara bays, the distance between the station was approximately 1 km. The position of each sampling station was set with GPS (geo-positioning system). At each phytoplankton sampling station, vertical temperature and salinity profiles were determined with a conductivity temperature depth (CTD) system.

Phytoplankton was sampled at each site by collecting the sea surface water using a plastic bucket of 10 liters as much as 10 times and filtered using a 30 cm diameter conical plankton net (mesh size of 53 µm). The filtered water was collected in the collecting bottle of 50 ml, then transferred to a polyethylene bottle of 30 ml. Macro-zooplankton were removed from phytoplankton water samples using 115 µm mesh nets (Havens et al. 1996).

The phytoplankton samples were preserved in 5% neutral formaldehyde (final concentration) in polyethylene bottles. Concentrated formalin (37-40%), buffered by borax (sodium tetraborate, $Na_2B4O_7.10H_2O$), and was added to a sample to the fixative ratio of 9: 1, using a graduated cylinder or a dosing feeder (i.e., 90 ml sample, 10 ml formaldehyde). Buffering of fixative was prepared a day before sampling takes place by adding 2 g of borax to 98 ml of 40% formaldehyde. The jar was gently rotated to mix the contents repeated several times within 1 h. The samples were stored in a cool room for later phytoplankton identification and counting.

Phytoplankton abundances

Phytoplankton samples were observed with an inverted microscope with phase contrast at 100, 200, or 400 magnifications. Each preserved phytoplankton sample bottle was shaken by flipping through the bottle, taking 1 ml using a pipette, and then gently pouring evenly into Sedgwick-Rafter Slide. About 50 to 100 fields (or more than 100 fields if the abundance was low) were observed, the phytoplankton was identified to species level where possible using taxonomic keys (Yamaji 1991; Tomas 1997) and counted. Cells counting was started from the most abundance then followed the less. Population densities were estimated from the counts as numbers per liter, based on the volume of water sampled by the net and assuming 100% sampling efficiency.

Horizontal distribution of temperature, salinity, and phytoplankton abundances

The salinity and surface temperature data and the density of the phytoplankton horizontally were made contour maps by connecting the location of each sampling station having the same value—the contour patterns were drawn using surfer software with the kriging method. The value of the contours was adjusted to the range of the highest value with the lowest.

RESULTS AND DISCUSSION

Hydrographic conditions

During this investigation, the average temperature at the 1 m surface layer ranged from 23.8oC to 28.1oC; the surface temperature ranged from 22.7°C (26th September) to 28.7°C (29 th August). The horizontal distribution of temperatures at the surface layer on 22nd August showed the highest temperatures were located on the southeast side of the bay, while the lowest was on the northwest side of the bay (Figure 2). The surface temperature is affected by

the weather, the season, offshore input driver runoff from the mainland. The weather condition a few days before sampling was very hot and cloudy. Those conditions indicated a high temperature of the water from the river was distributed to the bay's east side.

On the 29th of August, the surface temperature showed the highest temperature was located in the middle of the bay. Water mass with high temperature shifted to the southwest, while the temperature was gradually decreased on the northwest side of the bay. The weather before the measurement date showed cloudy on 23rd and 24th August, and then rainy on 25th August with accumulated rainfall reaching 50 mm in Toyo and over 150 mm in the upstream area, meanwhile from 26th to 28th August mainly was sunny.

Meanwhile, at the beginning of September, the water mass with high temperature continued to move towards the southwest, so the highest temperature of the surface layer was located on the southwest side of the bay. The surface temperature was gradually decreased toward the river mouth off on the northeast side of the bay. The weather before sampling was sunny on 30th August, then cloudy with a shower on 31st August and 1st September. The influence of typhoon No. 12 was seen from 1st September with increasing wind speed. As the typhoon approached Shikoku Island on 2nd September, the easterly wind started to blow out. Because the typhoon moved very slowly, the strong easterly wind lasted until 5th September. In the Typhoon period, the rainfalls accumulated about 100mm in the middle and lower, and 300mm in the upper Toyo River watershed. The typhoon pushed the surface layer moved to the northeast, so the river runoffs took effect around Toyo River.

The surface water temperature was horizontally homogeneous during sampling on 12 th September. Water conditions were seen turbid up to station 7 off Toyo River, and stations 16 to 18 were observed very turbidly, which was affected by the inflow from Umeda River waters.

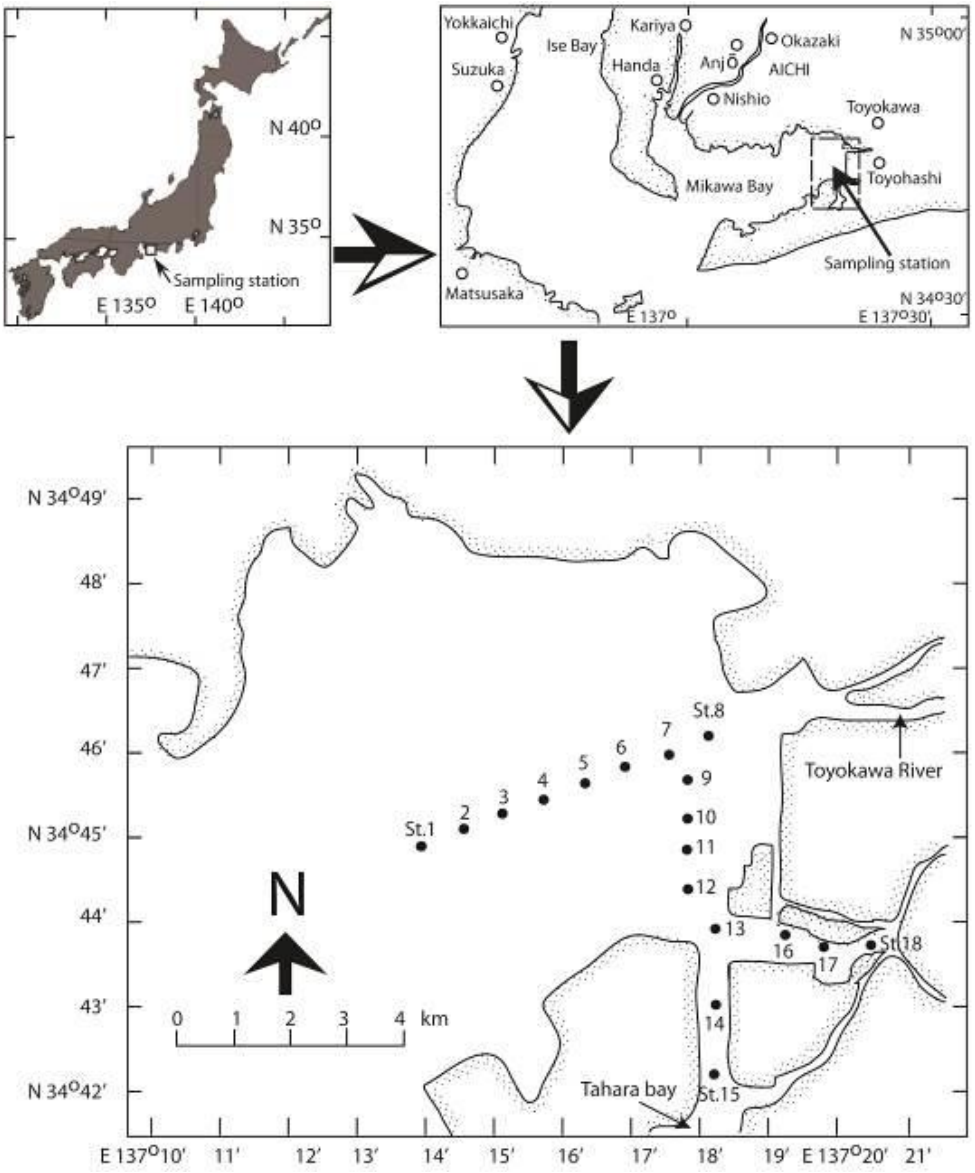

Figure 1. The map showing phytoplankton sampling station from station 1 to st. 18 (dark circle) in Mikawa Bay of Japan

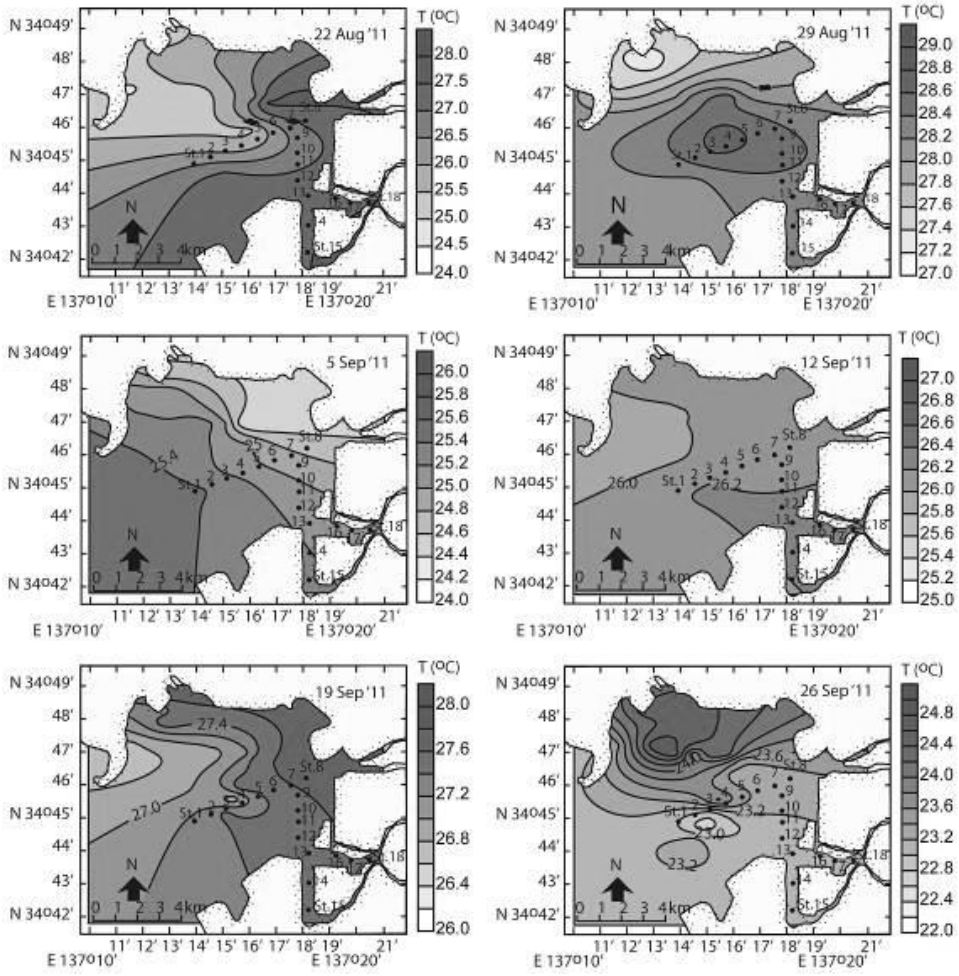

Figure 2. Horizontal structures of temperature (°C) among stations of sampling. Isotherm showed by contour lines.

The surface temperature profile on the 19th of September was relatively almost similar to the temperature on the 22nd of August. The highest temperature was located on the east side, while the lowest was on the west side of the bay. The surface temperature at the off Toyo River mouthwash around 27.8°C, and then to the westward direction was gradually decreased to26.8°C. Higher temperature carried by freshwater river runoff was depressed by the southwest offshore current to the northeast. Meanwhile, the surface temperature profile on 26 September showed the highest on the north side and the lowest on the bay's south side.

The average salinity at the 1 m surface layer ranged from 24.9psu to 28.3psu; the surface salinity ranged from 11.8psu (5th September) to 30.0psu (19th August). The horizontal distribution of salinity at the surface layer on 22nd August showed the highest salinity was located in the southwest, while the lowest was in the northeast, close to the Toyo River mouth (Figure 3). Freshwater from Toyo River was distributed to the narrow area at a northern part of the bay caused by the offshore current. On the other hand, the higher salinity from offshore pushed the freshwater approach to inshore. Hence salinity was drastically decreased in the inshore area.

The surface salinity profile on 29th August showed the highest was 30.0 psu, and the lowest was 23.8 psu. The highest salinity was concentrated in the narrow area in the center of the bay. The salinity from offshore was gradually decreased to the river mouth.

The surface salinity profile on 5th September showed the highest was 31.3psu, and the lowest was 11.8psu, with an average salinity of 28.3psu. The highest salinity was concentrated in the southwestern part of the bay, while the lowest was found in the northeastern part of the bay. The salinity profile showed the salinity was gradually decreased with the narrower isohaline area in the eastern part.

The surface salinity profile on 12 September showed the highest was 29.5psu, the lowest was 26.1psu, and the average salinity was 28.3psu. The difference between the highest and the lowest was 3.4psu. The surface salinity was gradually decreased from the center to the edge of the bay.

The horizontal distribution of salinity profiles on 19 September showed the lowest salinity was 26.8psu, and the highest was 30.5psu, while an average was 29.2psu. The most elevated salinity was located on the north side of the bay, while the lowest was located on the south-eastern side of the bay. High salinity in the north was gradually decreased to the south with the rate of decline of about 0.5psu in each km of distance.

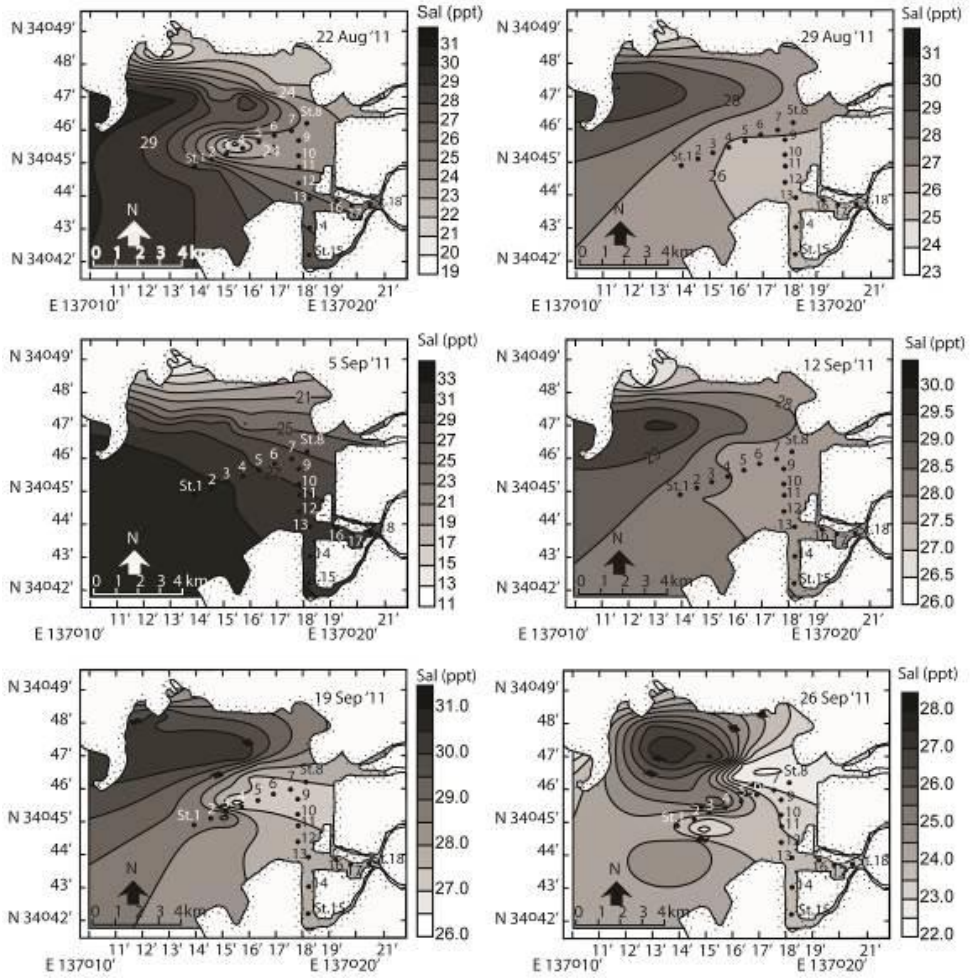

Figure 3. Horizontal profile of salinity (psu) among station of sampling during the study period and contour lines showed isohaline

Phytoplankton abundance

A total of 19 species of Dinophyceae and 12 species of Bacillariophyceae were identified in all samples from Mikawa Bay (Table 1). The most abundant species in Bacillariophyceae was *Chaetoceros* sp(p). (52.2%) followed by *Pseudo-Nitzschia* sp(p). (27,7%), and then *Coscinodiscus* sp (p). (6.3%) of total phytoplankton. Those species were most abundant among the station of sampling. On the other hand, the most abundant in Dinophyceae was *Dinophysis* sp(p). (1.1%) followed by *Ceratium fusus* (0.9%) and then *Ceratium furca* (0.8%), which are most dominant in the off-river mouth.

Phytoplankton distribution

Figure 4 indicates weekly changes in cell densities of phytoplankton at the surface layer in Mikawa Bay from late August to September 2011. During sampling, the phytoplankton population showed the most density occurred on 29th August, followed on 12 September, and the least density occurred on 5th September. The phytoplankton population's density center and contour lines were changed and moved depending on the salinity or temperature profiles or both combinations.

The most density of phytoplankton population on 22nd August was located in the center of the bay, while the least density was found in the northern side of the bay. The phytoplankton density was decreased drastically from the south to the north side of the bay. The contour pattern of phytoplankton population was relatively similar to those of temperature contour pattern, which was decreasing of temperature from station 1 to 5 followed by decreasing of phytoplankton density, and increasing of temperature from station 5 to 7 followed by rising of phytoplankton density, and then dropped afterward both for temperature and phytoplankton density.

The highest phytoplankton density was found in the middle of the bay and then declined in all directions. The most rapid decrease in density was from the middle of the bay to the mouth of the Toyo River, increasing phytoplankton density from station 1 to 7 and decreasing phytoplankton density from station 13 to 18, similar to those for temperature in the same station. However, it was a contrasting condition for the rest stations.

Table 1. The average density of phytoplankton (cell/L) in Mikawa Bay during weekly sampling from mid-August to September. The station number refers to Figure 1.

Species name/ Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**(%)**
Dinophyceae																			
Alexandrium sp(p).	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0,0
A. affine	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0,0
A. tamarensa	0	0	0	0	0	6	0	29	0	0	0	0	0	0	0	0	0	0	0,0
Ceratium sp(p).	188	146	268	147	151	142	140	198	92	79	19	72	38	48	4	6	14	5	0,3
C. furca	295	428	731	503	691	432	186	140	277	124	106	7	6	1	0	0	0	0	0,8
C. fusus	46	42	125	119	219	167	580	1813	378	306	131	441	122	94	72	39	18	10	0,9
Dinophysis sp(p).	40	54	185	302	439	980	414	136	1901	369	149	646	55	8	10	10	0	0	1,1
D. acuminate	0	0	0	0	0	0	0	0	13	19	2	7	1	0	0	0	0	0	0,0
D. caudata	0	0	2	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0,0
D. fortii	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0,0
Gymnodinium sp(p).	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Noctiluca scintillans	2	1	2	1	4	3	5	15	13	5	9	9	18	8	17	23	19	10	0,0
Oxytoxum sp(p).	0	0	0	0	0	0	0	1	0	0	0	7	4	0	0	1	0	0	0,0
Prorocentrum sp(p).	1	0	0	0	0	0	0	0	7	2	0	0	2	0	0	0	0	0	0,0
P. triestinum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Protoperidinium sp(p).	16	12	110	22	38	24	77	100	71	59	20	8	6	5	3	8	13	2	0,1
P. depressum	9	5	8	3	1	11	1	2	11	1	1	21	0	1	0	0	0	0	0,0
Pyrophacus steinii	2	2	1	2	2	3	12	13	5	1	1	4	1	2	2	4	0	0	0,0
Scrippsiella sp(p).	1	1	1	2	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0,0
Bacillariophyceae																			
Actinoptychus senaris	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Chaetoceros sp(p).	26120	35824	14114	34044	40405	36512	1755	1517	1520	3070	3546	2259	13612	22184	21016	6681	942	1101	52,2
Coscinodiscus sp(p).	2180	1916	1657	3271	3104	6108	1335	2107	2654	2180	1207	1577	973	364	321	314	252	92	6,3
Ditylum brightwellii	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0,0
Pseudo-Nitzschia sp(p).	12135	16475	1337	26991	26713	29516	594	166	657	946	906	642	5572	10731	5565	1810	258	211	27,7
Rhizosolenia sp(p).	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,0
R. setigera	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0,0
Skeletonema costatum	2223	63	687	8896	11774	10600	467	398	186	112	278	389	695	6945	2778	459	183	75	9,3
Stephnopyxis palmeriana	6	34	46	4	0	3056	107	53	33	46	16	28	12	2	2	0	1	1	0,7
Thalassionema nitzschioides	55	10	116	57	75	56	3	16	23	185	0	70	1	56	2	1	0	0	0,1
Thalassiosira sp(p).	15	1	1	1	0	0	0	0	0	2	0	0	0	0	0	0	12	9	0,0
Thalassiothrix sp(p).	42	40	63	117	54	49	21	71	122	205	192	253	212	180	93	72	144	126	0,4
Total density	43372	55054	19457	74482	83673	87665	5701	6774	7986	8019	6582	6468	21330	40629	29884	9427	1858	1642	

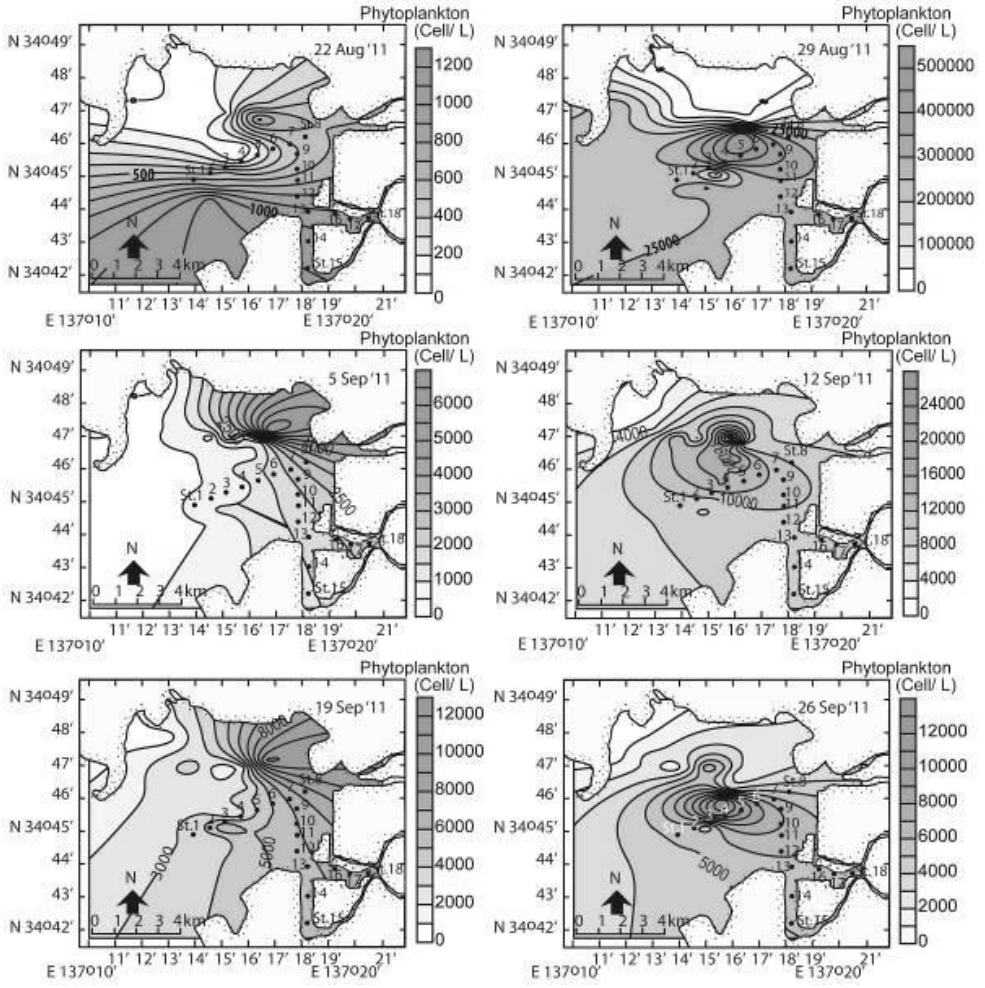

Figure 4. The contour showing the horizontal distribution of phytoplankton during sampling in Mikawa Bay from late Augustus to September

The horizontal distribution of phytoplankton density profile on the 5th of September contrasted with the distribution of phytoplankton in the previous weeks. The higher phytoplankton density was found in the Toyo River mouth and then decreased gradually to offshore. That pattern profile was opposite with the horizontal distribution profile of salinity, which was progressively increased from the river mouth to the offshore direction.

On 12 September, the highest phytoplankton population was concentrated in the center of the bay, and then phytoplankton density gradually decreased in all directions. That distribution profile was similar to the salinity distribution profile but not with temperature profiles because the temperature among stations was relatively the same.

The horizontal distribution of phytoplankton on 19 th September was relatively similar to that on 5th September, the highest population located close to the Toyo River mouth and then decreased to offshore direction. That profile pattern was relatively the same with the temperature distribution; however, rather different with salinity pattern distribution.

The highest population of phytoplankton on 26 th September was located in the center of the bay and then decreased in all directions. That profile pattern was relatively similar to the salinity distribution pattern. However, it was very different with temperature distribution.

The distribution of the dominant species of phytoplankton, namely *Chaetoceros* sp(p), *Pseudo-Nitzschia* sp(p) (27,7%), and *Coscinodiscus* sp(p), was similar to those with the distribution profile of the total phytoplankton. Most of the dominant species were the highest density in the center of the bay and then gradually decreased to all directions.

Discussion

Phytoplankton distribution

Mikawa Bay comprises two bays, namely Atsumi Bay (eastern part) and Chita Bay (northwestern part. It extends to Ise Bay through the Nakayama and Morozaki channels.

Ise Bay is connected to the Pacific Ocean through the Irago channel. These waters are stratified to make two layers of circulation, i.e., outflow in the upper layer and inflow in the lower layer, usually occur from June to September (Matsukawa and Suzuki 1985; Suzuki et al. 1987). Marine water flows into Ise Bay through the bottom layer of the Irago channel. It mixes with the middle-layer water of Ise Bay at the mouth of Mikawa Bay and with inflow to Chita Bay through the lower layer of the Morozaki channel. In contrast, the influx to Atsumi Bay through the Nakayama channel is intercepted in the head region of the Atsumi Peninsula. Therefore, the influence of marine water in Mikawa Bay appears first in Chita Bay, then followed by Atsumi Bay (Suzuki and Hirasawa 1985; Suzuki and Terasawa 1997).

Mikawa Bay is a semi-enclosed bay with a narrow mouth in the west tip and a wide central part restricting the exchange of bay waters. Moreover, the hinterland of Mikawa Bay, a large city, has over 1.5 million. Eutrophication in the inner bay, which has deteriorated due to contamination by pollutants from domestic and industrial wastes, has continued since the1980s (Suzuki and Matsukawa 1987). Since then, harmful algal blooms were frequently occurred in the bay from spring to summer, particularly domination of small diatoms and microflagellates in phytoplankton communities. A massive algal bloom of *Gephyrocapsa oceanica* was firstly developed in Mikawa Bay in April 1996. The bloom was preceded by deviated oceanographic conditions combined with other factors. The water temperatures of the upper and bottom layers before the algae bloom were lower by about 2°C compared to the average of the last five years and almost constant at about 11°C. The concentration of dissolved inorganic nutrient (DIN) was relatively high (3.5-14 µg-at N/l), whereas the concentration of PO_4-P was very low (0.15 < µg-at P/L). The salinity of the upper layer was higher by about 1 psu compared to the average of the last five years. The saltiness of the bottom layer ranged from 31 to 32 psu, which was almost constant and almost the same compared to the average of the last five years (Kai et al. 1999).

Those anomalies in oceanographic conditions were not found during this study. Therefore, the chance of phytoplankton blooming can be ignored. However, the density distribution population of phytoplankton in Mikawa Bay was affected by the distribution of salinity, temperature, and other factors, such as the number of nutrients in the bay and nutrient input from the river runoff (Takahashi et al. 1992; Kai et al. 1999). However, each phytoplankton species requires a specific environmental condition to increase density. In the Yodo River estuary of Osaka Bay, the salinity was played as an ecological factor that controlled the abundance of *Alexandrium tamarense*. The population of *A. tamarense* was the most abundant when salinities were relatively higher than 15 psu, river discharge was low, and the water column was stable (Yamamoto et al., 2013).

Relationship between the phytoplankton distribution and marine environments

Many factors affect algal density, e.g., nutrients, light, wave action, physical and hydrographic conditions, etc. Dinoflagellates usually represent a minor component of microplankton. However, when conditions were right, they could replicate quickly and became the dominant species within 7-10 days (Siu et al. 1997). In this study, the density contour pattern of the phytoplankton population was relatively similar or contrasting against those of temperature or salinity contour pattern, depending on the distribution of temperature and salinity, the combination of both temperature and salinity, or other factors. In the range salinity of 25-28 psu and temperature of 23-27ºC, the increase of both temperature and salinity will be followed by increasing phytoplankton density, while decreasing temperature combines with increasing salinity caused by decreasing of phytoplankton density. At a constant salinity condition among stations, then when the temperature increase will lead to phytoplankton density decreases; otherwise, when the temperature decreases will be followed by increasing in phytoplankton density, vice versa with salinity contour pattern. However, on the temperature and salinity above 25, a stable temperature and salinities were not affected to phytoplankton fluctuated among stations. It appears that when the salinity is more than 28psu and the temperature is less than 25°C, the increasing or decreasing temperature will positively influence the density distribution of phytoplankton.

Temperature and nutrient input from the land appeared to affect population growth in *Chaetoceros*sp(p), *Pseudo-Nitzschia* sp(p), and *Coscinodiscus*; their population was the most dominant among station and sampling. A water temperature of 27-28 ºC promoted the highest density. At the high optimal temperature, the mean maximal phytoplankton reached a cell density of more than 400.000 cells ml L^{-1}, shown for *Alexandrium catenella* (Siu et al. 1997). However, the too high temperature was also unfavorable for population growth. At 30ºC, the maximal capacity, population growth rate, and the mean doubling time of *Alexandrium catenella* were decreased significantly (Siu et al. 1997).

In conclusion, Bacillariophyceae was the most abundant among phytoplankton groups, and the most abundant species in Bacillariophyceae was *Chaetoceros* sp(p), then *Pseudo*-Nitzschiasp(p). and*Coscinodiscus* sp(p). Their density population and distribution was affected by the distribution of salinity, temperature, and other factors, such as the quantity of nutrient in the bay and nutrient input from the river runoff. A water temperature of 27-28 ºC promoted the highest density. Population numbers of *Chaetoceros*sp(p), *Pseudo-Nitzschia* sp(p), and *Coscinodiscus* were the most dominant among station and sampling period, temperature, and nutrient input from the land was the significant effects of population growth of those species.

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Differentiation of soil organisms at different types of peatland in West Kalimantan, Indonesia

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Abstract. *Nusantara RW, Aspan A. 2017. Differentiation of soil organisms at different types of peatland in West Kalimantan, Indonesia. Bonorowo Wetlands 7: 26-30.* Peatland conversion could threaten the soil organisms' existence which is influenced by soil physical properties. This research aimed to analyze the changes in soil organisms of land use due to the conversion of peatlands in West Kalimantan, Indonesia. The study was conducted in secondary peat forest (SPF), shrub (SB), oil palm plantation (OPP), and cornfield (CF) in Kubu Raya District of West Kalimantan. The stages in this study include observation of water-table depth soil temperature and analysis of physical properties, including bulk density, moisture, and porosity. The results indicated a decline in colonies of bacteria and fungi in OPP than SPF, 50% and 53%, respectively. The condition of affected water content decreases due to the land conversion of secondary forests into oil palm plantations (22.8%). Additionally, conditions on the water-table depth were deeper, and soil temperature was higher in OPP than SPF (16.8%). This condition was the opposite in CF, where both bacteria and fungi increased 53% and 33.3%, respectively. The water content, water-table depth, and bulk density were characterized by the different conditions even though the temperature was almost the same between OPP and CF.

Keywords: soil organisms, land-use change, water content, bulk density, water-table depth

INTRODUCTION

The world's tropical peatlands are around 38 million hectares, mostly located in Indonesia (14.9 million hectares) (BBPPSDLP 2011). Peat swamp forest is one type of wetland most endangered in Indonesia due to pressure from human activities. Forest conversion to agricultural land and forest production can threaten the existence of natural peat swamp forests. Activities in the area of cultivation include land clearing, such as the felling of trees (deforestation), slashing the bushes and the burning remnants of vegetation, creation of drainage channels, soil compaction for land preparation and manufacture of ridges (Radjagukguk 2000; Page et al. 2009; Wösten et al. 2008; Hooijer et al. 2010). Peatland degradation occurs through deep drainage and uncontrolled combustion.

Burning the land as a form of accelerated oxidation can result in loss of soil organic matter of peat and leaching of soil nutrients due to increased decomposition of peat and soil micro-organisms death. Temperature between 40-70ºC can lead to the destruction of biological tissue, At the temperature range of 70-90ºC, seeds begin dying, and microbial death occurs between 50-120ºC (Hernandez et al., 1997). Making the edafon land devastated by fire damage (flora and fauna). After the fire activity, the number of bacteria increased in some specific forest land. The increase in activity and the number of soil bacteria, and the growth of legumes encourage nitrification (Notohadoprawiro 2006). On the other hand, another biophysical result of fires is encouraging nitrogen (N) leaching and polluting water bodies with nitrates. Instead of fires no good effect on soil macrofauna, especially earthworms. Earthworms do not like high temperatures and drought-related land with a high temperature (Chandler et al. 1983). Based on differences in soil conditions due to changes in land use. It is necessary to study the details of differentiation of soil biology in several types of peatland due to land-use change. So, with the study expected their efforts for the prevention, mitigation, and recovery to preserve peat awake.

MATERIALS AND METHODS

Study area

The study area was four peatland types, namely secondary peat forest (SPF) (00º21.70' S, 109º21.81' E), shrubs (SB) (00º21.42'S, 109º21.51' E), oil palm plantation (OPP) (00º23.87'S, 109º22.65'E) and corn-field (CF) (00º23.87' S, 109º22.65'E) in Kubu Raya District, West Kalimantan, Indonesia. Soil sampling was conducted in May 2016.

Measurement of water-table depth and soil temperature

At each sampling point, water-table depth was measured by the distance of groundwater to the soil's surface. Soil temperature data were taken using a digital thermometer inserted into the ground.

Soil sampling and sample analysis

Samples were taken from three sampling points at each land location as replication. Peat soil sampling in the

topsoil (0-20 cm). Soil samples were dried aired for approximately one to two days. Then the soil was separated from the roots of plants, gravel, and other debris. After setting up a soil sample with a size of <2 mm and <0.5 mm, the sample was weighed using pulverized and sieved to prepare the soil sample for analysis. Analysis of biological characteristics as the main parameter in total bacteria and fungi using total plate count (TPC). The physical features of the parameters include water content, bulk density, and porosity. Analysis of the contents by weight 'literan' method (tube servings) and soil porosity with the calculation method of BD and BJ. BJ measurements while using a pycnometer, the water content of the difference between wet weight and dry weight of soil.

Data analysis

Regression analysis was carried out using SPSS 2.1 to determine the relationship between the total bacteria and fungi and water-table depth, water content, bulk density, porosity, and temperature.

RESULTS AND DISCUSSION

Biological analysis of soil as the main parameters such as type and total of bacteria and fungi. The physical characteristic of soil as supporting parameters include water content, bulk density, and porosity to the water-table depth and soil temperatures (Table 1 and 2).

The population of bacteria and fungi on the study site varies. In SPF (as a control) has three species of bacteria, respectively of 14 x 10^5 cfu, 2 x 10^5 cfu and 1 x 10^5 cfu. The total of bacterial are highest in the CF, three species of bacteria each 24 x 10^5 cfu, 1 x 10^5 cfu, and 1 x 10^5 cfu, respectively. While OPP is the lowest, the two species of bacteria are 3 x 10^5 cfu and 2 x 10^5 cfu. Similar to the type and total fungi in SPF has two types of fungi (Rhizopus sp. and *Penicillium* sp.) With a total of fungi, each 1 x 10^5 cfu and 5 x 10^5 cfu. The type and number of fungi are the highest in CF with 3 types (Fusarium sp., Rhizopus sp. and *Penicillium* sp.) that each 2 x 10^5 cfu, 5 x 10^5 cfu, and 1 x 10^5 cfu. At the same time, OPP has 1 type (Rhizopus sp.), 1 x 10^5 cfu. The decrease in total bacteria and fungi in OPP than SPF, 50% and 53%, respectively.

The existence and diversity of soil microorganisms are affected by physical conditions such as water table depth and soil temperature. There is a strong negative correlation between the water-table depth and total bacteria and fungi with r between 0.816 and 0.872 (Figure 1a-b). In contrast to the temperature, there is a weak correlation with the total bacteria and fungi (r between 0.074 and 0.151) (Figure 1.C-D).

Table 1. The population of bacteria and fungi at secondary peat forest, shrubs, oil palm plantations, and corn-field in West Kalimantan Peatland, Indonesia

Type of land	Type of bacteria	Total of bacteria (10^5 cfu)	Fungi	Total of fungi (10^5 cfu)
Secondary peat forest (SPF)	Sp 1	14	*Rhizopus*	1
	Sp 2	2	*Penicillium*	5
	Sp 3	1	-	-
Shrubs (SB)	Sp 1	11	*Penicillium*	4
Oil palm plantations (OPP)	Sp 1	3	*Rhizopus*	1
	Sp 2	2	-	-
Corn-field (CF)	Sp 1	24	*Fusarium*	2
	Sp 2	1	*Penicillium*	5
	Sp 3	1	*Aspergillus*	1

Note: Sp 1 = form circular, convex slope, entire edge, white, smooth, shiny surface. Sp 2 = irregular shape, slope raised, undulating edge, white, smooth, shiny surface. Sp3 = circular shape, the slope of the flat, edge entire, transparent color, dull surface.

Table 2. Water-table depth (WTD, water content, bulk density, porosity, and temperature at secondary peat forest, shrubs, oil palm plantations, and corn-field in West Kalimantan Peatland, Indonesia

Type of land	WTD (cm)	Water content (%)	Bulk density (g cm^{-3})	Porosity (%)	Temperature (°C)
Secondary peat forest (SPF)	34.13	90.40±6.60	0.14±0.03	95.78±0.78	22.78
Shrubs (SB)	35.75	41.93±9.05	0.16±0.02	94.90±2.25	27.78
Oil palm plantations (OPP)	41.00	35.56±10.95	0.22±0.04	94.21±2.15	27.22
Corn-field (CF)	29.50	66.88±2.98	0.6±0.02	95.40±0.63	26.44

Water-table depth and temperature on the diversity of soil microbes

The deeper the water-table depth, especially on intensive agricultural, causing microorganism population decline. It is characterized by low water content (Figure 2. A-B) despite a weak positive correlation between the water content and the total bacteria and fungi (r between 0.305 and 0.239). The same research shows Mishra et al. (2016) that variations most influence microbial profiles from peatland sites in water-table and land-use patterns. Oil palm plantation monocultures supported the least diverse bacterial communities. On the other hand, mixed crop plantations consisting of up to only five plant species supported the most diverse bacterial communities. Agree with Hadi et al. (2001) that land conversion from secondary forest to paddy fields (monoculture plantations) led to a decrease in carbon content, together with a decrease in microbial abundance, which is consistent with these findings. This study shows that low bacterial diversity in OPP can be sensitive to environmental pressures.

Soil physical characteristic on the diversity of soil microbes

The physical characteristics of the soil influence the existence of soil organisms. The decline in soil bacteria and fungi in OPP affected water content reduction due to the land conversion of SPF into OPP; however, their relationship is weak (r 0.305 and 0.239) (Figure 2. A-B). The decline marked by the water-table depth in OPP is deeper (16.8%), and the soil temperature is higher (16.3%) (Table 2, Figures 1 and 2). This condition is the opposite in CF, where there is an increase in the total of bacteria and fungi, 53% and 33.3%, respectively. Different conditions are characterized by the shallow water-table depth (13.6%) and the high-water content (12.7%) (Table 2). There is a very weak correlation between the water content and the total bacterial and fungi; r 0.305 and 0.239. There is a strong positive correlation between bulk density, porosity, and a total of bacteria and fungi, r between 0.630, 0.765, 0.584, and 0,496, respectively (Figure 2. C-D and 2. E-F).

Overall findings indicate that CF has the highest of bacteria and fungi. This is likely due to factors of high bulk density (0.6 g cm^{-3}) and moderate water content (66.88%), while other lands such as OPP have a low bulk density (0.22 g cm^{-3}) and water content (35.56%). They are increasing the number of soil microbes in CF allegedly due to land management in regularly burning and fertilizing before planting. Results of interviews with local farmers showed that before corn planting is done, burning vegetation such as shrubs and above-ground plant residues of corn to get ash and fertilizers such as urea, SP36, and KCl. The existence of these additional elements into a source of nutrients and energy for the activity and growth of microbes in the soil. Contrary to Yule et al. (2016), the fire significantly impacted the microbial community composition. Degradation and burning caused a marked decrease in most Acidobacteria, apart from Koribacteraceae. The same explanation by Wasis et al. (2012) that the number of soil microbes decreases after the fire, but expected to happen temporarily and will go back to normal.

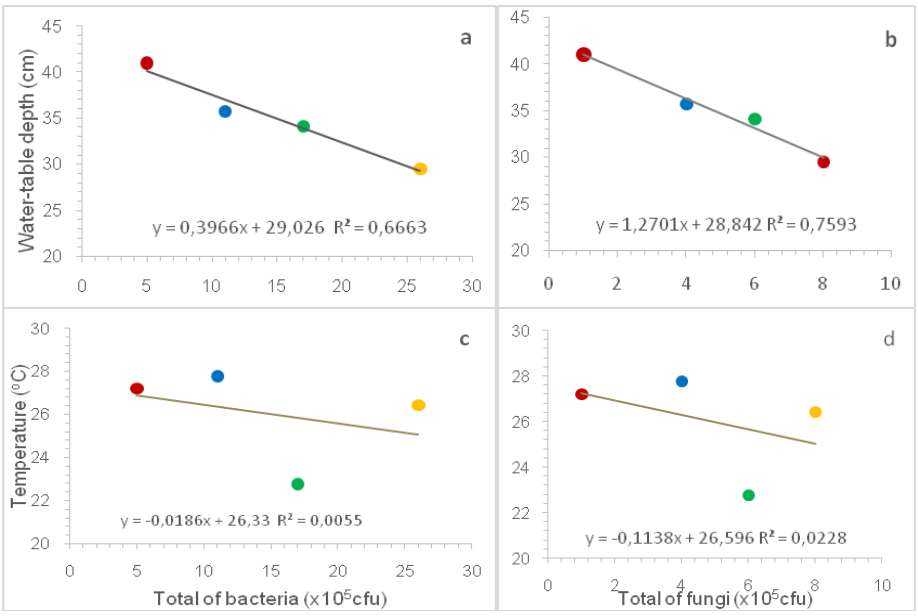

Figure 1. Correlation between the water-table depth (A-B), temperature (C-D) and) and a total of bacteria and fungi of peatland as the effect of land-use change. The green, blue, orange, and red circles show the land of SPF, SB, CF, and OPP, respectively.

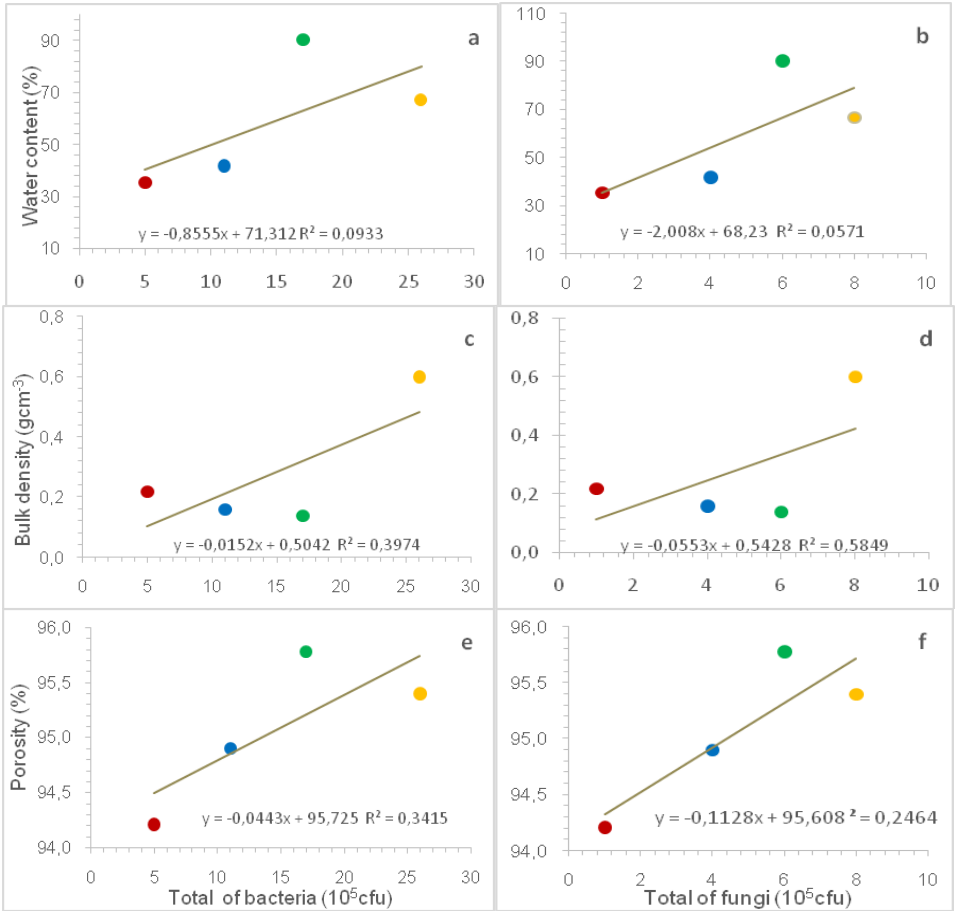

Figure 2. Correlation between water content (A-B), bulk density (C-D), porosity (E-F), and the total of bacteria and fungi of peatland as the effect of land-use change. The green, blue, orange, and red circles show the land of SPF, SB, CF, and OPP, respectively.

Peatland-use change caused changes in soil physical characteristics such as increased bulk density and soil temperature and decreased water-table depth, water content, and porosity. Changes in water content, bulk density, and porosity of the soil were positively correlated, in contrast to water-table depth, to the soil microbes (bacteria and fungi). This study provides baseline information about the microbial diversity in forestry and agricultural landscapes. The data is helpful to highlight the conservation value of those landscapes for microbes.

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Macroinvertebrate diversity role in water quality assessment of Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

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Abstract. *Nugrahaningrum A, Harianja MF, Nugroho H, Soesilohadi RCH. 2017. Macroinvertebrate diversity role in water quality assessment of Winongo and Gajah Wong rivers, Yogyakarta, Indonesia. Bonorowo Wetlands 7: 31-37.* Winongo and Gajah Wong are primary rivers in Yogyakarta Special Region that have important roles for society and surrounding areas; therefore, periodical river monitoring is needed. River monitoring can be conducted by utilizing macroinvertebrate diversity. This research aimed to study macroinvertebrate diversity and analyze both rivers' water quality. Data were collected at the upstream, the middle, and the downstream, 100 m each, by transect method. The diversity and the abundance of macroinvertebrates were analyzed. The results showed that the number of macroinvertebrate families at Winongo was 24, while at Gajah Wong was 26. Based on Shannon-Wiener and Margalef Indexes, the highest diversity was at Winongo upstream, while the lowest was at Gajah Wong middle zone. Based on Similarity Index, Winongo and Gajah Wong middle zones had the most similar diversity. Based on both Family Biotic Index (FBI) and BIOTILIK Index scores, Winongo upstream had good water quality, while Gajah Wong middle zone was severely polluted.

Keywords: Biodiversity, macroinvertebrates, Winongo, Gajah Wong, Yogyakarta

INTRODUCTION

Water is a vital natural resource required in various daily activities. The input of pollutants can pollute water bodies due to activities that cause degradation of water quality and alteration in the community of aquatic organisms (Dudgeon *et al.*, 2005; Giorgio *et al.*, 2016). The river is a freshwater habitat vulnerable to pollution and environmental conversion (Dewi 2013). The river current flow is unidirectional and influenced by physiology, geology, climate, flora, fauna, land use, and human activities (Anzani 2012).

Gajah Wong and Winongo are rivers that are located in Yogyakarta Special Region. The water basin of these rivers is divided into 3 parts, namely, the upstream at Sleman district, the middle zone at Yogyakarta City, and the downstream at Bantul district (Permana 2013). Both rivers have unique values for the surrounding community, as they are utilized in household utilities, home industries, agriculture, and factories. The state of both rivers is highly alarming because they are polluted by household and industry wastes (either organic or non-organic), which in turn causes the water to become degraded and could not be used by the surrounding community (BLH DIY 2015).

The water quality in water bodies can be determined by dissolved substances, suspended substances, and aquatic organisms. A biological indicator is a group or a community of organisms whose presence is associated with the condition of the surrounding environment. Macroinvertebrates usefully are utilized as biological indicators because they have a settled habitat. The composition and abundance of macroinvertebrates depend on their tolerance or sensitivity toward altering the environment. Alteration of water quality in macroinvertebrate habitats can influence their composition and abundance; therefore, they can give a more precise picture of the state of a particular river compared to environmental parameters (Stein *et al.*, 2008).

Water quality monitoring is a means to systematically evaluate the alteration of water body quality through the response of aquatic organisms. Biomonitoring is divided into four components such as the bioassessment study of the structure and function of life community, the toxicity bioassays, i.e., study of pollutant effect on life forms, the behavioral assays, i.e., analysis of the sublethal impact on the tested organism, and bioaccumulation study of the contaminant dosage absorbed by the organism and its impact in the food chain. Biomonitoring is useful for evaluating the impacts of development on aquatic ecosystems by acquiring information about the alteration of biological structure and diversity of a particular water body. The information can be used as a long-term barometer of the success of aquatic environmental management (Komarawidjaja and Titiresmi 2006).

Concerning the importance of periodical water quality monitoring, this research aimed to acquire information about macroinvertebrate abundance at Gajah Wong and Winongo rivers of Yogyakarta, Indonesia, and determine the water quality of both rivers.

MATERIALS AND METHODS

Study area

The study area of this research are Winongo and Gajah Wong Rivers. Both rivers were located across Yogyakarta City, Sleman, and Bantul districts in Yogyakarta Special Region, Indonesia. Near each riverside, there were residential areas. Samples were collected at 6 sample points, each of them representing upstream, middle, and downstream zones (Figure 1 and 2, Table 1).

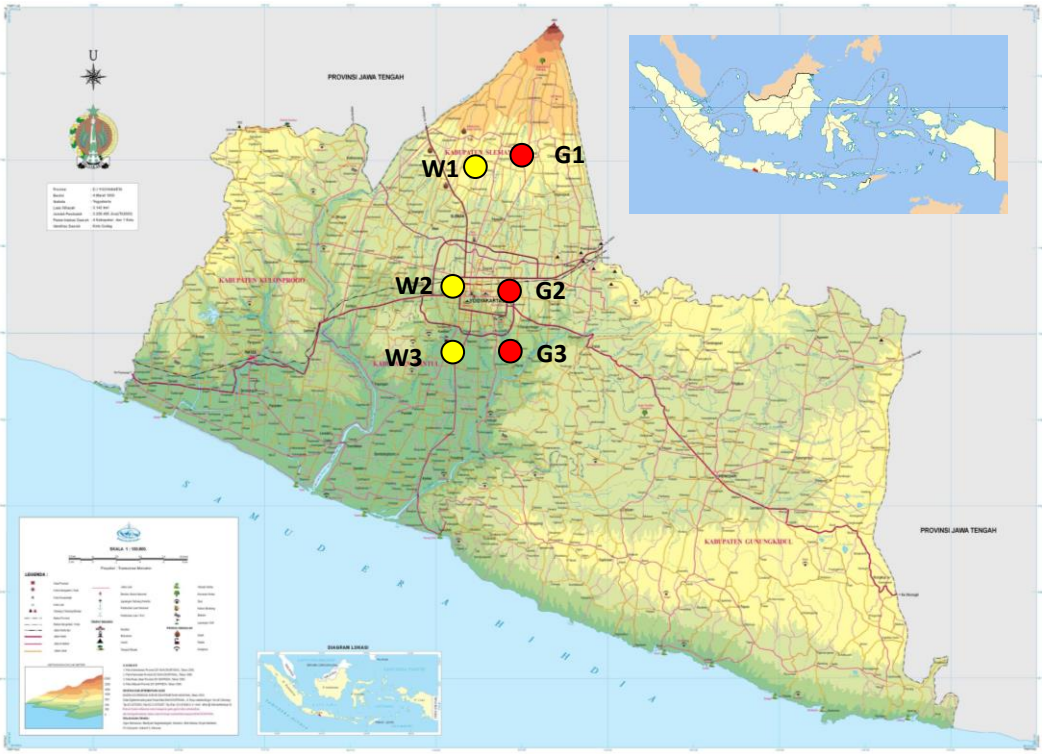
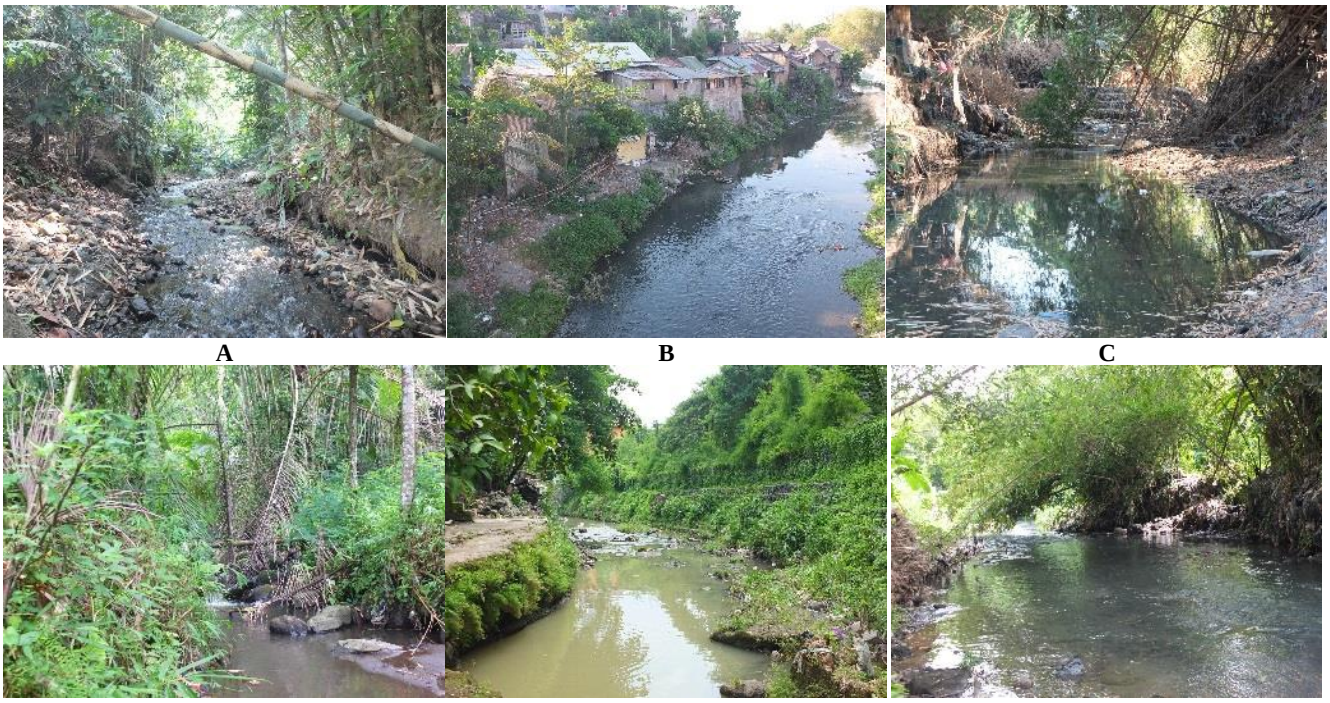


Figure 1.A. Map of Yogyakarta, Indonesia, with six sampling sites. A. W1 (Winongo upstream), B. W2 (Winongo middle), C. W3 (Winongo downstream), D. G1 (Gajah Wong upstream), E. G2 (Gajah Wong middle), F. G3 (Gajah Wong downstream)



A **B** **C**

D **E** **F**

Figure 1.B. Study sites at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia. A. W1 (Winongo upstream), B. W2 (Winongo middle), C. W3 (Winongo downstream), D. G1 (Gajah Wong upstream), E. G2 (Gajah Wong middle), F. G3 (Gajah Wong downstream)

Table 1. Location of six study sites at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

Site	Place	Latitude and Longitude
W1	Winongo upstream	7°38'03.0"S+110°23'14.9"E
W2	Winongo middle	7°48'04.2"S+110°21'16.8"E
W3	Winongo downstream	7°50'25.6"S+110°20'55.0"E
G1	Gajah Wong upstream	7°38'06.8"S+110°25'15.0"E
G2	Gajah Wong middle	7°47'02.4"S+110°23'46.9"E
G3	Gajah Wong downstream	7°50'28.4"S+110°23'46.4"E

Table 2. Ecological status categories for Shannon-Wiener Index

Category	H'
High	>4
Good	3.0-4.0
Moderate	2.0-3.0
Poor	1.0-2.0
Bad	0.0-1.0

Table 3. Degree of pollution based on Family Biotic Index (FBI)

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.75-4.25	Very Good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution is probable
5.01 5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly Poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very Poor	Severe organic pollution likely

Table 4. River water quality assessment based on BIOTILIK Index

Average Scores	Habitat Health Level
2.4-3.0	Healthy, provide diverse and stable habitat conditions to support biotic life.
1.7-2.3	Poorly healthy, provide less variable and less stable habitat to support biotic life.
1.0-1.6	Unhealthy, provide invariable and unstable habitat to support biotic life.

Procedures

Sample collection

This research was conducted in September and October 2015 by the transect method. Macroinvertebrate samples were collected by kick net. The net was put on the river substrate in the opposite direction from the river current. The samples were removed from the net by rubbing off the stones in each plot for 1 minute. The collection was done at 10 plots along 100 meters in each upstream, middle, and downstream zone of the Winongo and Gajah Wong rivers. The current velocity of the rivers was measured at every plot. Samples were placed in flacon bottles and preserved in formaldehyde solution.

Sample analysis

Samples were documented by camera Pro Summer Fuji Film XS 1 and identified by identification books. Samples were enumerated by eyes.

Data analysis

The samples were analyzed using the Diversity Index of Shannon-Wiener, Dominance Index, Evenness Index, Similarity Index of Bray-Curtis, Margalef Index, Family Biotic Index, and BIOTILIK Index.

Diversity Index of Shannon-Wiener (Jost 2010)

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

H': diversity index of Shannon-Wiener, ni: the number of individuals belonging to family i, N: the total number of collected individuals

Dominance Index (Simpson Diversity Index) (Firtiana 2005)

$C = \sum Pi^2$, $Pi = ni/N$

C: dominance index, ni: the number of individuals belonging to family i, N: the total number of collected individuals

Evenness Index (Heip 1974; Heip *et al.* 1998)

$e = H'/H\ max$, $H\ max = \ln S$

e: evenness index, H': Shannon-Wiener index, S: the total number of identified families

Similarity Index of Bray-Curtis (Wolda 1981)

$S_{BC} = \sum 2*\min (n_{1i}, n_{2i}) / \sum n_{1i} + \sum n_{2i}$

S_{BC}: similarity index of Bray-Curtis

n1i: the number of individuals of the ith family in sample 1

n2i: the number of individuals of the ith family in sample 2

min: refers to the lower abundance value for the family of the two samples being compared

Margalef Index (Gamito 2009)

$D_{Mg} = (S-1)/\ln N$

D_{Mg}: Margalef Index, S: the total number of identified families, N: the total number of collected individuals

Family Biotic Index (Rahayu *et al.* 2009)

$FBI = \sum x_i * t_i / n$

FBI=Family Biotic Index

x_i = the number of individuals belonging to family i

t_i = score of tolerance of family i

n = the total number of collected individuals

BIOTILIK Index (Ecoton 2013)

$BI = X/N$, $X = xi*ti$

BI: BIOTILIK Index

x_i = the number of individuals belonging to family i

t_i = score of tolerance of family i

N = the total number of collected individuals

RESULTS AND DISCUSSION

Macroinvertebrate diversity

The highest score of the Shannon-Wiener Diversity Index of macroinvertebrates was 2.412 the upstream of Winongo. The lowest score was 1.205 in the middle of

Gajah Wong. Based on Puente and Diaz (2008), the upstreams of both locations had moderate ecological conditions. Then, the other locations were included in poor environmental conditions because the range of their scores was 1-2.

Based on Margalef Diversity Index, the upstream of Winongo had the highest score, 3.539. Then, the upstream of Gajah Wong had a score of 2.811. The lowest score was in the middle of Gajah Wong, 1.361. The higher the Margalef score, the higher the macroinvertebrate diversity.

The evenness index of Winongo and Gajah Wong's upstreams was high, i.e., around 0.8. It showed that the macroinvertebrate individuals at the upstream were distributed evenly. The lowest scores of evenness index were at the middle and the downstream of Gajah Wong.

Based on figure 3., the highest score of the Simpson index was 0.432 in the middle of Gajah Wong. The second highest score was 0.390 in the middle of Winongo. It showed that there were dominating families in both zones. The similarity index of the middle of Winongo and the middle of Gajah Wong was valued the highest, with more than 50%. It showed that they had similar macroinvertebrate diversity. The other location did not have similar macroinvertebrate diversity.

The correlation value of macroinvertebrate diversity and current velocity was low. The change of current velocity did not directly influence the macroinvertebrate diversity at Winongo and Gajah Wong rivers. Many factors besides current velocity influenced macroinvertebrate diversity.

Based on Family Biotic Index, Winongo upstream had a good status, some organic pollution is probable. The status of Gajah Wong upstream and downstream was fair. Then, the other locations had very poor water quality. Based on the BIOTILIK index, upstreams of Winongo and Gajah Wong were included in slightly polluted water. The middle of Winongo and the downstream of Gajah Wong had fairly polluted water. Then, the middle of Gajah Wong and the downstream of Winongo had heavily polluted water.

Table 1. Macroinvertebrate family at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

Group	Taxa	Number of individuals					
		W1	W2	W3	G1	G2	G3
Ephemeroptera	Baetidae	2	0	0	6	0	0
	Caenidae	0	0	0	11	0	0
	Heptageniidae	12	0	0	0	0	0
	Leptophlebiidae	11	0	0	0	0	0
	Polymitarcyidae	0	0	0	22	0	0
Plecoptera	Chloroperlidae	3	0	0	0	0	0
	Perlidae	4	0	0	0	0	0
Trichoptera	Brachycentridae	1	0	0	0	0	0
	Goeridae	0	0	0	2	0	0
	Hydropsychidae	1	4	1	0	2	58
	Leptoceridae	1	0	0	0	0	0
	Philopotamidae	3	0	0	0	0	0
	Polycentropodidae	0	0	0	1	0	0
Cerithioidea	Pleuroceridae	27	4	25	10	0	2
Diptera	Chironomidae	1	64	38	18	107	2
	Simuliidae	1	0	0	0	0	0
	Tipulidae	0	0	0	1	0	0
Decapoda	Atyidae	0	0	4	0	0	0
	Palaemonidae	15	0	0	21	0	0
	Parathelphusidae	2	1	0	3	0	2
Hemiptera	Corixidae	5	0	26	0	1	1
	Mesoveliidae	0	0	0	1	0	0
	Veliidae	14	0	0	4	0	0
	Nepidae	0	0	0	1	0	0
Hirudinea		0	29	2	0	0	1
Megaloptera	Sialidae	0	1	0	0	0	0
Odonata	Coenagrionidae	0	0	0	0	0	1
	Euphaeidae	4	0	0	0	0	0
	Gomphidae	0	0	0	1	0	0
	Libellulidae	0	0	0	0	7	0
Pulmonata	Lymnaeidae	0	0	0	0	6	0
Pulmonata	Physidae	0	3	1	0	0	0
Rhynchobdellida	Glossiphoniidae	0	10	5	0	8	0
Sorbeoconcha	Thiaridae	15	0	0	0	6	43
Tubificina	Tubificidae	0	0	4	0	9	0
Veneroida	Corbiculidae	0	0	0	0	0	3
Viviparoidea	Viviparidae	0	0	0	0	0	2

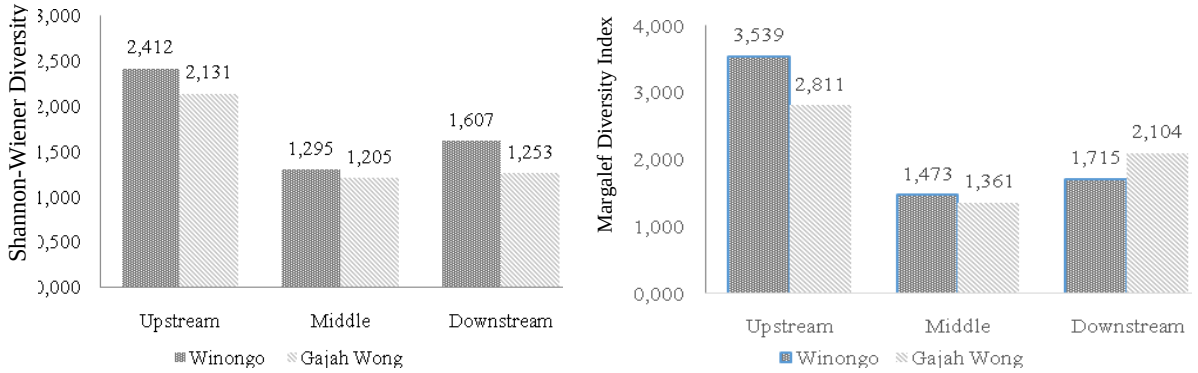


Figure 1. Macroinvertebrate diversity at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

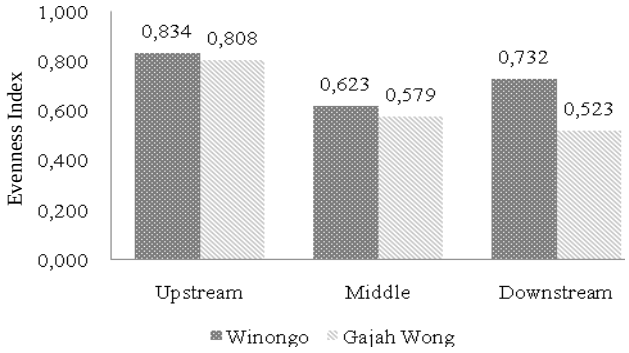


Figure 2. Evenness of macroinvertebrate at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

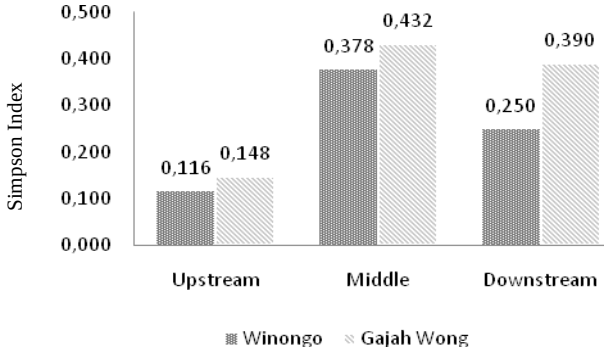


Figure 3. Dominance of macroinvertebrate at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

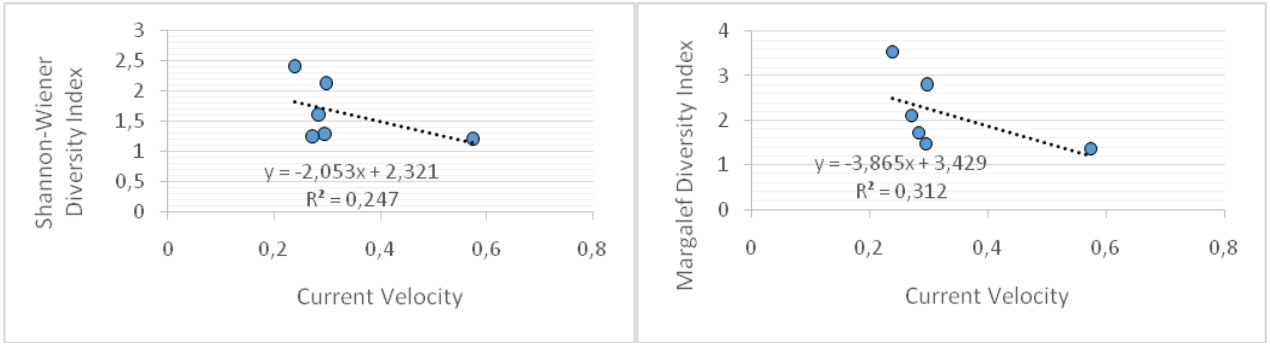


Figure 4. Correlation between current velocity and macroinvertebrate diversity

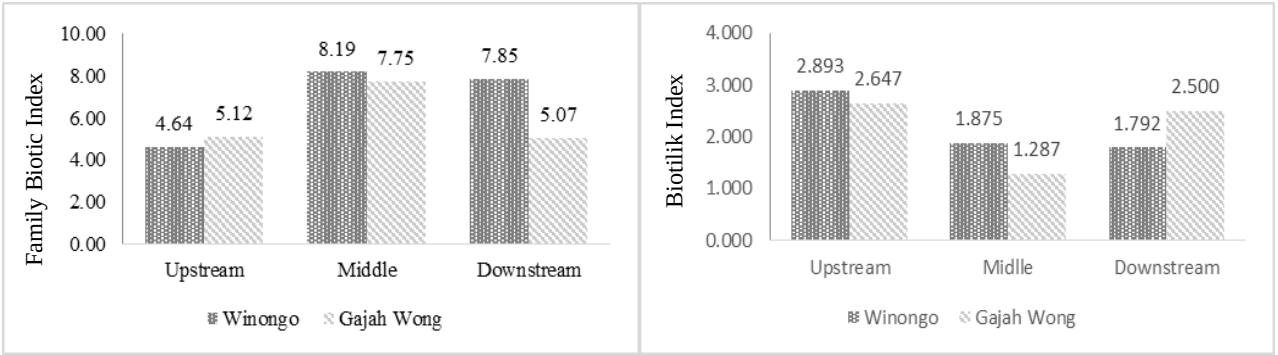


Figure 5. Water quality based on macroinvertebrate diversity at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

Table 2. Similarity and dissimilarity of macroinvertebrate at Winongo and Gajah Wong rivers, Yogyakarta, Indonesia

		Dissimilarity Index					
		Winongo			**Gajah Wong**		
		Upstream	Middle	Downstream	Upstream	Middle	Downstream
Similarity Index	**Winongo**						
	Upstream	0	94.12	71.93	69.64	89.76	81.51
	Middle	5.88	0	54.05	78.9	47.04	90.52
	Downstream	28.07	45.95	0	73.08	64.62	92.79
	Gajah Wong						
	Upstream	30.36	21.1	26.92	0	86.81	94.5
	Middle	10.24	**52.96**	35.38	13.19	0	87.46
	Downstream	18.49	9.48	7.21	5.5	12.54	0

Discussion

Based on Shannon-Wiener and Margalef diversity indexes, Winongo upstream had the highest score. Winongo upstream consisted of 18 families of macroinvertebrates. Nine of those families, which belong to Ephemeroptera, Plecoptera, and Trichoptera (EPT) orders, were intolerant and tolerant to a slight amount of pollutants. The intolerant members were Heptageniidae, Leptophlebiidae, Perlidae, Chloroperlidae, Philopotamidae, and Brachycentridae, while the semi tolerant ones were Baetidae, Leptoceridae, and Hydropsychidae (Rahayu *et al*. 2009; Ecoton 2013; Blakely *et al.* 2014). The other families were Euphaeidae, Vellidae, Palaemonidae, Corixidae, Pleuroceridae, Thiaridae, Simulidae, Parathelpusidae, and Chironomidae. The highest score of evenness index was 0.834, and the lowest of dominance index was 0.116. It suggests that there were no dominating families.

The river was shallow and clear, with the substrate composed of sand and rocks. Riverbank was dominated by thorny palm and bamboo plantations. Based on the Family Biotic Index score, Winongo upstream had good water quality with a probability of some organic pollution. Based on the BIOTILIK index, its water quality was slightly polluted. There is not any record of pollutant sources at Winongo upstream yet. The pollutant could be from a thorny palm plantation based on the observation.

Gajah Wong upstream had the second-highest score of Shannon-Wiener diversity, i.e., 2.131. It suggests that the macroinvertebrate diversity of Gajah Wong and Winongo upstreams was the same. They both had moderate ecological conditions (Puente and Diaz 2008). That score also suggests fair diversity and productivity status, fairly balanced ecosystem conditions, and fair ecological pressures (Fitriana 2005).

Macroinvertebrate diversity consisted of 14 families, 5 families belonging to EPT orders, and 8 Non-EPT families. The EPT members were Baetidae, Caenidae, Goeridae, Polymitarcyidae, and Polycentropodidae. Individuals belonging to Polymitarcyidae were the most commonly found. The evenness of the families was high, although the dominance score was low. A shallow and clear water body with a substrate composed of sand and rocks was suitable as a habitat for Polymitarcyidae. Polymitarcyidae burrows in rivers under rocks (Bouchard 2004) or sand. At this station, Gomphidae, Vellidae, Mesoveliidae, Tipulidae, Palaemonidae, and Nepidae families were not significantly tolerant to pollutants. Tolerant families were Chironomidae, Parathelpusidae, and Pleuroceridae (Rahayu *et al.* 2009; Ecoton 2013; Blakely *et al.* 2014).

Based on the FBI score, Gajah Wong upstream had fair water quality, which suggests fairly substantial pollution likely, while based on BIOTILIK score, it was slightly polluted. Pollutant sources have not been officially recorded by the environmental institution of the Yogyakarta Special Region. Physically, it was contaminated by the household wastes such as plastic bags. The water body was shallow and clear. Riverbank was in the form of mahogany and thorny palm plantation. There was much water drop from the stone gaps. Rock oxidation level in this area was adequately high.

The diversity status of macroinvertebrates at Winongo and Gajah Wong middle zone was poor ecologically (Puente and Diaz, 2008). Found 8 families at both locations. Families found dominantly were Chironomidae and Glossiphoniidae. Both families were tolerant of pollutants. Chironomidae was the most dominating family at both locations (Rahayu *et al.*, 2009; Blakely *et al.*, 2014).

The water quality of both middle zones was severely polluted. Based on the data provided by the environmental institution of Yogyakarta Special Region year 2015, the pollutants that get into the water bodies at the middle zones result from several sources, such as hospitals, local governmental clinics, maternity hospitals, environmental and health laboratories, metal industries, leather industries, food industries, automotive industries, *batik* fabric industries, print shops, gas stations, laundries, hotels, malls, and restaurants.

The high pollution level caused the presence of organic nutrients abundantly for Chironomidae (Armitage *et al.* 1995). Besides, competitors and predators were in small numbers in polluted water bodies.

Winongo and Gajah Wong's middle zones produced a foul odor. Winongo's middle zone was composed of rocks, while Gajah Wong's middle zone was sand and clay. Sand and clay were suitable for habitats of dragonfly nymphs; therefore, they were found in a pretty great number.

At Winongo downstream, found 9 families with 1 family belonging to EPT, i.e., Hydropsychidae, and 8 other families were non-EPT, i.e., Pleuroceridae, Chironomidae, Hirudinidae, Physidae, Glossiphoniidae, Tubificidae, Corixidae, and Atyidae. Individuals belonging to

Chironomidae were found most abundant. While Gajah Wong downstream had higher diversity, i.e., 11 families with 1 family of EPT, i.e., Hydropsychidae, and 10 family non-EPT, i.e., Thiaridae, Pleuroceridae, Corbiculidae, Viviparidae, Chironomidae, Coenagrionidae, Glossiphoniidae, Corixidae, Hirudinidae, and Parathelpusidae. Hydropsychidae and Thiaridae were found most abundant. Based on the Evenness Index, families found at Winongo downstream were distributed more evenly than Gajah Wong downstream. Based on Dominance Index, Winongo downstream had a lower score than Gajah Wong downstream. It suggests that family evenness at Winongo downstream was higher, and there was no dominating family. While at Gajah Wong downstream, it suggests low family evenness, and there were two dominating families, i.e., Hydropsychidae and Thiaridae.

High diversity is correlated to ecosystem health (Barbour *et al*. 1999). EPT is a macroinvertebrate group whose presence is limited by pollution and the embeddedness of rocks, which cause the macroinvertebrate habitat to become narrower (Spellman and Drinan 2001). The substrate at both river upstreams was dominated by sand and rocks, but the only EPT member found was Hydropsychidae. At Gajah Wong downstream, Hydropsychidae individuals were found abundantly but less at Winongo downstream. It suggests that the water body condition at Winongo downstream was relatively polluted. FBI score of Winongo downstream was high, i.e., 7.85, which means very poor water quality, while FBI score of Gajah Wong downstream was 5.07, which suggests fair water quality. Based on BIOTILIK Index, the score of Winongo downstream was 1.792, which means poorly healthy water quality, while the score of Gajah Wong downstream was 2.5, which suggests healthy water quality.

Pollutant sources in downstream areas, based on the data by Badan Lingkungan Hidup or environmental institution of Yogyakarta Special Region year 2015, consisted of hospitals, environmental and health laboratories, metal industries, leather industries, sugar industries, noodle industries, textile industries, alcohol industries, cow husbandries, slaughterhouses, fish canning industries, tofu industries, *tempeh* industries, *batik* fabric industries, automotive industries, print shops, gas stations, car wash industries, pharmacies, hotels, and restaurants.

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The density, composition and mangrove forest habitat in coastal areas of Torosiaje Jaya Village, Gorontalo, Indonesia

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Abstract. *Rahim S, Baderan DWK, Hamidun MS. 2017. The density, composition and mangrove forest habitat in coastal areas of Torosiaje Jaya Village, Gorontalo, Indonesia. Bonorowo Wetlands 7: 38-42.* The mangrove ecosystem is quite good, located in Torosiaje Jaya Village of Popayato Subdistrict, Pohuwato District, Gorontalo Province, Indonesia. This is because the beach in the coastal of Torosiaje Jaya Village is gently sloping; this beach has deposited sediment. A promontory grave is formed that causes the mangrove in that region to grow large and relatively fertile. In addition, the mangrove, which is located in Pohuwato, has relatively high various species. One of them is found from the Avicenniaceae family, namely the *Avicennia marina (*Forsk.) Vierh. This study aims to (i) obtain the information about the density of the mangrove; (ii) to determine the composition of mangrove species in coastal areas of Torosiaje Jaya Village; and (iii) to know the habitat of the species which is found in coastal areas Torosiaje Jaya Village. Besides, the data were collected by purposive sampling. Moreover, for measuring density, distribution type, diameter trees, and mangrove vegetation height, use a distance method (*Point-Centered Quarter Method*). Further, the composition types of views are based on the number of species found. To obtain the data of the habitat conditions of the species discovered using direct observation in the field by a tree and laboratory test sample originating from soil samples in the study sites. Moreover, this study finds the four tree species that dominate the mangrove in Torosiaje Jaya Village. They are *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Rhizophora apiculata*, and *Rhizophora stylosa* with a density value of 51.55 trees/3 ha with an average distance of 581.94 m/tree. *B. gymnorrhiza* and *R. mucronata* dominate in the region due to supply mud as a suitable habitat for its growth; besides, the substrate of mangroves in the Torosiaje Jaya Village is also affected by salinity and temperature. Further, the data obtained can be used to manage mangrove forests located in the coastal of Torosiaje Jaya Village. They can also be data in mangrove conservation efforts to reduce the effects of global warming.

Keywords: Composition, density, habitat, mangrove forests

INTRODUCTION

Mangrove forests have a role in mitigating climate change due to global warming. They can reduce CO_2 through the sequestration mechanism that carbon sequestration from the atmosphere and storage in several compartments such as vegetation, litter, and soil organic matter (Hairiah and Rahayu 2007). Through photosynthesis, the mangrove plants absorb carbon dioxide from the atmosphere and are converted into organic carbon distributed to all body parts and stored in the biomass plant. According to Nugraha (2011), about 50% of tree biomass is carbon.

One of the mangrove areas in Indonesia is in the coastal region of Gorontalo Province, Torosiaje Jaya Village of Pohuwato region. Pohuwato is a famous green belt of mangrove and coastal ecosystems where the mangrove is broad enough to stretch from the District of Paguat until Popayato District of West. Mangrove areas have contained in Pohuwato relatively high species diversity. One of the mangrove species found, among others, from the family Avicenniaceae, namely *Avicennia marina* (Forsk.) Vierh. According to Dharmawan and Siregar (2008), *A. marina* is one of the mangrove species that can absorb and store carbon because of the habitat characteristic of wetlands with muddy soil types.

Based on the results of interpretation of *Landsa*t imagery reported by Damanik (2012), the mangrove area Pohuwato has undergone significant changes, which in 1988 reached the mangrove area of 13243.33 hectares, in 2010 the remaining 7420.73 ha. The damage to the mangrove forests in the coastal Torosiaje Jaya Village impacts other Tomini bay ecosystem conditions such as Togean Islands National Park in Tojo Una-Una, Central Sulawesi Province. By reducing the coastal mangrove area in Torosiaje Jaya Village cause of carbon in the atmosphere cannot be absorbed and stored in plant biomass optimally. This further confirms the need for a precautionary measure to damage that occurred in the coastal mangrove Torosiaje Jaya Village needs to be immediately addressed through the information on the density, composition, and habitat of mangrove forests. The findings of this research may serve as a database for mangrove forest conservation management purposes in Torosiaje and other regions and for addressing global warming and climate change issues.

MATERIALS AND METHODS

Study area

The study area is located in the coastal areas of mangrove forest Torosiaje Jaya Village, Popayato Subdistrict, Pohuwato District, Gorontalo Province, Indonesia (N 0º 28' 45" E, 121º26' 15"). The geographical position of the study area is presented on the map (Figure 1).

Methods

The method used in this research is using the quadrant method or P-CQM (Point Centered Quarter Method). Each plant is contained in the quadrant, recorded the species' name (as seen by recognition by the research team and mangrove identification books (Tomlinson 1986; Giesen et al. 2006). The tree's diameter is measured based on diameter at breast height (dbh) of 1.3 m above the ground or above the buttresses. In contrast, the total tree height is calculated from the above buttress without counting the canopy.

The stages will be undertaken in this study are: (i) The preparation phase, covering: observation, setting up data collection methods, and preparing the equipment used for data collection in the field. (ii) The data collection stage includes determining the density of vegetation.

To determine the density of the vegetation at the study site, created transect lines perpendicular to the shoreline landward by determining the point of observation or sampling point along the transect. At every point of measurement is made abscissa and imaginary ordinate line, so that at each measurement point there are four quadrants: I, II, III, and IV. Select one of the trees in each quadrant located closest to the end of a benchmark tree and measure the distance from each tree to the tree point benchmark.

Each plant is contained in the quadrant and recorded the species' name. The tree's diameter is measured based on diameter at breast height (dbh) of 1.3 m above the ground or above the buttresses. In contrast, the total tree height is calculated from the above buttress without counting the canopy; furthermore, in calculating the density of the wood. Mangrove species that cannot be identified in the field were taken, for instance, leaves, fruits, and flowers to be made herbarium and further identified in the Laboratory of Botany, Universitas Negeri Gorontalo, Indonesia. In addition to data mangrove species, also measured the temperature, salinity, soil pH, and moisture.

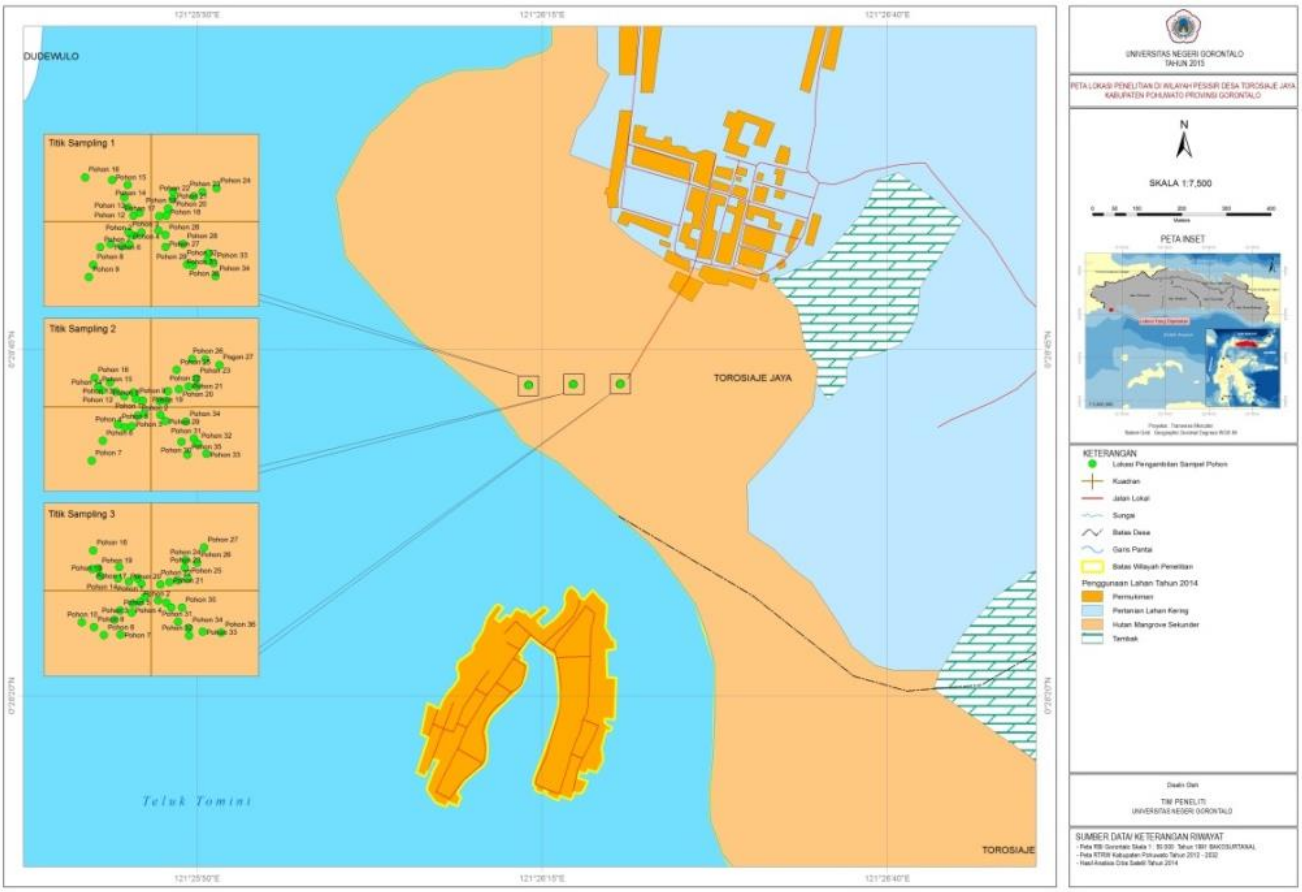

Figure 1. The study site in the coastal region of Torosiaje Jaya Village, Gorontalo, Indonesia

Data analysis

Density

To calculate the density, calculated the average distance of each individual tree with the following formula (Indriyanto 2010):

The distance of the average individual tree to tree points benchmark (d):

$$d = \frac{d1+d2+d3+\cdots+dn}{n} \quad (1)$$

Where:

d1, d2, d3, ..., dn = distance of each tree to the point of measurement

n = number of trees

d = average distance of individual trees to the measuring point

The density of all species per hectare (K)

To calculate the density of all types of trees using the following formula (Indriyanto 2010):

$$k = \frac{\text{Area}}{(\text{average distance of tree})^2} \quad (2)$$

Volume of trees

The volume of trees is the content or the magnitude of a sample obtained from the width and height of the sample. Tree volume calculated using the formula Brown (1997):

$$V = ¼.\pi.d^2.t.f \quad (3)$$

Where:

V = volume of trees (m^3)

π = constant (3.14)

d = diameter of tree height chest (cm)

t = total height (m), and

f = figures tree form (0.6)

Composition type

Composition kind is calculated based on the number of mangrove species are found.

Habitat

The research used descriptive analysis towards the habitat analysis obtained from the soil sample analysis done in the laboratory. The laboratory examination included soil texture (sand, silt, and clay). In addition, the research also covered temperature, humidity, and salinity aspects, which are significant factors in the development of mangroves.

RESULTS AND DISCUSSION

Results

Density, the density of all species per hectare, and tree volume

The density of trees in the Torosiaje Jaya Village indicates a density value of 51.55 trees/3 ha with an average distance of 581.94 m/tree. All species density values were presented in (Table 1)

Composition type

In Table 2, it can be argued that in the mangrove forest Torosiaje Jaya Village number of species found little that four types,i.e., *Bruguiera gymnorrhiza, Rhizophora mucronata*, *Rhizophora apiculata*, dan *Rhizophora stylosa*, of trees 36 individual per 300 m^2 with an average distance of 581,94 (trees/3 ha). The number of trees in sampling points 300 m^2 in the village of Mangrove Forests Torosiaje Jaya, Gorontalo, Indonesia, is presented in Table 2 below.

Habitat for mangrove species

Texture, detritus, and pH are the dominant factors that affect the development of mangroves. Mangrove soil is alluvial, which is brought and sedimented by the river and seawater. Alluvial can be classified as sand, silt, and clay. It is these three components that form soil in different compositions. Mud is composed of silt and clay, which are rich in detritus.

The analysis conducted at the Laboratory of PG Tolangohula and the site investigation revealed that the habitat of the species found in Torosiaje for Sampling Point 1, *Bruguiera gymnorrhiza* is in the habitat which contains sand (0%), silt (61.0-62.1%), and clay (38.9-39.0%). Sampling Point 2, *Rhizophora mucronata* contains sand (0%), silt (62.5-69.7%), and clay (30.8-37.5%). Sampling Point 3, the habitat of *Rhizophora stylosa* contains sand (0%), silt (52.0%), and clay (47.0%). The habitat of *Rhizophora apiculate* contains sand (0%), silt (33.4%), and clay (67.0%). The temperature at Sampling Point 1 for *Bruguiera gymnorrhiza* ranges between 31.5-31.8^{0}C, its salinity is between 21.6 ppt – 22.1 ppt and its humidity level is between 84.8-85%. At Sampling Point 2, the temperature for *Rhizophora mucronata* ranges between 31-31.5^{0}C, its salinity is between 21.8-22.1 ppt, and its humidity level is between 85-86%. At the Sampling Point 3, the temperature for *Rhizophora apiculate* ranges between 30-30.5^{0}C, its salinity is between 21.2-21.8 ppt, and its humidity level is between 86.5-87%; the temperature for *Bruguiera gymnorrhiza* is 30^{0}C, its salinity is 20.5 ppt, and its humidity level is 87%; the temperature for *Rhizophora stylosa* is 30.5^{0}C, its salinity is 201 ppt, and its humidity level is 86.5%; and the temperature for *Rhizophora mucronata* is between 30-30.2^{0}C, its salinity is between 20-20.5 ppt, and its humidity is 87%.

Discussion

The data density of trees in the village of Torosiaje Jaya shows that sampling point 3, 2, and 1 has the highest density. This is evidenced, with 36 trees found at sampling point 3, *Bruguiera gymnorrhiza is* the dominant species, 35 trees for sampling point 2 with dominant species *Rhizophora mucronata*, and found 34 trees for one sampling point with the dominant species *Rhizophora stylosa*. These species were classified as dominant as they are the dominant species found at the research site and had the widest distribution over the site.

Table 1. Density value, the density of all species per hectare, and tree volume at the research site

Species names	TS	Quadrant	NP	JP (m)	DP (cm)	VP (m^3)
B.gymnorrhiza	1	I	1	8	82	2,566.68
B.gymnorrhiza			2	12	86	2,826.5
B.gymnorrhiza			3	14	92	3,638.98
B.gymnorrhiza			4	18	102	4,473.06
B.gymnorrhiza			5	21	82	2,248.47
B.gymnorrhiza			6	26	108	4,457.58
B.gymnorrhiza			7	33	83	1,974.55
B.gymnorrhiza			8	42	85	2,416
B.gymnorrhiza			9	49	74	1,831.15
B.gymnorrhiza		II	10	8	72	1,485.86
B.gymnorrhiza			11	10	68	1,104.46
B.gymnorrhiza			12	16	82	1,927.26
B.gymnorrhiza			13	21	86	2,826.5
B.gymnorrhiza			14	26	72	1,485.86
B.gymnorrhiza			15	35	92	2,830.32
B.gymnorrhiza			16	47	68	1,104.46
B.gymnorrhiza		III	17	5	72	1,485.86
B.gymnorrhiza			18	7	82	2,248.47
B.gymnorrhiza			19	12	85	2,761.15
B.gymnorrhiza			20	18	65	1,009.16
B.gymnorrhiza			21	22	82	2,248.47
B.gymnorrhiza			22	29	93	3,305.35
B.gymnorrhiza			23	35	100	3,821.66
B.gymnorrhiza			24	44	120	6,191.08
B.gymnorrhiza		IV	25	6	75	1,612.26
B.gymnorrhiza			26	11	72	1,485.86
B.gymnorrhiza			27	17	82	2,248.47
B.gymnorrhiza			28	23	65	1,009.16
B.gymnorrhiza			29	32	83	2,303.65
B.gymnorrhiza			30	34	68	1,104.46
B.gymnorrhiza			31	37	72	1,485.86
B.gymnorrhiza			32	40	64	978.34
B.gymnorrhiza			33	43	89	2,648.74
B.gymnorrhiza			34	49	93	3,305.35
R. mucronata	2	I	1	5	68	1,104.46
R. mucronata			2	8	84	2,022.42
R. mucronata			3	16	82	1,927.26
R. mucronata			4	19	65	1,009.16
R. mucronata			5	21	98	3,670.32
R. mucronata			6	35	74	1,569.55
R. mucronata			7	48	95	3,880.18
R. mucronata		II	8	6	68	1,325.35
R. mucronata			9	9	75	1,880.97
R. mucronata			10	12	81	2,193.96
R. mucronata			11	17	72	1,485.86
R. mucronata			12	22	103	4,054.39
R. mucronata			13	28	102	4,473.06
R. mucronata			14	30	82	1,927.26
R. mucronata			15	33	96	3,081.78
R. mucronata			16	37	99	3,277.4
R. mucronata		III	17	5	68	1,104.46
R. mucronata			18	9	69	1,137.18
R. mucronata			19	13	74	1,569.55
R. mucronata			20	19	78	1,743.82
R. mucronata			21	24	68	1,104.46
R. mucronata			22	28	75	1,612.26
R. mucronata			23	31	82	1,927.26
R. mucronata			24	42	86	2,119.87
R. mucronata			25	26	96	3,522.04
R. mucronata			26	37	106	3,757.26
R. mucronata			27	45	116	5.785.22
R. mucronata		IV	28	7	98	3,211.53
R. mucronata			29	11	64	978.34
R. mucronata			30	26	102	3,976.05
R. mucronata			31	30	68	1,104.46
R. mucronata			32	33	76	1,655.54
R. mucronata			33	42	69	1,364.62
R. mucronata			34	22	74	1,569.55
R. mucronata			35	35	82	1,927.26
R. mucronata	3	I	1	5	69	1,364.62
R. mucronata			2	9	69	1,137.18
R. mucronata			3	13	72	1,485.86
R. mucronata			4	17	74	1,569.55
R. mucronata			5	22	86	2,473.18
B.gymnorrhiza			6	28	88	2,589.55
B.gymnorrhiza			7	32	65	1,210.99
R. apiculata			8	38	66	1,040.45
R. apiculata			9	40	74	1,569.55
R. apiculata			10	45	96	3,522.04
R. stylosa		II	11	7	64	978.34
R. stylosa			12	11	85	2,070.86
R. stylosa			13	13	96	3,522.04
R. stylosa			14	20	103	4,054.39
R. stylosa			15	23	112	5,393.12
R. stylosa			16	42	96	3,522.04
R. mucronata			17	37	92	2,830.32
R. mucronata			18	31	88	2,219.62
R. mucronata			19	34	102	4,473.06
R. apiculata		III	20	5	72	1,485.86
R. apiculata			21	11	68	1,104.46
R. apiculata			22	18	66	1,248.54
R. apiculata			23	24	89	3,027.13
R. apiculata			24	26	102	4,473.06
R. stylosa			25	21	115	5,.685.91
R. stylosa			26	31	92	3,234.65
R. stylosa			27	39	96	3,522.04
B.gymnorrhiza		IV	28	6	65	1,009.16
B.gymnorrhiza			29	10	86	2,119.87
B.gymnorrhiza			30	15	72	1,485.86
R. stylosa			31	24	68	1,325.35
R. stylosa			32	34	72	1,485.86
R. stylosa			33	38	86	2,119.87
R. mucronata			34	30	102	4,473.06
R. mucronata			35	21	64	978.34
R. mucronata			36	48	121	8.392.93
The mean distance of tree (m^2)					581,94	
The density of all species/ha					51,55	

Notes: TS: Sampling Point, Np: Tree Number, Jp: Tree Distance, Dp: Tree Distance, Vp: Tree Volume

Table 2. The number of trees in sampling points 300 m^2 in Mangrove Forests Torosiaje Jaya, Gorontalo, Indonesia.

Location	Number of species	Number of trees
Side point 1	1	34
Side point 2	1	35
Side point 3	4	36

Data showed that the dominant species found in each Sampling Point possessed the highest adaptation skills towards their habitats for survival purposes. The species composition of coastal mangrove forests Torosiaje Jaya Village found four species of *Bruguiera gymnorrhiza*,

namely, *Rhizophora mucronata*, *Rhizophora apiculata*, *Rhizophora stylosa*.

Salinity, substrate, and temperature affect mangrove density and species composition. Salinity affects the growth and density of mangroves, based on further research towards the sea, the salinity or salt content of the higher places. Mangrove is not a plant that needs salt, but mangrove is a plant tolerant of salt. This is in line with the opinions by Hutahaean et al. (1999), which examined the mineral elements needed for the growth of mangrove plants are the macro elements such as N, P, S, K, Ca, and Mg and microelements consisting of Zn, Mn, and Cu. Based on these results, the elements Na and Cl are not needed for the growth of mangrove plants. If the salt content on the site is too high, the growth will be stunted mangrove. According to Hutahaean et al. (1999) that the range of salinity for *Rhizophora mucronata* is 12-30 ppt. Based on the results of research that salinity in coastal areas Torosiaje Jaya Village for 21.5 to 22 ppt of *Rhizophora mucronata.* Species, a species that is from 21.5 to 22 ppt of *Bruguiera gymnorrhiza*, *Rhizophora stylosa* species are 20 to 21.5 ppt. Therefore, the coastal of Torosiaje Jaya Village is a coastal region that can support the growth of three species of mangrove dominance.

Various types of mangroves overcome salinity levels in different ways. Rhizophora, for instance, secretes excess salt through the glands under its leaves to overcome high salinity. The absorbed water has almost become fresh water, with 90-97% of salt content in seawater being unable to pass through this root filter. Salt from the plant body was accumulated in the old leaves and wasted along with fall leaves. Mangrove vegetation should seek to maintain water because of the difficulty in obtaining fresh water.

In addition to salinity, density substrate also affects the mangroves. The substrate is generally composed of sand, clay, and dust. Based on the laboratory analysis results, soil dominant mangrove species Bruguiera gymnorrhiza is a land with a <5% sand, dust from 61.1 to 75.3%, and 17.1 to 47.9% clay. According to Indah et al. (2008), this ground, including clayey loam soil, is dominated by a blend of silt and clay that causes the formation of good texture. That is why the substrate in this region is classified as good and supports the growth of various mangrove species found in the research site.

Based on observations of air temperature at the study site ranged from 30-31.8ºC. At the point of observation that high temperature caused by sunlight is still hindered by the mangrove canopy cover so that the temperature becomes lower. Temperatures in the coastal mangrove forests Torosiaje Jaya Village is the range of temperature that supports mangrove growth. This is confirmed by Kusmana (2010) states that if the temperature is higher than 35ºC, it will have an unfavorable influence on the process of photosynthesis, so that the process of mangrove growth will be hampered.

In conclusion, the value density types of mangrove forests in the coastal regions of Torosiaje Jaya Village for the entire species is 51.55 trees/ha with an average distance of 581.94 m/tree. The species composition of coastal mangrove forests of Torosiaje Jaya Village found four species, namely *Bruguiera gymnorrhiza*, *Rhizophora mucronata*, *Rhizophora apiculata*, and *Rhizophora stylosa*. Mangrove density and species composition in an area are influenced by several factors: salinity, substrate, and temperature. Habitat that affects the growth of mangrove species on the coast of Torosiaje village is mangrove soil which contains sand (<5%), dust (61.1-75.3%), and clay (17.1-47.9%). The soil includes clay because dust and clay form a good texture. Therefore, the substrate found on this coast is classified as good and can support the growth of various mangrove species found in the research site.

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Carbon storage potential of mangrove forest in Guyana

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Abstract. *Jaikishun S, Ansari AA, DaSilva P, Hosen A. 2017. Carbon storage potential of mangrove forest in Guyana. Bonorowo Wetlands 7: 43-54.* This research was carried out to estimate carbon storage in the three protected species at study sites located in Berbice (Regions 5 and 6), Demerara (Regions 3 and 4), and Essequibo (Regions 1 and 2), Guyana during the period 2014-16. The research focused on quantification of aboveground biomass and the respective carbon storage of mangroves species in Guyana**,** determination of the amount of carbon stored in the mangrove soil, prediction of the future carbon storage capacity in mangrove species, and justification on the importance of conservation and restoration of mangrove forests towards climate mitigation in Guyana. The results from all the regions of Guyana indicate that the two species (*R. mangle* and *A. germinans*) have greater aboveground carbon stock capacity (481 Mg/ha), which can absorb carbon dioxide released from various sources within Guyana. The total forest coverage of Guyana is 18.570.000 ha containing over 5 gigatonnes of CO_2 in aboveground biomass. Mangrove total coverage in Guyana is 22632.4 ha and locked 0.09gt estimated above-ground carbon, equivalent to 0.257 gigatonnes of CO_2. This is significant, considering the low stature, coverage, and density of mangroves. The phenomenon of global warming has recently generated interest in understanding the carbon stock capacity of mangrove species. The results of this study support mangrove reforestation and afforestation in the coastal zones of Guyana. The present study led to understanding the carbon stored in the mangrove forest and its relevance to carbon dioxide trapping in the standing forest. Such a relationship establishes the holistic approach to mangrove restoration and climate change prevention strategy for Guyana.

Keywords: Mangroves, carbon storage, climate mitigation, conservation

INTRODUCTION

Mangroves are coastland forests at the interface between land and sea. They are highly dynamic ecosystems composed of littoral species of trees, shrubs, and ferns. Some mangrove forests also include the palm *Nypa fruticans* Wurmb. They tolerate and provide habitat for many species of other organisms and provide significant services to human communities worldwide (Fanshaw 1952; Li and Lee 1997; Richards 1998; Spalding et al. 2010).

According to Balsco et al. (1998), mangrove forests can be described or categorized based on four main criteria: ecosystem, plant species, land type, and locality. Based on ecosystems, mangroves can be defined mainly as littoral halophytes that are uniquely adapted to survive in conditions with varying salinities. Except for the palm *Nypa fruticans* and the fern *Acrostichum aureum* L., mangroves are all woody dicotyledonous trees and shrubs (Richards 1998). They are mainly evergreen trees with thickly cutinized leaves and shed them all year round (Fanshaw 1952; Tomlinson 1978).

Protecting our pristine rainforest is essential to fight against climate change, as forest deforestation and degradation result in about 17% of global greenhouse gas emissions. Mangroves play a vital function in preventing and reducing coastal erosion and provide nearby communities with protection against the effects of the wind, waves, and water currents. Almost 86% of Guyana's land space is covered with a tropical rainforest that is still untouched (NDULP 2013). While more focus is placed on the rainforest, and rightly so because of its coverage, mangroves are also critically important in the Low Carbon Development Strategy (LCDS) because of their high productivity rate. This means that mangroves occupying only about 0.2% of forest coverage can fix many carbons in their tissues through photosynthesis (NDULP 2013). In addition to the high productivity of mangroves, there is evidence that high levels of carbon are deposited in soil sediments.

Mangrove forests are one of the primary natural resources of the coastlines throughout the tropical and subtropical regions of the world. Mangroves are indicated by the presence of trees that mainly occur in the intertidal zone, between land and sea, sedimentation, and tidal currents (Aksornkoea 1993; Nagelkerken et al. 2008). High-resolution satellite images were used to calculate Guyana's coastal zone forest area from 2004 to 2009. The results indicated that coastal zone forest is 22,632 ha of mangroves (Figure 1), with region one having the highest coverage of 10,161 ha or 44.90 % of 22,632 ha of mangroves. This area is less than previous coastal zone forest estimates as reported by FAO in 1990, which was 91,000 ha and 80,432 ha (NLUP 2013; NMMAP 2010; GFC 2011).

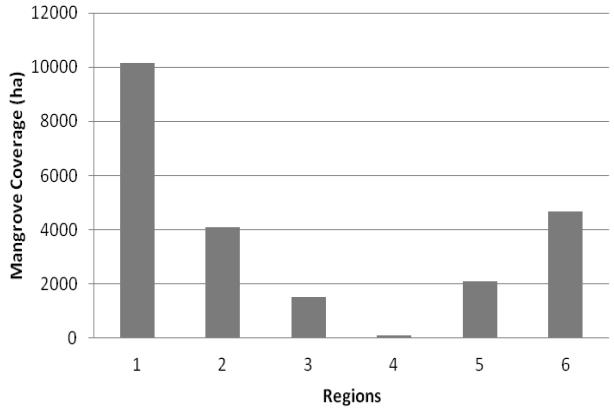

Figure 1. Regional distribution of mangroves in Guyana (GFC 2011)

Five mangrove species are found along most of the coastlines of Guyana, with main stands between the Pomeroon and Waini Rivers to the west, which represents the largest untouched mangrove forest in the country. Other areas with mangrove stands are located on the northern coast of Wakenaan and Leguan Islands and in Hogg Island. These are *Avicennia germinans* (L) Stearn, *Avicennia schaueriana* Stapf & Leechman ex Moldenke, *Conocarpus erectus* L., *Languncularia racemosa* (L) Gaertn. and *Rhizophora mangle* (Ellison et al. 2010, Fanshaw 1952, Hussein 1990*)*. This research focused on the biomass carbon of the two most dominant species, *A. germinans*, and *R. mangle***.**

Among the least studied ecosystem services of mangroves is their importance as global carbon stock. The carbon stored within the mangrove forest ecosystem has started to take significant economic value, as seen with the emergence of carbon markets. Its economic value arises from the knowledge that CO_2, a significant greenhouse gas, is sequestered by forest ecosystems, including mangrove forests, thus reducing the effects of global climate change (Barbier *et al.* 2011; Alongi 2008; Bouillon et al. 2008). The mangroves trap and fix atmospheric carbon dioxide into organic compounds in their biomass through the process of primary production (Bouillon et al., 2008). Many studies have shown that the mangrove ecosystem is a vital carbon sink (Bouillon et al., 2009). The comparatively high aboveground biomass carbon and carbon-rich soils resulted in large ecosystem carbon stocks compared to other tropical forests (Donato et al., 2011). Komiyama et al. (2008) reported mangrove aboveground biomass carbon ranges from 20 to 230 Mg ha^{-1} in the Pacific region, while Donato et al. (2011) reported the estimated aboveground biomass carbon in Palau was estimated aboveground biomass carbon 257 Mg ha^{-1}. Siikkamki et al. (2012) disclosed that the global estimated aboveground biomass carbon is 147 Mg ha^{-1} in the mangrove forest. A study in Soloman Islands by Albert et al. (2012) also revealed that the aboveground mangrove component contained 190-430 Mg C ha^{-1}. These data represented higher carbon storage capacity than most of the other hardwood forests, which have estimated aboveground biomass carbon in the range of 38-90 Mg ha^{-1} (Brown 2002). The net carbon sink of the terrestrial ecosystem is controlled by the net effect of land-use practices (agriculture, deforestation, and degradation), the indirect effects of human activities, and the changing climate, climatic variation, and disturbances (Brown 2002). From all indications, the estimated aboveground biomass carbon varies based on environmental conditions (McLeod and Salm 2006).

Mangroves play an integral role in our ecosystem and the livelihood of man. Mangrove forest ecosystems fulfill many essential functions and offer a wide range of services at the local and national levels. Fishers, farmers, and other rural populations depend on mangroves as a supply of wood (e.g., charcoal, fuelwood, timber, poles, posts) and non-wood forest products (food, thatch, fodder, alcohol, sugar, medicine, and honey). Mangroves are also used to produce tannins suitable for the leather industry (FAO 2007). Mangrove forests provide many ecological services such as protecting coasts from storm surges, sediment trapping, and production of wood, fish, and shellfish (Watson 1928; Hamilton and Snedaker 1984; Ewel et al. 1998). Mangroves support the conservation of biological diversity by providing flourishing habitats, spawning grounds, nurseries, and nutrients for several animals. Mangroves play a critical role in protecting the coastal zone by breaking the force of the wind. In addition, they also provide many other ecological services. However, with the current trend in rising global temperature, mangroves can also be an important sink for carbon by reducing the concentration of carbon dioxide in the atmosphere and lowering the global temperature (Kridiborworn et al., 2,012). Mangroves are known to have high productivity (Spalding et al. 2010) and can, therefore, sequester carbon. Global estimates indicated the mangrove forests could fix about 17 metric tons of carbon/hectare/year (NMMAP 2010).

However, no comprehensive study was done to ascertain the amount of carbon stored in the mangrove forest in Guyana. This research is intended to estimate carbon storage in the three protected species and quantify the carbon and other physicochemical properties of the soil in the mangrove forest in Guyana, and hence; justify the restoration of mangrove forests along the coast. It will also help quantify the carbon stored in the mangrove forest and help to create an understanding and relevance between the carbon and carbon dioxide trapped in the standing forest. Developing such a relationship will foster the whole concept of mangrove restoration and protection and their importance to our daily existence.

MATERIALS AND METHODS

Study area

The study sites were located in Fringe Forest and Riverine Forest of Berbice (Regions 5 and 6), Demerara (Regions 3 and 4) and Essequibo (Regions 1 and 2). These sites include: (i) Essequibo: *Region 1*: Mora Passage (N070 09.8 951 W 0580 20.5 621) {Plate 1} and Shell Beach (N100 22.6 671 W056027. 1 231) {Plate 2}; *Region 2:*

Better Hope (N060 23.7 801 W0570 13.2 661) {Plate 3}. (ii) Demerara: *Region 3:* Kashidhaam (N060 50.4 60 ^{1}W0580 15.6 07^{1}) {Plate 4}; *Region 4:* Coven John (N 090 13.6 42^{1} W 0590 32.2 751) {Plate 5}. (iii) Berbice: *Region 5*: (N06^{0} 36.7 99^{1} W57^{0} 36.18^{1}) {Plate 6}; *Region 6:* Borlam (N06^{0} 23.78^{1} W057^{0} 14.176^{1}) {Plate 7}.

Methods

In this study, belt transects with a length of 140 x 14 m running from the inland boundary of the mangroves and going out into the shore were demarcated (Figure 2. A). This was further subdivided into smaller squared plots measuring 14 x 14 m each, resulting in ten (10) plots in the entire transects (Figure 2. B). From these ten plots, three plots were selected using a random number table for carbon assessment (Brown 1997). This was repeated for the other regions to select the required three plots for the different study areas.

Aboveground trees

Diameter at breast height (1.3 meters aboveground)) and a total height of all mangrove tree species was measured as follows:

Diameter at breast height. All mangrove trees within the plot were measured and recorded based on species type and categorized into diameter classes of >5-10 cm, >10-20 cm, >20-30 cm, >30-40 cm, and >40 cm. The following procedure was adopted for determining the DBH of the mangrove trees in the plots: (Pearson et al. 2005): (i) staff was selected and cut to the height of 1.3m. This was used to quickly measure the 1.3m height requirement from the base of the tree to the point of measurement of DBH (Figure 4 (a)-(h)), (ii) The hook of the DBH tape was then inserted into the bark of the tree at the 1.3m point and then pulled to the right. The DBH tape should always start left and be pulled tight around the tree. (iii) As the DBH tape is wrapped around the tree and returned to the hook, the tape should come above the hook where the measurement is recorded. (iv) If the tree is on a slope, measure breast height on the uphill side. (v) If the tree is leaning, the DBH tape must be wrapped according to the natural angle of the tree, not straight across parallel to the ground. (vi) If the tree is forked at DBH, measure just below the fork point. If it is impossible to measure below the fork, measure as two trees. (vii) If a tree has fallen over but is still alive, place the measuring stick at the bottom and measure at DBH as if the tree was standing upright. Trees were considered alive based on the presence of green leaves.

Tree height. Tree height was determined using a TruPulse 7005025 Laser Technology 200 Laser Range Finders. The data collected were then inserted into the regression equation already developed for mangrove species to determine the estimated biomass of the trees (Chave et al., 2005).

Aboveground non-trees

Harvesting techniques measured aboveground non-tree vegetation. For herbaceous plants, a 30 x 30cm square sample frame made from PVC pipe is sufficient for sampling. Use larger frames for shrubs and other large non-tree vegetation (1m^{2} or 2m^{2}). All vegetation within the frame to ground level was clipped. The structure was viewed as extending vertically, and any vegetation falling outside the boundaries of the plot (even if it began inside the plot) would be excluded. The sample was weighed, and a well-mixed subsample was removed to determine the dry-to-wet mass ratio. The subsample was weighed in the field, then oven-dried to a constant mass (usually at 70°C).

Forest floors (litter)

The forest floor (or litter) is all dead organic surface material on top of the mineral soil. Some of this material was recognizable (e.g., dead leaves, twigs, dead grasses, and small branches), and some were unidentifiable, decomposed fragments of organic material. Note that the litter layer will include a deadwood diameter of >10cm. Litter was sampled at least once every month to eliminate seasonal effects. A 30 x 30cm square sample frame made from PVC pipe is sufficient for sampling. (i) All litter inside the frame was collected and placed on a tarpaulin next to the frame. Subsamples were oven-dried to constant weight at 70°C. (ii) Where the sample bulk was excessive (above 0.5kg), the fresh weight of the total sample was recorded in the field, and a subsample of a manageable size (approximately 80 to 100g) will be taken. This was oven-dried to constant weight (usually at 70°C).

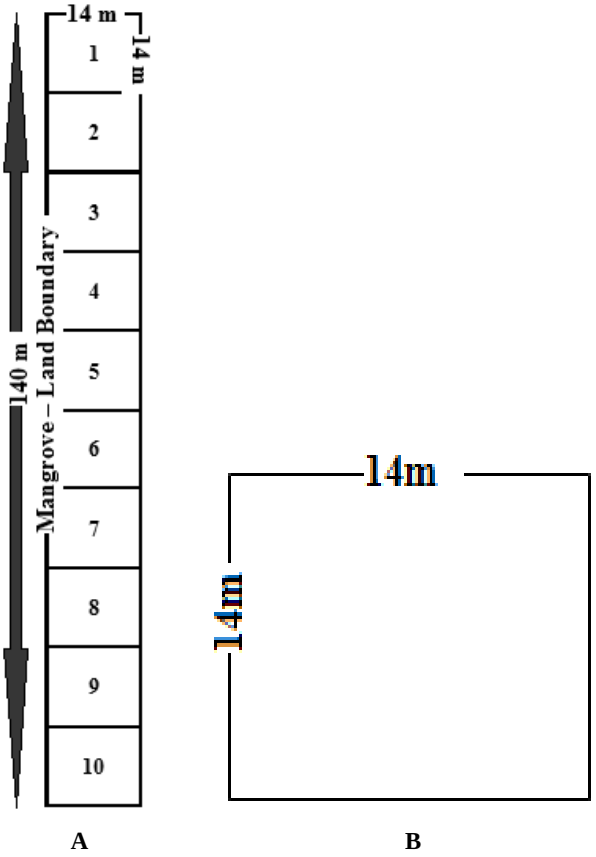

Figure 2. An outlay of study sites. A. Belt transect. B. Quadrate

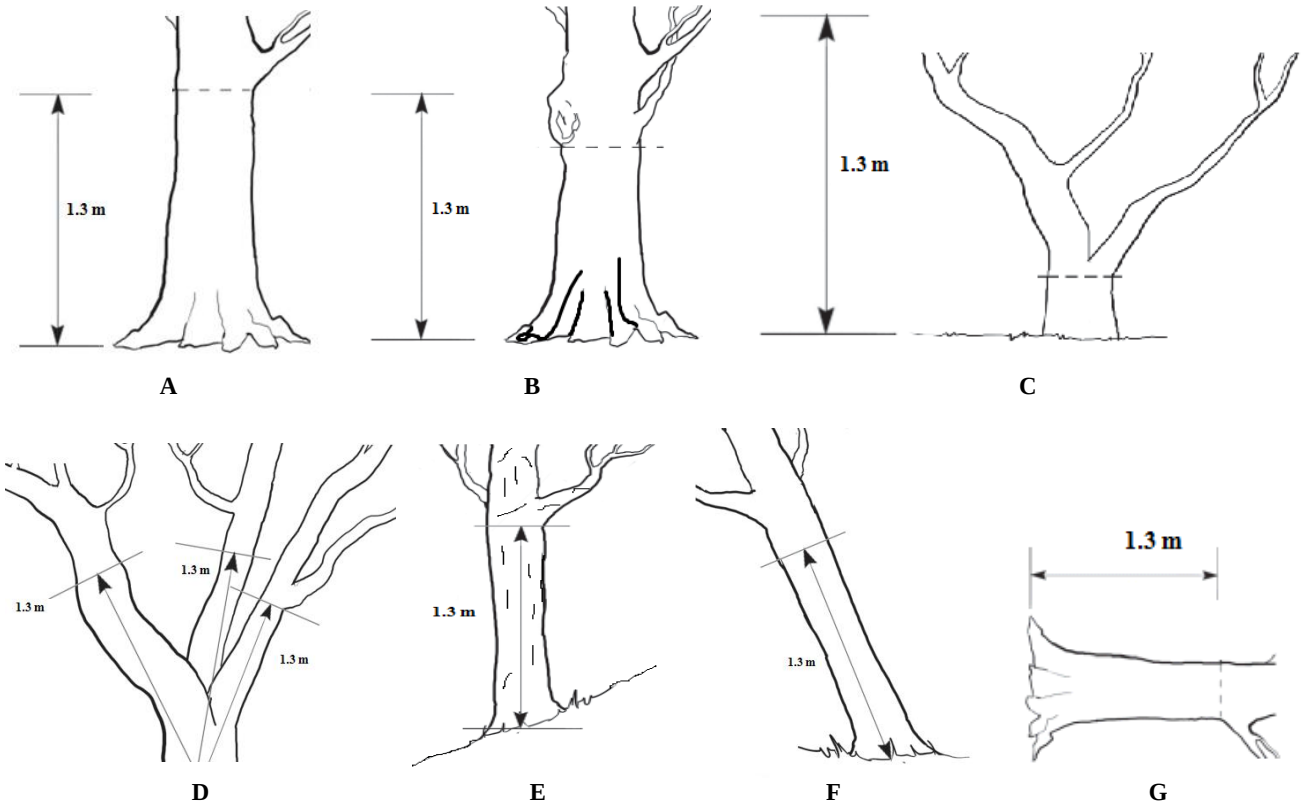

Figure 4. A. Tree with a single straight trunk, B. Tree with branches or uneven (bumps) surface, C. A tree that forked below the 1.3 m, D. A tree with several branches just above the ground, E. A tree growing vertically on a slope, F. A slanted tree on a slope, G. A tree that has fallen over but is still alive

Destructive analyses

During the research, three mangrove species *Avicennia germinans, Languncularia racemosa,* and *Rhizophora mangle* each, with the average DBH, would be destructively harvested to determine the aboveground and belowground biomass. This would determine the accuracy and assess the validity of the regression equation used in the calculations.

One each mature *Avicennia germinans, Languncularia racemosa,* and *Rhizophora mangle* tree species to be destructively analyzed would be identified and felled from each of the sites. The trees would then be divided into leaves, branches, stems, and, where possible, aboveground roots.

Each component's total harvested fresh mass would be measured in the field, and representative subsamples would be moved to the laboratory, where they would be oven-dried to constant mass at 80 ^{0} C. The sub-sample dry mass of each component would be calculated from the dry mass ratio to fresh-weight of the corresponding subsamples (Clough and Scott 1989; Tam et al. 1995; Cairns et al. 2003; Lasco et al. 2006).

Soil carbon

To obtain an accurate record of organic carbon stocks in mineral or organic soil, three types of variables will be measured: (i) Depth (ii) Bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material). (iii) The concentrations of organic carbon within the sample. (ii) The soil probe was inserted to a 30cm depth. The probe was carefully extracted and the sample placed into a bag. (iii) Prepared soil samples were analyzed by laboratories at GuySuCo for soil carbon determination, bulk density, and total soil carbon using the Walkley-Black method.

RESULTS AND DISCUSSION

Aboveground tree carbon

Data were collected from sampling plots set up in six coastal regions of Guyana (2014-16). These include Region 1 (Barima-Waini), Region 2 (Pomeroon-Supenaam), Region 3 (Essequibo Islands-West Demerara), Region 4 (Demerara-Mahaica), Region 5 (Mahaica-Berbice), and Region 6 (East Berbice Corentyne). These coastal regions have a varying degree of mangrove forest coverage that

makes up the 0.2 % of the 88 % of the total forest coverage of Guyana. The areas sampled consist of fringe and riverine forest types (Lugo and Snedaker 1974; NLUP 2013).

Fringe Forest

The fringe forest exists along the periphery of the shoreline and islands where the shoreline elevations are higher than the mean high tide. This forest type experiences low tidal velocities. However, Mangroves are affected by strong winds, resulting in immense physical damage and accumulation of wastes and debris that can cover the root system leading to death (Carolina et al. 2006; Lugo and Snedaker 1974).

Region 1: Barima-Waini

Barima-Waini is located northwest of Guyana. This region is heavily forested with a total land coverage of 20,339 km² with 24,275 people (Census 2002). The northern and northeastern sections include thousands of acres of rich alluvial soil. The region borders the Atlantic Ocean to the north, the region of Pomeroon-Supenaam to the east, the region of Cuyuni-Mazaruni to the south, and Venezuela to the west (Macmillan 2009; Census 2002).

This region has the highest mangrove coverage in the country. The study area was Iron Point (located along the bank of the Waini River. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots for each site (2, 6, and 10 and 1, 8, and 9) were randomly selected using a random number table, and the DBH of all the mangrove trees (>5 cm) within the three plots was measured.

Both *R. mangle* and *L. racemosa* stands were absent from the sampling area. The entire study area was monospecific with *A. germinans.* The total carbon density in region 1 was 1328.36 Mg/ha (Table 1).

Region 2: Pomeroon-Supenaam

The Atlantic Ocean borders Pomeroon-Supenaam to the north, the region of Essequibo Islands-West Demerara to the east, Cuyuni-Mazaruni to the south, and the region of Barima-Waini to the west. It has total land coverage of 6,195 km² and a population of 49, 243 (Macmillan 2009; Census 2002).

The study area was Better Hope, located along the coast of the Essequibo. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 1, 5, and 6 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

Rhizophora mangle and *L. racemosa* were not found in the study area. All the trees in the study area were *A. germinans.* The total number of trees measured was 88, while the average among the plots was 29.33 ± 4.16 with the highest mean diameter class distribution of >10-20 cm with17.67±3.79 and 60.23 % of the overall stand and no tree at >40 cm. The tree's density was 1496 trees/ha. The minimum DBH recorded was 5.5 cm, while the maximum was 32 cm (Table 2).

This region is unaffected by human influence. However, there was some evidence of freshwater intrusion through a drainage canal from the rice field areas. A large section of the area is deforested, resulting from the mudflat's high tidal energy and movement (Woodroffe 1987; Sherman et al. 2001; Cahoon and Hensel 2006, Adame *et al*. 2013).

Region 3: Essequibo Islands-West Demerara

The Essequibo River bisects in Essequibo Islands-West Demerara. It has the Atlantic Ocean to the north, the region of Demerara-Mahaica to the east, the region of Upper Demerara-Berbice to the south, and the Atlantic Ocean. The land coverage is 3,755 km² with a population of 103,061 (Macmillan 2009; Census 2002).

The study area was Ruimzeight ($6^0$50'31"N $58^0$13'6" W), located along the west coast of the Demerara. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 2, 9, and 10 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

Table 1. Summary of tree and carbon densities in Region 1

DBH (cm)	*A. germinans* Trees (Mean±SD)	Tree Density (ha)	Distribution (%)	Carbon Density (Mg/ha) (mean±SD)
5-10	9.00±0.99	459.18	7.69	0.89±0.20
>10-20	79.00±2.71	4030.8	67.52	3.16±1.22
>20-30	25.00±3.10	1275.5	21.36	7.73±3.09
>30-40	2.00±0.56	102.04	171	15.18±0.65
Total	31.89±5.69	5969.34	100.00	1328.36±491.69

Table 2. Summary of tree and carbon densities in Region 2

DBH /cm	*A. germinans* Trees (Mean±SD)	Tree Density (ha)	Dominance (%)	Carbon Density (Mg/ha) (mean±SD)
5-10	5.33±2.89	272.00	18.18	2.91±2.16
>10-20	17.67±3.79	901.00	60.23	42.07±8.77
>20-30	6.00±1.73	306.00	20.45	54.61±19.23
>30-40	0.33±0.58	17.00	1.14	5.66±9.8
>40	0.00±0.00	0.00	0.00	0.00±0.00
Total	29.33±4.16	1496.00	100.00	105.25±11.15

Table 4. Summary of carbon density Region 3

DBH (cm)	Carbon Density (Mg/ha) *R. mangle* (mean±SD)	*A. germinans* (mean±SD)
5-10	0.41±0.39	2.74±0.52
>10-20	1.71±1.00	35.74±6.63
>20-30	8.35±7.12	76.06±39.37
>30-40	9.38±16.25	65.47±30.75
>40	33.79±31.15	85.38±55.51
Total	**67.59±62.31**	**265.42±33.05**

Table 3. Summary of tree measurement in Region 3

DBH/ cm	*R. mangle* Tress (Mean ± SD)	*R. mangle* Tree Density (ha)	*R. mangle* Dominance (%)	*A. germinans* Tress (Mean ± SD)	*A. germinans* Tree Density (ha)	*A. germinans* Dominance (%)
5-10	0.67±0.58	34.00	28.57	4.67±0.58	238.00	14.74
>10-20	0.33±0.58	17.00	14.29	13.33±3.79	680.00	42.11
>20-30	0.67±0.58	34.00	28.57	8.33±5.03	425.00	26.32
>30-40	0.33±0.58	17.00	14.29	3.67±1.15	187.00	11.58
>40	0.33±0.58	17.00	14.29	1.67±0.58	85.00	5.26
Total	**2.33±2.08**	**119.00**	**100.00**	**31.67±8.50**	**1615.00**	**100.00**

The study area in region three has both *R. mangle* and *A. germinans* while *L. racemosa* was absent notably. The total number of trees measured was 102 (*R. mangle* 7 and *A. germinans 95*). For *R. mangle*, the highest distribution of 28 % was seen in the diameter classes of 5-10 cm and >20-30 cm, with a mean among the plots of 0.67±0.58. The other diameter classes were consistent with a 14.29 % distribution and an average of 0.33±0.58. The average number of trees was 2.33 ± 2.08 among the plot, while the density of the trees was 119 trees/ha (Table 3). The minimum DBH of *R. mangle* was 6.0 cm, while the maximum was 35.2 cm. The mean number of *A. germinans* was 31.67±8.50. Among *A. germinans*, the highest distribution was observed in the diameter class of >10-20 cm with 42.11% at an average of 13.33±3.79 the lowest trees distributing in the diameter class > 40 cm at 5.26 % at1.67±0.58 among the plots. In contrast, the tree density was 1615 ha. The minimum DBH of *A. germinans* was recorded as 5.7 cm, while the maximum was 58.0 cm (Table 4). The estimated carbon density was highest (32.85±19.70 Mg/ha) at both species'>20-30 diameter class. The lowest estimated carbon was observed in the 5-10 cm for *R. mangle* (0.39±0.39 Mg/ha) and *A. germinans* (2.57±0.38).

Mangrove with all the measured diameter classes existed in the study area. However, over 70 % of the mangrove forest in this area are within the diameter class of 5-10 cm (28%), >10-20 cm (14%), and >20-30 cm (28%). This is probably due to human influence, where the more mature trees are cut and used for cooking and as poles for fishing nets. The area is also covered with lots of garbage, preventing the roots from breathing freely. Pollution appeared to impact the growth and development of the mangrove species. Most of the garbage seemed to have floated and deposited there from other places (Sherman et al. 2001; FAO 2007).

Region 4: Demerara-Mahaica

The Atlantic Ocean borders Demerara-Mahaica to the north, Mahaica-Berbice to the east, Upper Demerara-Berbice to the south, and the Essequibo Islands-West Demerara to the west. Its land coverage is 2,233 km^2 and is occupied by 310,320 people (Macmillan 2009; Census 2002). The study area was Coven John, located along the coast of the Demerara. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 5, 7, and 9 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

Both *R. mangle* and *L. racemosa* were not found in the study area. All the trees in the study area are *A. germinans*. The total number of trees measured was 73, while the average among the plots was 24.33 ± 2.89 with the highest mean diameter class distribution of >10-20 cm with15.67±2.08 and 64.38 % of the overall stand and no trees at >40 cm (Table 5). The tree's density was 1,241 trees/ha. The minimum DBH was recorded as 5.0 cm, while the maximum was 26.5 cm. The study area is highly influenced by population pressure leading to deforestation, land-use changes, and global climate (Valiela et al. 2001; Langner et al. 2007). The estimated aboveground carbon was 105.25±11.15 Mg/ha, with the highest value centered at the DBH class interval of >10-20. This was due to the high distribution (64 %) within this DBH class interval. The mean DBH was 13.18±5.27 cm with the highest (15.67±2.08 cm) at the >10-20 cm class interval.

Region 5: Mahaica-Berbice

The Atlantic Ocean borders Mahaica-Berbice to the north, East Berbice-Corentyne to the east, Upper Demerara-Berbice to the south, and Demerara-Mahaica to the west. Its land coverage is 4,170 km^{2,} with a population of 52,400 (Macmillan 2009; Census 2002). The study area is Bath Settlement, located along the coast of the Berbice. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 1, 6, and 10 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

Table 5. Summary of tree and carbon densities in Region 4

DBH/cm	*A. germinans* Tree (Mean ± SD)	*A. germinans* Tree Density (ha)	*A. germinans* Distribution /%	*A. germinans* Carbon Density (Mg/ha) (mean±SD)
5-10	6.33±0.58	323.00	26.03	2.57±0.2
>10-20	15.67±2.08	799.00	64.38	38.45±5.81
>20-30	2.33±2.31	119.00	9.59	19.39±17.74
>30-40	0.00±0.00	0.00	0.00	0.00±0.00
>40	0.00±0.00	0.00	0.00	0.00±0.00
Total	24.33±2.89	1241.00	100.00	64.45±17.15

Neither *R. mangle* nor *L. racemosa* was found in the study area. All the trees in the study area were *A. germinans.* The total number of trees measured was 81, while the average among the plots was 27.00 ± 1.00. The mean diameter class with the highest distribution was >10-20 cm with 13.00±1.73 at 48.15 % of the overall stand with the lowest in the diameter class at >30-40 cm with 0.33±0.58 at 1.23 (Table 6). The tree's density was 1,377 trees/ha. The minimum DBH recorded was 5.2 cm, while the maximum was 42.0 cm. The estimated aboveground carbon was 91.73±19.91 Mg/ha, with the highest (30.77±5.62 Mg/ha) being at the DBH class interval of >10-20 cm and the lowest (4.94±1.33 Mg/ha) at the DBH class interval 5-10 cm.

Region 6: East Berbice-Corentyne

The Atlantic Ocean borders east Berbice-Corentyne to the north, Brazil to the south, Suriname to the east, and the regions of Mahaica-Berbice, Upper Demerara-Berbice, Potaro-Siparuni, and Upper Takutu-Upper Essequibo to the west. Its land coverage is 36,255 km^2 with a population of 161,412 (Macmillan 2009; Census 2002). The study area was Borlam, located along the coast of the northern side of the Corentyne Highway. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 3, 6, and 9 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

The study area included both *R. mangle* and *A. germinans* while *L. racemosa* was absent. The total number of trees measured was 59 [*R. mangle* (5) and *A. germinans* (54)]. For *R. mangle*, the highest distribution of 40 % was in the diameter class >20-30 cm, with a mean among the plots of 0.67±1.15. In comparison, the other diameter classes had a consistent distribution of 20%, with the average being 0.33±0.58 (Table 7). The minimum DBH of *R. mangle was* 6.0 cm, while the maximum was 35.2 cm. The minimum DBH of *R. mangle* was 6.3, with the maximum being 39.0 cm. The tree density was 85 trees/ha (Table. 4.8). The mean number of *A. germinans* was 18.00±1.00, with the highest distribution measured in the diameter class of >30-40 cm, while 27.78% at an average of 5.00±1.73, with the lowest being > 40 cm at 14.81 % with a mean of 2.67±1.53. Tree density was 918 ha, with the minimum DBH of *A. germinans* recorded as 5.3 cm while the maximum was 50.1 cm (Table. 8). The mean DBH was 25.86 ± 12.37 cm, indicating standard distribution patterns of the A. germinans species. The area has been affected by human pressure and influence, especially recently. The area is bisected by a road that is the main transit to traverse the Berbice River Bridge, a case of land-use change. The road also prevents the free flow of water within the area, leading to poor growth and possible natural destruction 'mangrove heart attack.' The result of this human influence will not be noticed immediately but in the future. Also, there was evidence of pollution within the study area emanating from travelers (Ellison and Stoddart 1991; FAO 2007; Spalding et al. 2010). The estimated aboveground carbon density estimated was 28.21±39.31 Mg/ha and 245.06±72.29 for *R. mangle* and *A. germinans*, respectively, for region 6 (Table 7). The highest estimated aboveground carbon (95.83±51.03 Mg/ha) was observed at the DBH class interval >30-40 and the lowest (1.75±0.80 Mg/ha at 5-10 cm for *A. germinans*. The highest (17.95±25.39 Mg/ha) estimated aboveground carbon was observed at the DBH class interval >30-40 while the lowest (0.21±0.28 Mg/ha) was observed at 5-10 cm DBH class interval. As the DBH increases, the estimated aboveground carbon increases (Stone and Leon 2010).

Table 6. Summary of tree and carbon density in Region 5

	A. germinans			
DBH/cm	**Tree (Mean ± SD)**	**Tree Density/ha**	**Distribution /%**	**Carbon Density (Mg/ha) (mean±SD)**
5-10	10.67±3.21	544.00	39.51	4.94±1.33
>10-20	13.00±1.73	663.00	48.15	30.77±5.62
>20-30	2.33±2.31	119.00	8.64	28.10±19.55
>30-40	0.33±0.58	17.00	1.23	7.06±12.15
>40	0.67±1.15	34.00	2.47	21.01±36.39
Total	27.00±1.00	1377.00	100.00	91.73±19.91

Table 8. Summary of carbon density Region 6

DBH (cm)	**Carbon Density (Mg/ha)**	
	***R. mangle* (mean±SD)**	***A. germinans* (mean±SD)**
5-10	0.21±0.28	1.75±0.80
>10-20	1.01±1.42	7.22±4.26
>20-30	9.05±12.79	47.75±26.44
>30-40	17.95±25.39	95.83±51.03
>40	0.00±0.00	92.49±60.14
Total	28.21±39.31	245.06±72.29

Table 7. Summary of tree measurement in Region 6

	R. mangle			***A. germinans***		
DBH/ cm	**Tree Mean ± SD)**	**Tree Density/ Ha**	**Distribution (%)**	**Tree (Mean ± SD)**	**Tree Density/ ha**	**Distribution (%)**
5-10	0.00	0.00	20.00	3.00±1.00	153.00	16.67
>10-20	0.33±0.58	17.00	20.00	3.00±1.00	153.00	16.67
>20-30	0.67±1.15	34.00	40.00	4.33±2.08	221.00	24.07
>30-40	0.33±0.58	17.00	20.00	5.00±1.73	255.00	27.78
>40	0.00±0.00	0.00	0.00	2.67±1.53	136.00	14.81
Total	1.67±2.08	85.00	100.00	18.00±1.00	918.00	100.00

Riverine forest

Riverine forest type occurs along the floodplain of the river and creek drainages and is flushed by freshwater daily. This forest type is often behind the fringe forest. The riverine type consists of relatively straight-trunked trees dominated by *R. mangle* and varying mixtures of *A. germinans* and *L. racemosa*. Measurements were taken from the three main rivers on the coast: Berbice, Demerara, and Essequibo rivers.

Berbice River

The Berbice River, located in eastern Guyana, rises in the highlands of the Rupununi region. The Berbice River flows northward for 370 miles (595 km) through dense forests to the coastal plain. The river's tidal limit is 160 and 320 km from the sea. The Berbice River's mouth is the location of Crab Island, opposite the mouth of the Canje River, the Berbice's main tributary (Macmillan 2009; Census 2002). The study area was an eastern bank of the Berbice River. The area is better known as Crab Island ($6^0$18'18.1"N $57^0$31'0.9"W). The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 1, 4, and 8 were randomly selected using a random number table, and the DBH of all the mangrove trees was measured.

The study area included both *R. mangle* and *A. germinans* while *L. racemosa* was absent. The total number of trees measured was 63 {*R. mangle (61)* and *A. germinans (2)*}. For *R. mangle*, the highest distribution of 42 % was in the diameter class >30-40 cm with a mean among the plots of 8.67±7.02, and the lowest distribution was in the diameter class >40 with a mean of 1.33±1.15. The minimum DBH of *R. mangle* was 5.2 cm, while the maximum was 48.90 cm. The minimum DBH of *A. germinans* was 10.2 cm, with the maximum being 17.6 cm. The total tree density was 1037 trees/ha (Table 9). The mean DBH for R. mangle in Berbice River was 24.94±12.14. The total estimated aboveground carbon was 340.42±114.09 Mg/ha and 2.15±1.86 Mg/ha for *R. mangle* and *A. germinans*, respectively, for Berbice River (Table 10). The area is heavily polluted by discharging pollutants from an alumina loading area. The area is also frequented by individuals who often go camping out and cook. There is also rapid erosion leading to the washing away of the mudflat, thereby leading to further deforestation (Ellison and Stoddart 1991; FAO 2007; Spalding et al. 1997; FAO 2007).

Demerara River

The Demerara River, located in eastern Guyana, arises in its central rainforests and flows to the north for 346 kilometers until it reaches the Atlantic Ocean. The river's deep brown color is primarily a result of the massive quantities of silt carried from upriver by the powerful currents (Macmillan 2009; Census 2002). The study area was Nismes ($6^0$45'11.3"N $58^0$12'7.7"W) on the western bank of the Demerara River. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 2, 7, and 8 were randomly selected, and the DBH of all the mangrove trees was measured.

The study area included both *R. mangle* and *A. germinans* while *L. racemosa* was absent. The total number of trees measured was 66 {*R. mangle* (62) and *A. germinans* (4)}. For *R. mangle*, the highest distribution of 41.94 % was in the diameter class of >30-40 cm with mean among the plots was 8.67±3.06 and the lowest distribution existed at the diameter class of >40 with a mean of 1.33±1.15 (Table 11). The minimum DBH of *R. mangle* was 5.0 cm, while the maximum was 48.90 cm. The minimum DBH of *A. germinans* was 17.8 cm, while the maximum was 28.6 cm. The total tree density was 68 ha. The estimated aboveground carbon was 111.74±25.26 Mg/ha and 4.28±5.46 Mg/ha for *R. mangle* and *A. germinans*, respectively, for Demerara River (Table 12). The DBH class interval >30-40 cm has the highest estimated aboveground carbon with 71.28±24.36 Mg/ha, while the lowest (2.67±2.63 Mg/ha) was observed at 5-10 cm diameter class.

Table 10. Summary of carbon density Berbice River

DBH (cm)	Carbon Density (Mg/ha)	
	R. mangle **(mean±SD)**	***A. germinans*** **(mean±SD)**
5-10	2.97±1.00	0.00±0.00
>10-20	14.64±16.23	2.14±1.86
>20-30	33.88±18.48	0.00±0.00
>30-40	227.29±109.72	0.00±0.00
>40	61.62±54.01	0.00±0.00
Total	340.42±114.09	2.15±1.86

Table 9. Summary of tree measurement in Berbice River

DBH/cm	***R. mangle***			***A. germinans***		
	Trees Mean ± SD)	**Tree Density/ Ha**	**Distribution /%**	**Trees (Mean** ± SD)	**Tree Density/ ha**	**Distribution /%**
5-10	4.67±2.08	238.00	22.95	0.00±0.00	0.00	0.00
>10-20	2.67±3.46	136.00	13.11	0.67±1.15	34.00	100.00
>20-30	3.00±1.53	153.00	14.75	0.00±0.00	0.00	0.00
>30-40	8.67±7.02	442.00	42.62	0.00±0.00	0.00	0.00
>40	1.33±1.15	68.00	6.56	0.00±0.00	0.00	0.00
Total	20.33±11.85	1037.00	100.00	0.67±1.15	34.00	100.00

Essequibo River

The Essequibo River is the largest river in Guyana and the largest river between the Orinoco and Amazon. Rising in the Acarai Mountains near the Brazil-Guyana-Venezuela border, the Essequibo flows to the north for 1,010 km through forest and savannah into the Atlantic ocean (Macmillian 2009; Census 2002). The study area was Truli Island, one of the many islands in the Essequibo River. The area was identified and demarcated (140 m x 14 m). This area was then subdivided into ten plots (14 m x 14 m) and marked 1 to 10. Three plots 2, 3, and 5 were randomly selected, and the DBH of all the mangrove trees was measured.

The study area included both *R. mangle* and *A. germinans* while *L. racemosa* was absent. The total number of trees measured was 61 {*R. mangle* (58) and *A. germinans* (3)}. For *R. mangle*, the highest distribution of 43.10 % was in the diameter class >10-20 cm with a mean among the plots of 8.33±1.53 and the lowest distribution in the diameter class > 30-40 with a mean of 0.33±0.58 (Table 13). Minimum DBH of *R. mangles* 5.0 cm while the maximum being 32.0 cm. The minimum DBH of *A. germinans* was 9.6 cm, with the maximum being 26.0 cm. The total tree density was 165.33/ha. The mean DBH of *R. mangle* in the Essequibo River was 17.53±7.73 cm. The mangrove forest ecosystem is stable and less affected by human influence. The area is not close to a residential area and, therefore, less contact with the inhabitants for domestic purposes. There was also no evidence of pollution and farming, two principal means of destruction and degradation (FAO 2007; Saplding et al. 2010). The total estimated aboveground carbon was 125.55±33.75 Mg/ha and 4.49±5.25 Mg/ha for *R. mangle* and *A. germinans*, respectively, for Essequibo River (Table 14). The highest aboveground estimated carbon, 80.32±21.56 Mg/ha, was observed at the DBH class interval >20-30 cm, while the lowest (2.40±0.24 Mg/ha) was at 5-10, which indicates that DBH is proportional to estimated aboveground carbon (Stone and Leon 2010).

Table 12. Summary of carbon density Demerara River

DBH (cm)	Carbon Density (Mg/ha)	
	R. mangle **(mean±SD)**	***A. germinans*** **(mean±SD)**
5-10	2.67±2.63	0.00±0.00
>10-20	6.77±4.99	0.80±2.62
>20-30	15.91±9.18	1.68±2.922
>30-40	71.28±24.36	0.00±0.00
>40	15.08±13.10	0.00±0.00
Total	111.74±25.26	4.28±5.46

Table 14. Summary of carbon density Essequibo River

DBH (cm)	Carbon density (Mg/ha)	
	R. mangle **(mean±SD)**	***A. germinans*** **(mean±SD)**
5-10	2.40±0.24	0.00±0.00
>10-20	35.58±7.91	1.07±1.46
>20-30	80.32±21.56	3.42±5.93
>30-40	7.15±12.39	0.00±0.00
>40	0.00±0.00	0.00±0.00
Total	125.55±33.75	4.49±5.25

Table 11. Summary of tree measurement in Demerara River

DBH/cm	***R. mangle***			***A. germinans***		
	Tree (Mean ± SD)	**Tree Density/ Ha**	**Distribution /%**	**Tree (Mean ± SD)**	**Tree Density/ ha**	**Distribution /%**
5-10	5.33±5.51	272.00	25.81	0.00±0.00	0.00	0.00
>10-20	2.33±1.53	119.00	11.29	1.00±1.00	51.00	75.00
>20-30	3.00±1.73	153.00	14.52	0.33±0.58	17.00	25.00
>30-40	8.67±3.06	442.00	41.94	0.00±0.00	0.00	0.00
>40	1.33±1.15	68.00	6.45	0.00±0.00	0.00	0.00
Total	20.67±6.66	1054.00	100.00	1.33±1.53	68.00	100.00

Table 13. Summary of tree measurement in Essequibo River

DBH/cm	***R. mangle***			***A. germinans***		
	Tree (Mean ± SD)	**Tree Density/ Ha**	**Dominance (%)**	**Tree (Mean** ± SD)	**Tree Density/ ha**	**Dominance (%)**
5-10	4.00±1.00	204.00	20.69	0.00±0.00	0.00	0.00
>10-20	8.33±1.53	425.00	43.10	0.67±1.15	34.00	66.67
>20-30	6.67±1.53	340.00	34.48	0.33±0.58	17.00	33.33
>30-40	0.33±0.58	17.00	1.72	0.00±0.00	0.00	0.00
>40	0.00±0.00	0.00	0.00	0.00±0.00	0.00	0.00
Total	19.33±1.53	986.00	100.00	1.00±1.00	51.00	100.00

Mangroves of all the diameter classes were found in all the study areas. Based on the research, the total distribution of mangroves in Guyana indicated that for *R. mangle*, the maximum distribution existed in the diameter class >10-20 cm. In contrast, the minimum distribution existed at > 40 for the fringe forest. The maximum distribution for *A. germinans* existed in the diameter class >10-20, while the minimum distribution existed in the diameter class >30-40. There is no significance between the biomass carbon between the two methods (DBH and height) based on the chi-square test (2.6).

Destructive analysis

The estimated aboveground carbon for the *R. mangle* and *A. germinans* using the two methods is quantitatively similar (Table 15). The equation already includes the correction factor of 19.5 % if height (H) is unavailable when estimating the tree's biomass (Chave et al. 2005). The calculated X^2 (0.85, 0.81, 0.45 and 0.74) values (respectively for each tree species) are less than the tabulated value X^2 (3.84). This indicated no significant difference between the two methods used to determine the biomass of *R. mangle* and *A. germinans.* This indicated that the total carbon storage is greater in *A. germinans* than in *R. mangle* (Table 15) (Zar 1996).

Aboveground non-tree carbon

Regions 3 and 5 have an undergrowth of non-tree vegetation (Table 16). Mangrove distribution is clustered, resulting in a very close canopy, thus preventing light penetration from growing forest floor vegetation. Region 6 shows a higher amount of carbon stored in non-tree vegetation. This is because of more canopy opening and less trespassing of individuals.

Aboveground litter

Litter collected from the forest floor shows interesting amounts of carbon captured and stored within the organic matter. The region has the highest amount of carbon stored in the litter, while Region two shows the least amount (Table 17). The regions with the highest significant amount of litter and consequently carbon are less frequently flooded, thereby leaving most of the litter on the floor.

Soil carbon

Soil also serves as an essential reservoir for carbon. The carbon stored in the mangrove shows wide variation based on the soil activity and environmental condition.

Table 15. DBH and destructive carbon content

Species	DBH/cm	Methods	
		Destructive (Carbon/kg)	Non-destructive (Carbon/kg)
R. mangle	16.4	73.22	70.95
R. mangle	9.5	21.67	20.10
A. germinans	36	340.57	360.5
A. germinans	15	40.38	43.76

Table 16. Non-tree carbon

Region	Mangrove Coverage/ha	Carbon/ha	Carbon per Region
1	10161.8	ND	ND
2	4097.1	ND	ND
3	1513.5	3.06±0.53	4646.41±1.65
4	91.9	ND	ND
5	2082.8	ND	ND
6	4685.3	3.32±0.42	15555.07±1.42

Table 17. Aboveground litter

Region	Mangrove Coverage/ ha	Carbon (Mg/ha)	Carbon per Region
1	10161.80	3.23±0.82	32822.35±2.64
2	4097.10	3.13±0.45	12823.82±1.41
3	1513.50	2.66±0.99	4025.88±2.62
4	91.90	2.38±0.53	218.72±1,25
5	2082.80	2.57±1.17	5352.75±3.00
6	4685.30	1.61±0.64	7543.27±1.03

Table 18. Estimated soil carbon in Guyana

Region	Mangrove Coverage/ha	Soil Carbon (Mg/ha)
1	10161.80	500
2	4097.10	439
3	1513.53	390
4	91.90	289
5	2082.80	403
6	4685.30	521

The carbon stored in the soil is highest (500 Mg/ha) in Region one, while the lowest is in Region 4 (298 Mg/ha) (Table 18). The soil contains a significant amount of carbon trapped in the mangrove forests; the estimated global average is 396 Mg C/ha. It is estimated that the amount of carbon per hectare in the world's most carbon-rich mangroves is 703 ± 38 Mg C ha−1) and the lowest in poor carbon soil, which is 272 ± 49 Mg C ha−1). We also find substantial within-country variation in mangrove soil carbon (Jardine and Siikamäki 2014). Mangrove forests captured and stored a significant amount of carbon dioxide from the atmosphere through carbon sequestration. While most of the carbon is stored as biomass carbon in trees, a significant quantity is also found in the forest floor, and non-tree vegetation and is applied in deadwood. However, none of the study sites, specifically the sampling plots, did not have dead woody materials. The average estimated aboveground (live tree) carbon stored in mangrove species, in litter collection, and non-tree in different regions of Guyana was 497.05 Mg/ha. This represented a higher estimate than Donato et al. 2011 who concluded that the aboveground carbon in mangrove forests with the minimum being 159 Mg C/ha and the maximum 435 MgC/ha. (Hussein 1995).

The results from all the regions of Guyana indicate that the two species (*R. mangle* and *A. germinans*) have greater aboveground carbon stock capacity (481 Mg/ha), which

can absorb carbon dioxide released from various sources within Guyana. The total forest coverage of Guyana is 18570000 ha containing over 5 gigatonnes of CO_2 in aboveground biomass (MNRE 2012). Mangrove total coverage in Guyana is 22632.4 ha and locked 0.09gt estimated aboveground, carbon, equivalent to 0.257 gigatonnes of CO_2. This is significant, considering the low stature, coverage, and density of mangroves (Spalding 2010). The phenomenon of global warming has recently engendered much discussion and interest in understanding the carbon stock capacity of mangrove species. The results of this study support mangrove reforestation and afforestation in the coastal zone of Guyana.

The data generated by the research indicate that although mangroves are the most carbon-rich ecosystems in Guyana, this ecosystem accounts for less than 1% of the total carbon storage potential for the country. This level of carbon storage potential is far below the global average of 3%. The relatively low level of the carbon storage potential in Guyana's mangrove ecosystems reflects a comparatively low (0.12%) level of mangrove forest coverage with other forest ecosystems. In light of Guyana's commitment to a low carbon development strategy, the carbon storage potential of mangroves relative to its small areal extent underscores the need for strategies to preserve existing mangrove forests and restore and expand the areal coverage of mangrove. These measures will enhance the carbon storage potential of mangrove ecosystems in Guyana and better synchronize the LCD policy with measurable implementation actions. Specific actions which are recommended based on the output of this research include (i) Mapping of appropriate sea-edge locations the expansion of mangrove conservation areas. (ii) Develop a mangrove expansion/conservation strategy/policy, indicating specific timeframes and benchmarks. (iii) Institute a program for monitoring trends in carbon stock. (iv) Ecological modeling for carbon storage prediction concerning climate change. (v) Integration of mangrove conservation/protection considerations into public and private sector development programs. (vi) Promote mangrove conservation at all levels of the education system, especially in primary and high schools. (vi) Conduct a review of Guyana's mangrove conservation-related policies, programs, and regulations.

In conclusion, the results indicated no significant difference in the diameter class intervals concerning carbon storage capacity of the mangrove species *R. mangle* and *A. germinans* in regions 1-6 in Guyana. Based on the Chi-square test, there is a significant difference in carbon storage in all Guyana regions (1-6). The maximum storage capacity was observed in region 1, which is statistically significant. This is due to the region's high mangrove coverage, 49.9 % of the other 5 regions. The present study proved with all statistical subjugation that the mangrove ecosystem contributes significantly towards absorbing carbon dioxide, thereby reducing the effects of global warming.

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