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

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Abstract. Öketener A., Alaş A., Türkær 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 aims to present 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 characterised in possessing a flattened body, which is well adapted for life on a moving object - the fish. They feed on the blood, mucus, and epithelial cells of their host (Ho 2004). Members of this family have been responsible for most of the 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 pelamidis* Krøyer, 1863, *Caligus solea* Demirkale, Özak, Yanar, Boxshall, 2014, *Caligus temnodontis* Brian, 1924, and *Lepeophtheirus europaeensis* Zeddam, Berrebi, Renaud, Raibaut, Gabrion, 1988 (Alaş et al. 2016). In this paper, we present 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 the aid of Canon EOS 1100D connected to a microscope. Measurements were taken in millimeters (mm), with a micrometric program (Pro-way). The scientific names, synonyms of parasite and host were checked with WoRMS Editorial Board (2016), 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 collections of 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 male; **Dissected material:** 2 male

All parasites were firmly attached to the gill filaments of the host. The prevalence of parasite were 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, distal segment comprising claw with short setae. The setae on exopod of first leg carry teeth. The first segment of second leg endopod carries four teeth, while 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).
**Hosts:** *Caligus bonito* parasitizes several teleost species belonging to the family Scombridae, such as *Euthynnus affinis*, *Euthynnus aletteratus*, *Katsuwonus pelamis*, *Sarda sarda*, *Sarda orientalis*, *Sarda australis*, *Sarda chilensis chilensis*, *Scomberomorus regalis*, *Thunnus thynnus*, *Euthynnus lineatus*, *Gymnosardaunicolor* (Walter and Boxshall 2008), *Scomberomorus carvalia*, *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 platams* (Knoff et al. 1994), *Mugil curema* (Cavalcanti et al. 2006), *Oligoplites paloma* (Takimoto 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).
Discussion

Especially, Scombridae family fishes are the host of Caligus bonito. This parasite selects carnivorous and pelagic fishes as host for habitat and feeding habits. In this study, we examined Sarda sarda and Auxis rochei which are 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 platamans; 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 of the infestation values and morphology of the parasite can result from the parasite-host interactions and host species which 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 antenna, teeth on three setae of exopod of first leg, four teeth and teeth in two slightly alternating rows on first and second segment of second leg endopod, maxilliped proximal segment with four small tubercules, setal and spinal formula of from first leg to fourth leg in this study are compatible according to these literatures. 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, 1758) with morphological characters in Turkey. *Bonorowo Wetlands* 1: 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 report from *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 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 species of parasite, its size and the type of bulla (Lester and Hayward 2006). *Salmincola edwardsii* in brook trout caused severe diffuse exuberant proliferation of gill epithelium, resulting in severe lamellar fusion and aneurysms (Duston and Cusack 2002).

Fifteen species of 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 polyculopus* 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 findings of the other countries in next time. This study aims to confirm of 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 aid of Canon EOS 1100D camera attached to the microscope. The measurements were taken in millimeter (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 were 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, mean intensity of parasite were 40%, 2.3 respectively.

**Description-female:** Body length varies from 4 to 5 mm. The cephalothorax longer than the trunk. The trunk is ovate or pyriform, with truncated posterior margin. Ovisacs 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. 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 composed of short digitiform process surmounted with one long, one 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 myxal 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)](image)

![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)](image)
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; Bennmansour 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; Bennmansour and Ben Hassine 1997; Raibaut et al. 1998; Martorell 2004; Souidienne 2010), *Spondyliosoma cantharus* (Ben Hassine et al. 1978; Essafi et al. 1984; Bennmansour 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 of 8 hosts belong to 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
confirmed record of Clavellotis fallax from Dentex dentex

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 first antenna; the status exopod/endopod on 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 Clavellotis at genus level was also 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 1: 8-10. Masked Finfoot (*Heliopais personata*) currently listed as Endangered based having a very small and very 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 of Masked Finfoot in Indonesia is very little known. Since October 1992, there was no further information of 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 local resident) in southern Thailand, Peninsular Malaysia and vagrant in Singapore (Robson 2011). In Indonesia, the bird is 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 uncertain in South Thailand, Malaysia and Sumatra (Figure 1) (Bertram and Boesman 2017).

The currently status is listed as Endangered based having a very small, and very rapidly declining population caused by ongoing loss and degradation of wetlands and especially riverine lowland forest in Asia (BirdLife International 2014). World population is estimated at fewer than 10,000 birds (Bertram 1996). However, further update population number may now number as low as 1,000 individuals, and 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 was no further information of 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 forest, settlements, and agriculture. The incident of Masked Finfoot in Bangko Lake was recorded on the 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 an adult Masked Finfoot by its gray hind crown and neck, black face and upper fore neck with 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 from 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 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 an 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 possible regular visitor in small number in Sumatra, but the limitation number of birdwatcher could make it overlook in the past.

To conclude, the recent record of Endangered Masked Finfoot in Sumatra after 17 years break in unexpected. The status in Sumatra or Indonesia is uncertain, but it presumed Indonesia is important wintering habitat for this species during the migration period. 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 1: 11-15. 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 result of this 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 the biological complexity and physical structure of habitats which increases biodiversity within the littoral zones (Esteves 1998; Wetzel 2001; Pelicice et al. 2008). In addition, both live and dead materials (detritus) from aquatic macrophyte 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 and many of them serve as food for fishes (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 explosively large population only when the environment is altered.

Nigerian inland water bodies serve as an important refuge for numerous animals and vascular plants which have sustained the communities around them. But in recent times, both natural and human-induced environmental problems had 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 in 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 the city of Abeokuta, Ogun State, Nigeria (Figure 1) that lies on latitude between 7° 15' and 7° 25' and longitude 3° 5' and 3° 15'. It is a gated spillway lake and covers an area of 40km² with a normal reservoir capacity of 140million m³. The Lake was constructed on Oyan River which is a major tributary to Ogun River with a catchment area of 9,000km²; it is a man-made 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 Oyan River and meets with Ofiki River; the Hausas are predominantly the inhabitants Ofiki while the Ijazes dominates the Oyan River. The climate of the study area is warm and humid. Two distinct seasons are felt during the year: the rainy season (March-October) and dry season (November-February). The range of rainfall was between 1600mm and 2900mm. In order to provide all year round picture 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 | 2271m³ per 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 the Oyan Lake during October 2012 to January 2013 and sampling was done twice in 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 different 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 the use of a paddled boat to the different zones through the assistance of a fisherman. A wooden square quadrat of 1m² 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 ($H'$) = $-\sum_{i} \left[ \frac{ni}{N} \times \ln \frac{ni}{N} \right]$ (Shannon and Weaver 1963)

Where:
$H'$ = Diversity index, $ni$ = the total number of individuals belonging to the $ith$ species, $N$ = total number of individuals for the site and $\ln$ = the natural log of the number.

- Simpson diversity $(1-\Delta)$ = $1 - \frac{\sum n(n-1)}{N(N-1)}$ (N-1)

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

- Margalef's value is the measure of species richness. It is expressed as $d=S-1/\ln N$,

Where:

Menhinicks Index ($D$) = $\frac{S}{\sqrt{N}}$

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:

$J=1/H_{\text{max}}$ (Pielou 1969)

Where:
$J$ = Diversity evenness or Equitability Index. $H_{\text{max}}$ = calculated Shannon-Weiner diversity index. ($\text{Shannon-Weiner}$) $H_{\text{max}}+\ln S$ $S$ = total number of species in a population $n$ = natural log of number

Simpson dominance index($C$) = $\sum (n/N)^2$ (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. The families Cyperaceae and Poaceae had the highest species of four each followed by Mimosaceae with two species while 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, are also 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 plant families which constituted thirty-one species, family Poaceae ranked the commonest with fourteen species while other families were represented by one species each. 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 while 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. From the result family Cyperaceae recorded the highest number of species with 3 species, while 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 which is in accordance with the results of this study.

The species samples were zoned, into three groups: as floating, submerged and emergent. Table 2 shows a total of 15 species out of twenty species identified were grouped as emergent, two as submerged while the remaining three species were grouped 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 species grouped as floating and none was grouped as submerged during the sampling period. This finding shows that in the zonation of macrophytes emergent species ranked the highest 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 Echinocloa stagnina while Ludwigia decurrens recorded the lowest distribution. In the study of 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 Echinocloa stagnina and Oryza longistaminata with the same level of richness. Ceratophyllum demersum recorded the lowest richness among the species sampled in the community.

Similarity index shows the similarity between the different zones i.e. the presence and absence of different 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 Station i.e. Station 2 and 3 followed by Station 1 and 3 with 31.58% with the least 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               |                        |
|                  | Fimbristylis ferruginea          | Yellow Nutsedge        |
| Poaceae          | Echinocloa pyramidalis          |                        |
|                  | Echinocloa stagnina              |                        |
|                  | Sacciolepsis africana           |                        |
|                  | Orzya longistaminata            | Wild rice              |
| Onagraceae       | Ludwigia decurrens              |                        |
| Araceae          | Pistia stratiotes               |                        |
| Polygonaceae     | Polygonium lanigerum            |                        |
| Curcubitaceae    | Luffa aegyptica                 |                        |
| Azollaceae       | Azolla africana                 |                        |
| Hydrophyllaceae  | Hydrocolea glabra               |                        |
| Mimosaceae       | Mimosa pigra                    | Giant sensitive plant  |
| Salvinaceae      | Salvinia nymphyllula            |                        |
| Convolulaceae    | Ipomea triloba                  |                        |
| Nymphaeaceae     | Nymphaea lotus                  |                        |
| Ceratophyllumace | Ceratophyllum demersum          | Water lily             |

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

| Species                      | Floating | Submerged | Emergent |
|------------------------------|----------|-----------|----------|
| Ludwigia decurrens           | +        |           |          |
| Pistia stratiotes            |          | 0.25      | 0.18     |
| Polygonium lanigerum         | 0.03     | 0.06      | 0.15     |
| Echinocloa pyramidalis       | 0.05     | 0.09      | 0.22     |
| Neptunia oleracea            | 0.08     | 0.14      | 0.36     |
| Rynchospora corymbosa        | 0.08     | 0.14      | 0.36     |
| Echinocloa stagnina          | 0.03     | 0.06      | 0.15     |
| Oryza longistaminata         | 0.03     | 0.07      | 0.16     |
| Luffa aegyptica              |          | 0.12      | 0.29     |
| Azolla africana              | 0.02     | 0.04      | 0.10     |
| Fimbrystis ferruginea        | 0.06     | 0.11      | 0.28     |
| Mariscus longibracteatus     | 0.08     | 0.15      | 0.37     |
| Cyperus esculentus           | 0.08     | 0.15      | 0.37     |
| Hydrocolea glabra            | 0.06     | 0.11      | 0.27     |
| Sacciolepsis africana        | 0.05     | 0.09      | 0.23     |
| Mimosa pigra                 | 0.05     | 0.10      | 0.24     |
| Salvinia nymphyllula         | 0.03     | 0.06      | 0.14     |
| Ipomea triloba               | 0.05     | 0.10      | 0.24     |
| Nymphaea lotus               | 0.05     | 0.09      | 0.22     |
| Ceratophyllum demersum       | 0.10     | 0.18      | 0.45     |

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

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

| Species                      | Akiri | Ibaro | Iloba | Total | Mean Value |
|------------------------------|-------|-------|-------|-------|------------|
| 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       |
| Echinocloa 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       |
| Echinocloa stagnina          | 0.03  | 0.06  | 0.06  | 0.15  | 0.05***    |
| Oryza longistaminata         | 0.03  | 0.07  | 0.06  | 0.16  | 0.05***    |
| Luffa aegyptica              | 0.06   | 0.12  | 0.11  | 0.29  | 0.10       |
| Azolla africana              | 0.02   | 0.04  | 0.04  | 0.10  | 0.03**     |
| Fimbrystis 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       |
| Hydrocolea 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       |
| Salvinia nymphyllula         | 0.03   | 0.06  | 0.05  | 0.14  | 0.05       |
| Ipomea triloba               | 0.05   | 0.10  | 0.09  | 0.24  | 0.08       |
| Nymphaea 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 |
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, as well as 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 of temperature at the 1 m surface layer was ranged from 22.7 to 28.7 °C. Meanwhile, salinity was ranged from 11.8 psu to 30.0 psu. Phytoplankton was abundant in the area with the high temperature and low salinity. The most abundant species among station of sampling 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 furcatus (0.9%), and then Ceratium furca (0.8%) which was mostly dominant in off river mouth area. The density center and contour lines of phytoplankton population 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 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 as a quality element for determining the ecological status water ecosystems. Phytoplankton is responsible for about 40% of global primary production and forms the base of the aquatic food web. 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 to be high (Mann 2000), due to high nutrient input from adjacent land or river runoff, and hence often serve as nursery grounds for commercially important finfish and shellfish species.

Mikawa Bay is coastal water system which freshwater runoff from some rivers supplies nutrient influx and circulation in the bay induce 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 condition within the water system, which are driven by the wind, freshwater input, tides, and hurricane. Wind strength and direction, precipitation, and tides may vary substantially within a short time, 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 by 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 was two layers circulation, and the upper layer of the river mouth region has higher production of particulate organic nitrogen due to strong upwelling and river inflow, whereas in the lower layer of the bay mouth region has higher deposition of particulate organic nitrogen caused by weak upwelling and down welling. In one hand, study about a massive coccolithophorid bloom found that occurrence of blooming...
were set with GPS (geo positioning system). At each approximately 1 km. The position of each sampling station Tahara bays, the distance between the station was straight line west-east towards Toyo rivers, while the station 9 to 15 formed a straight line north-south towards Toyo rivers. This bay is the most eutrophicated bays in Japan area because of inorganic and organic loadings from these rivers. This bay is located in mid-Japan, has a surface area of 604 km2 with an average depth of 9.2 m. Two major rivers, the Yahagi and Matsukawa 1987). The Bay is a semi-enclosed estuary composed of Kinu-ura Bay, the estuary of the Yahagi River (37 m³ s⁻¹ the annual mean) in the northwest, and Atsumi Bay, the estuary of Toyo River (35 m³ s⁻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 km² with an average depth of 9.2 m. Two major rivers, the Yahagi and Toyo Rivers, empty into the bay from the northwest and the northeast, respectively. Mikawa Bay is a rich fishery area because of inorganic and organic loadings from these rivers. This bay is the most eutrophicated bays in Japan because of high economic growth during the last two decades (Yamamoto and Okai 2000).

**MATERIALS AND METHODS**

**Study site**

Mikawa Bay is partially mixed estuary composed of Kinu-ura Bay, the estuary of the Yahagi River (37 m³ s⁻¹ the annual mean) in the northwest, and Atsumi Bay, the estuary of Toyo River (35 m³ s⁻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 km² with an average depth of 9.2 m. Two major rivers, the Yahagi and Toyo Rivers, empty into the bay from the northwest and the northeast, respectively. Mikawa Bay is a rich fishery area because of inorganic and organic loadings from these rivers. This bay is the most eutrophicated bays 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 the station 1 to 8 formed a straight line west-east towards Toyo rivers, while the station 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 were set with GPS (geo positioning system). At each phytoplankton sampling station, vertical profiles of temperature and salinity 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 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 polyethylene bottle of 30 ml. Macrozooplankton were removed from phytoplankton water samples using 115 μm mesh nets (Havens et al. 1996).

Phytoplankton samples were preserved in 5% neutral formaldehyde (final concentration) in polyethylene bottles. Concentrated formalin (37-40%), buffered by borax (sodium tetraborate, Na₂B₄O₇·10H₂O), and was added to a sample to the fixative ratio of 9:1, using 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 magnification. Each preserved phytoplankton sample bottle was shaken by flipping through the bottle then taken 1 ml using a pipette, and then gently poured 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, as well as 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 krigging method. The value of the contours was adjusted to the range of the highest value with the lowest.
located on the southeast side of the bay, while the lowest was in the northwest side of the bay (Figure 2). The surface temperature was affected by the weather, the season, offshore input and river 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 east side of the bay.

The surface temperature on the 29th August 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 measurement date showed cloudy on 23rd and 24th August, and then rainy on 25th August with accumulated rainfall reached 50 mm in Toyo and over 150 mm in upstream area, meanwhile from 26th to 28th August was mostly 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 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 off Shikoku Island on 2nd September, the easterly wind started to blow out. Because the typhoon moved very slowly, so the strong easterly wind lasted until 5th September. The rainfalls were accumulated about 100 mm in the middle and lower, and 300 mm upper Toyo River watershed in the Typhoon period. The typhoon pushed the surface layer moved to the northeast, so the river runoffs take effect around off Toyo River.

The surface water temperature was horizontally homogeneous during sampling on 12th September. Water conditions were seen turbid up to station 7 off Toyo River, and in stations 16 to 18 were observed very turbid which 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.
The surfac temperature profile on the 19th September was relatively almost similar with temperature profile on the 22nd August, where the highest temperature was located on the east side, while the lowest was in the west side of the bay. The surfac temperature at the off Toyo River mouth was around 27.8°C, and then to the westward direction was gradually decreased to 26.8°C. Higher temperature carried by fresh water river runoff was depressed by the southwest offshore current to the northeast. Meanwhile, the surface temperature profile on the 26 September showed the highest at the north side and the lowest at the south side of the bay.

The average of salinity at the 1 m surface layer ranged from 24.9psu to 28.3psu, and as overall the surface salinity was ranged from 11.5psu (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 the southwest, while the lowest was in the northwest 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 average salinity 28.3psu. The highest salinity was concentrated in the southwestern part of the bay, while the lowest was found in northeastern part of the bay. 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, and the lowest was 26.1psu, and an 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 highest 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 0.5 psu 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 abundance 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 mostly abundance to among station of sampling. On the other hand, the most abundance in Dinophyceae was Dinophysis sp(p). (1.1%) followed by Ceratium fusus (0.9%), and then Ceratium furca (0.8%) which mostly dominant in off river mouth.

Phytoplankton distribution
Figure 4 indicates weekly changes in cell densities of phytoplankton at surface layer in Mikawa Bay from late August to September 2011. The population of phytoplankton during sampling showed the most density was occurred on 29th August followed on 12 September, and the least density occurred on 5th September. The density center and contour lines of phytoplankton population was 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 located in northern side of the bay. The phytoplankton density was decreased drastically from southern to northern 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 increasing of phytoplankton density, and then decreased afterward both for temperature and phytoplankton density.

The highest density of phytoplankton 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. The increasing of phytoplankton density from station 1 to 7 and decreasing of phytoplankton density from station 13 to 18 was relatively similar to those for temperature in the same station. However, it was a contrasted 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. 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  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *A. affine*           | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 0  | 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  |
| *Ceratium* sp(p.)     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Dinophysis* sp(p.)   | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Gymnodinium* sp(p.)  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Noctiluca scintillans* | 2  | 1  | 1  | 2  | 3  | 2  | 1  | 1  | 2  | 1  | 1  | 1  | 2  | 2  | 2  | 2  | 2  | 2  | 2  |
| *Oxytoxum* sp(p.)    | 0  | 0  | 2  | 1  | 5  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Prorocentrum* sp(p.)| 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *P. triestinum*       | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Protoperidinium* sp(p.) | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Rhizosolenia* sp(p.) | 9  | 5  | 8  | 3  | 1  | 1  | 1  | 2  | 1  | 1  | 2  | 1  | 1  | 1  | 2  | 2  | 2  | 2  | 2  |
| *Pseudo-Nitzschia* sp(p.) | 55  | 10  | 116  | 57  | 75  | 56  | 3  | 16  | 23  | 185  | 0  | 70  | 1  | 56  | 2  | 1  | 0  | 0  | 1  |
| *Stephanopyxis palmeriana* | 6  | 34  | 46  | 4  | 0  | 3056  | 107  | 53  | 33  | 46  | 16  | 28  | 12  | 2  | 2  | 0  | 1  | 1  | 0  |
| *Thalassionema nitzschioides* | 55  | 10  | 116  | 57  | 75  | 56  | 3  | 16  | 23  | 185  | 0  | 70  | 1  | 56  | 2  | 1  | 0  | 0  | 1  |
| *Thalassiosira* sp(p.) | 1  | 1  | 1  | 2  | 1  | 0  | 0  | 0  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| *Thalassiothrix* sp(p.) | 42  | 40  | 63  | 117  | 54  | 49  | 21  | 71  | 122  | 205  | 192  | 253  | 212  | 180  | 93  | 72  | 144  | 126  |
| **Total density**     | 43372  | 55054  | 19457  | 74482  | 83673  | 87665  | 5701  | 6774  | 7986  | 8019  | 6582  | 6468  | 21330  | 40629  | 29884  | 9427  | 1858  | 1642  |
The horizontal distribution of phytoplankton density profile on the 5th September contrasted with the distribution of phytoplankton in the previous weeks. The higher density of phytoplankton was found in Toyo River mouth and then decreased gradually to the offshore directions. That pattern profile was opposite with horizontal distribution profile of salinity, which was increased gradually from the river mouth to offshore direction.

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

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

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

The distribution of the dominant species of phytoplankton, namely Chaetoceros sp(p), Pseudonitzschia 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 highest density in the center of the bay, and then gradually decreased to all direction.

**Discussion**

**Phytoplankton distribution**

Mikawa Bay is composed of two bays, namely Atsumi Bay (eastern part) and Chita Bay (northwestern part. It
species of phytoplankton require a specific environmental (Takahashi et al. 1992; Kai et al. 1999). However, each nutrient in the bay, and nutrient input from the river runoff. A water temperature of 27-28 °C was found to promote 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 , as has been shown for Alexandrium catenella (Siu et al. 1997). However, the too high temperature was also unfavorable for population growth. At 30°C, the maximal capacity, population growth rate, and the mean doubling time of Alexandrium catenella was decreased significantly (Siu et al. 1997).

In conclusion, Bacillariophyceae was the most abundant among phytoplankton groups, and the most abundance species in Bacillariophyceae was Chaetoceros sp(p), then Pseudo-Nitzschia sp(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 (Takahashi et al. 1992; Kai et al. 1999). However, each species of phytoplankton require a specific environmental condition in order to grow to maximum density. In the Yodo River estuary of Osaka Bay, the salinity was played as an environmental factor 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 the 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 phytoplankton population was, relatively similar or contrast against to those of temperature or salinity contour pattern, depended on the distribution of temperature and salinity, the combination of both temperature and salinity or others factor. In the range salinity of 25-28 psu and temperature of 23-27 °C, the increasing of both temperature and salinity will be followed by increasing of 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 decreased, otherwise when the temperature decreased will be followed by increasing of phytoplankton density, vice versa with salinity contour pattern. However, on the temperature and salinity above 25, a stable condition of temperature and salinities were not affect to phytoplankton fluctuated among stations. It appears that when the salinity more than 28psu and temperature less than 25°C, the increasing or decreasing temperature will positively influence to the density distribution of phytoplankton.

Temperature and nutrient input from the land appeared to have major effects on population growth in Chaetoceros sp(p), Pseudo-Nitzschia sp(p), and Coscinodiscus which their population was the most dominant among station and sampling. A water temperature of 27-28 °C was found to promote 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 , as has been shown for Alexandrium catenella (Siu et al. 1997). However, the too high temperature was also unfavorable for population growth. At 30°C, the maximal capacity, population growth rate, and the mean doubling time of Alexandrium catenella was decreased significantly (Siu et al. 1997).

In conclusion, Bacillariophyceae was the most abundant among phytoplankton groups, and the most abundance species in Bacillariophyceae was Chaetoceros sp(p), then Pseudo-Nitzschia sp(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 °C was found to promote the highest density. Population numbers of Chaetoceros sp(p), Pseudo-Nitzschia sp(p), and Coscinodiscus was the most dominant among station and sampling period, temperature and nutrient input from the land was the major 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 1: 26-30. Peatland conversion could threaten the soil organisms existence which is influenced by soil physical properties. The aim of this research was 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 corn-field (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 include bulk density, moisture, and porosity. The results indicated that a decline in colonies of bacteria and fungi in OPP than SPF, 50% and 53% respectively. The decline in the condition of affected water content decrease due to the land conversion of secondary forests into oil palm plantations (22.8%). Additionally characterized by conditions on the water-table depth was 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 different conditions characterized by the water content, water-table depth, and bulk density 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 around 38 million hectares, mostly located in Indonesia (14.9 million hectares) (BBPPSDLP 2011). Peat swamp forest is one type of wetland that is 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). The 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 microorganisms death. Temperature between 40-70°C can lead the destruction of biological tissue, a temperature range of 70-90°C death begins seeds and microbial death occurred between 50-120°C (Hernandez et al. 1997). Edafon land a devastating fire damage (flora and fauna). After the fire activity and 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 leaching of nitrogen (N) and tend to pollute 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 in order to the preservation of peat awake.

MATERIALS AND METHODS

Study area

The study area were four peatland types, namely secondary peat forest (SPF) (00°21.70’ S, 109°21.81’ E), shrubs (SB) (00°21.42’S, 109°21.51’ E), oil palm plantation (OPP) (00°23.87’S, 109°22.65’E) and corn-field (CF) (00°23.87’ S, 109°22.65’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 ground water to the surface of the soil. Soil temperature data were taken using a digital thermometer that is inserted into the ground.

Soil sampling and sample analysis

At each location of the land, samples were taken from three sampling points 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. The sample was weighed, after it set up a soil sample with a size <2 mm and <0.5 mm using pulverized and sieved so that the soil sample ready for analysis. Analysis of biological characteristics as the main parameter in the form of 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), soil porosity with the method of calculation 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 in OPP is the lowest, two species of bacteria that each 3 x 10^5 cfu and 2 x 10^5 cfu. Similarly to the type and total fungi in SPF has two types of fungi (Rhizopus sp. and Penicillium sp.) With a total of fungi that 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. While 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 is affected by soil physical conditions such as depth of water table and soil temperature. There is a strong negative correlation between the water-table depth and total of 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 of bacteria and fungi (r between 0.074 and 0.151) (Figure 1.C-D).

Table 1. 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 diversity of soil microbes

The deeper the water-table depth, especially on intensive agricultural, causing microorganism population decline. It is characterized by low of water content (Figure 2.A-B) in spite of a weak positive correlation between the water content and the total of bacteria and fungi (r between 0.305 and 0.239). The results are shown by the same research by Mishra et al. (2016) that microbial profiles from peatland sites are most influenced by variations 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 this findings. Low bacterial diversity in OPP, as seen in this study, can be sensitive to environmental pressures.

Soil physical characteristic on diversity of soil microbes

The existence of soil organisms is influenced by the physical characteristics of the soil. The decline in soil bacteria and fungi in OPP affected water content reduction due to the land conversion of SPF into OPP. Although the relationship between them 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 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 of 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%). Increasing the number of soil microbes in CF allegedly due to land management in the form of regularly burning and fertilizing before planting. Results of interviews with local farmers showed that prior to corn planting is done burning of 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 activity and growth of microbes in the soil. Contrary to the opinion by Yule et al. (2016) that the microbial community composition was significantly impacted by the fire. 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 decrease after the fire, but expected to happen temporarily and will go back to normal.

Figure 1. Correlation between water-table depth (A-B), temperature (C-D) and a total of bacteria and fungi of peatland as the effect of land-use change. The green, blue, orange and red circle 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 microbes diversity in both forestry and agricultural landscapes. The information is useful 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 1: 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 to analyze water quality of both rivers. Data was 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 one was at Gajah Wong middle zone. Based on Similarity Index, Winongo and Gajah Wong middle zones had the most similar diversity. Based on both scores of Family Biotic Index (FBI) and BIOTILIK Index, 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 as it is required in various daily activities. Water bodies can be polluted by the input of pollutants, as a result of activities that cause degradation of water quality and alteration in the community of aquatic organisms (Dudgeon et al. 2005; Giorgio et al. 2016). River is one type of freshwater habitat that is vulnerable to pollution and environment conversion (Dewi 2013). The river current flow is unidirectional and influenced by the state of physiology, geology, climate, flora, fauna, land use, and human activities (Anzani 2012).

Gajah Wong and Winongo are rivers that are located at Yogyakarta Special Region. 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 special values for surrounding community, as they are utilized in household utilities, home industries, agriculture, and factories. The state of both rivers is extremely alarming because they are polluted by the household and industry wastes (either organic or nonorganic), which in turn causes the water to become degraded and can not be used by the surrounding community (BLH DIY 2015).

The water quality in water bodies can be determined by the factor of dissolved substances, suspended substances, and aquatic organisms. A biological indicator is a group or a community of organisms which its presence is associated with the condition of the surrounding environment. Macroinvertebrates are very useful to be utilized as biological indicators because they have settled habitat. Composition and abundance of macroinvertebrates depend on their tolerance or sensitivity toward alteration of the environment. Alteration of water quality in macroinvertebrate habitat 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 evaluate alteration of water body quality through the response of aquatic organism systematically. 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 behavioural assays, i.e. study of the sublethal effect on tested organism, and bioaccumulation study of the contaminant dosage absorbed by the organism and its impact in the food chain. Biomonitoring is useful to evaluate the impacts of development toward 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 the 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 to determine the water quality of both rivers.
MATERIALS AND METHODS

Study area

The study area of this research were 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 represented 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)

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)
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 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)

\[ H' = -\sum P_i \ln P_i, \quad P_i = n_i/N \]

\( H' \): diversity index of Shannon-Wiener, \( n_i \): the number of individuals belong to family i, \( N \): the total number of collected individuals

Dominance Index (Simpson Diversity Index) (Firtiana 2005)

\[ C = \sum P_i^2, \quad P_i = n_i/N \]

\( C \): dominance index, \( n_i \): the number of individuals belong to family i, \( N \): the total number of collected individuals

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

\[ e = H'/ H_{max}, \quad H_{max} = \ln S \]

\( e \): 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

\( n_{1i} \): the number of individuals of the ith family in sample 1
\n(2): 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)

\[ D_M = (S-1)/ \ln N \]

\( D_M \): 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 belong to family i
\n(2): score of tolerance of family i
\n(3): the total number of collected individuals

BIOTILIK Index (Ecoton 2013)

\[ BI = X/N, \quad X = \sum x_i * t_i \]

\( BI \): BIOTILIK Index

\( x_i \): the number of individuals belong to family i
\n(2): score of tolerance of family i
\n(3): the total number of collected individuals

RESULTS AND DISCUSSION

Macroinvertebrate diversity

The highest score of Shannon-Wiener Diversity Index of macroinvertebrates was 2.412 at the upstream of Winongo. The lowest score was 1.205 at 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 ecological 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 score of 2.811. The lowest score was at the middle of Gajah Wong, 1.361. The higher the Margalef score, the higher the macroinvertebrate diversity.

Evenness index of both upstreams of Winongo and Gajah Wong were high, i.e. around 0.8. It showed that the macroinvertebrate individuals at the upstream were distributed evenly. Lowest scores of evenness index were at the middle and the downstream of Gajah Wong.

Based on figure 3., the highest score of Simpson index was 0.432 at the middle of Gajah Wong. The second highest score was 0.390 at the middle of Winongo. It showed that there were dominating families at both zones. Similarity index of the middle of Winongo and the middle of Gajah Wong valued the highest, with its value was 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. Macroinvertebrate diversity was influenced by many factors, besides current velocity.

Based on Family Biotic Index, Winongo upstream had a good status, some organic pollution probable. Status of Gajah Wong upstream and downstream was fair. Then, the other locations had very poor water quality. Based on 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             | 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  |
|              | Perlida          | 4  | 0  | 0  | 0  | 0  | 0  |
| Trichoptera  | Brachycentridae  | 1  | 0  | 0  | 0  | 0  | 0  |
|              | Goeridae         | 0  | 0  | 0  | 2  | 0  | 0  |
|              | Hydropsychidae   | 4  | 1  | 0  | 0  | 0  | 0  |
|              | Leptoceridae     | 1  | 0  | 0  | 0  | 0  | 0  |
|              | Philopotamidae   | 3  | 0  | 0  | 0  | 0  | 0  |
|              | Polycnemidae     | 0  | 0  | 0  | 2  | 0  | 0  |
| Cerithioidea | Pleuroceridae    | 27 | 4  | 25 | 10 | 0  | 2  |
| Diptera      | Chironomidae     | 1  | 64 | 38 | 18 | 107| 2  |
|              | Simulidae        | 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    | Sialidae         | 0  | 29 | 2  | 0  | 0  | 1  |
| Megaloptera  | Coenagrionidae   | 0  | 1  | 0  | 0  | 0  | 0  |
| Odonata      | Euphaeidae       | 0  | 0  | 0  | 0  | 0  | 1  |
| Pulmonata    | Lymnaeida        | 0  | 0  | 0  | 0  | 0  | 0  |
| Pulmonata    | Physidae         | 0  | 3  | 1  | 0  | 0  | 0  |
| Rhynchobdellida | Glossiphonidae  | 0  | 0  | 0  | 0  | 0  | 0  |
| Soroecooncha | Thiaridae        | 15 | 0  | 0  | 0  | 6  | 43 |
| Tubificina   | Tubificidae      | 0  | 0  | 4  | 0  | 9  | 0  |
| Veneroida    | Corbiculidae     | 0  | 0  | 0  | 0  | 0  | 3  |
| Viviparoida  | 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

| Winongo          |        |        | Gajah Wong          |        |        |
|------------------|--------|--------|---------------------|--------|--------|
|                  | Upstream | Middle | Downstream       | Upstream | Middle | Downstream |
| 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 up to tolerant to a slight amount of pollutant. The intolerant members were Heptageniidae, Leptophlebiidae, Perlidae, Chloroperlidae, Philopotamidae, and Brachycentridae, while the semi tolerant ones were Leptoceridae, Perlidae, Chloroperlidae, Philopotamidae, and Trichoptera (EPT). The EPT members were Baetidae, Caenidae, Goeridae, Polymitarcyidae, and Polycentropodidae. Individuals belong to Polymitarcyidae were the most commonly found. Evenness of the families was high, although the dominance score was low. Shallow and clear water body, with substrate composed of sand and rocks, was suitable as habitat for Polymitarcyidae. Polymitarcyidae burrows in river under rocks (Bouchard 2004) or sand. At this station, also found Gomphidae, Vellidae, Nepidae families which were not significantly tolerant to pollutants. Tolerant families were Chironomidae, Parathelpusidae, and Pleuroceridae (Rahayu et al. 2009; Eceton 2013; Blakely et al. 2014).

Based on 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 Yogyakarta Special Region. Physically, it was polluted by the household wastes such as plastic bags. 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.

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 to 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 are resulted 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 level of pollution 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 middle zones produced a bad odor. Winongo middle zone was composed of rocks, while Gajah Wong middle zone was composed of 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 belong to EPT, i.e. Hydropsychidae, and 8 other
families were non-EPT, i.e Pleuroceridae, Chironomidae, Hirudinidae, Physidae, Glossiphoniidae, Tubificidae, Corixidae, and Atyidae. Individuals belong 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 Parathelphusa. Hydropsychidae and Thiaridae were found most abundant. Based on Evenness Index, families found at Winongo downstream were distributed more evenly than at Gajah Wong downstream. Based on Dominance Index, Winongo downstream had lower score compared to 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, which its presence is limited by pollution and embeddedness of rocks, that cause the macroinvertebrate habitat 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 were found less at Winongo downstream. It suggests that the condition of water body at Winongo downstream was relatively polluted. FBI score of Winongo downstream was high, i.e. 7.85, which suggests 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 suggests 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 ecosystem of mangrove is a quite good ecosystem which is located in Torosiaje Jaya Village of Popayato Subdistrict, Pohuwato District, Gorontalo Province, Indonesia. This because of the beach in the coastal of Torosiaje Jaya Village is a gently sloping beach. Further, this beach has deposited sediment and it is formed a promontory grave that causes that mangrove in that region grows large and relatively fertile. In addition, the mangrove which is located in Pohuwato has fairly high various species. One of them is found from Avicenniaceae family namely 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 the measurement of 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 species are found, and to obtain the data of the habitat conditions of the species which has discovered is using a direct observation in the field by a tree and laboratory test sample originating from soil samples in the study sites. Moreover, the result of this study finds the four species of tree which dominates 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 are species that dominate in the region due to supply mud as suitable habitat with its growth, besides it is affected by the substrate of mangroves in the Torosiaje Jaya Village it is also affected by salinity and temperature. Further, the data which have obtained, they can be used in a management of mangrove forest which located in the coastal of Torosiaje Jaya Village and they can also be data in mangrove conservation efforts in order 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 because it can reduce CO2 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 the process of photosynthesis carbon dioxide which is from the atmosphere is absorbed by the mangrove plants and converted into organic carbon that will be distributed to all parts of the body and stored in the biomass plant. According to Nugraha (2011), it is 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 known as a famous green belt of mangrove and coastal ecosystems where the mangrove as broad enough to stretch from the District of Paguat until Popayato District of West. Mangrove areas have contained in Pohuwato fairly high species diversity. One of the mangrove species found, among others, from family Avicenniaceae namely Avicennia marina (Forsk.) Vierh. According to Dharmawan and Siregar (2008), A. marina is as one of the mangrove species that can absorb and store carbon is greater, because of habitat that is characteristic of wetlands with muddy soil types.

Based on the results of interpretation of Landsat imagery which is reported Damanik (2012), that the mangrove area Pohuwato has undergone significant changes, which in 1988 reached the mangrove area of 13243.33 hectares and in 2010 the remaining 7420.73 ha. The damage to the mangrove forests in the coastal Torosiaje Jaya Village has an impact on other Tomini bay ecosystem conditions such as Togean Islands National Park in Tojo Una-Una, Central Sulawesi Province. By reducing area of coastal mangrove 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 in order to damage that occurred in the coastal mangrove Torosiaje Jaya Village need to be immediately addressed through the information on the density, composition, and habitat, of mangrove forests. Findings of this research may serve as a database for mangrove forest conservation management purposes in
Torosiaje and other regions as well as 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 0° 28' 45"E, 121°26' 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 name of the species (as seen by recognition by the research team and mangrove identification books (Tomlinson 1986; Giesen et al. 2006). Measured the diameter of the tree is calculated based on diameter at breast height (dbh) of 1.3 m above the ground or above the buttresses, while 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, prepare the equipment that will be used for data collection in the field. (ii) The data collection stage, include the determination of the density of vegetation.

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

Each plant is contained in the quadrant, recorded the name of the species. Measured the diameter of the tree is calculated based on diameter at breast height (dbh) of 1.3 m above the ground or above the buttresses, while 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, that it was taken 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):

\[
d = \frac{d_1 + d_2 + d_3 + \ldots + d_n}{n}
\]

(1)

Where:
- \(d_1, d_2, d_3, \ldots, d_n\) = distance of each tree to the point of measurement
- \(n\) = number of trees
- \(d\) = average distance of individual trees to the measuring point

Density all species per hectare (K)
To calculate the density of all types of trees used the following formula (Indriyanto 2010):

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

(2)

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

\[
V = \frac{1}{4} \pi d^2 t f
\]

(3)

Where:
- \(V\) = volume of trees (m³)
- \(\pi\) = 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 examining soil texture (sand, silt, and clay). In addition, the examination also covered temperature, humidity and salinity aspects, which are significant factors in the development of mangrove.

RESULTS AND DISCUSSION

Result

Density, density of all species per hectare, and tree volume
Based on 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 value are 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 m² with an average distance of 581.94 (trees/3 ha). Number of trees in sampling points 300 m² 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 mangrove. Mangrove soil is alluvial, which is brought and sedimented by the river and the seawater. Alluvial can be classified as sand, silt and clay. It is these three components which form soil in different composition. Mud is composed by silt and clay which are rich in detritus.

The analysis conducted at the Laboratory of PG Tolanganhula 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 apiculata contains sand (0%), silt (33.4%), and clay (67.0%). The temperature at the Sampling Point 1 for Bruguiera gymnorrhiza ranges between 31.5-31.8°C, its salinity is between 21.6 ppt – 22.1 ppt, and its humidity level is between 84.8-85.%. At the Sampling Point 2, the temperature for Rhizophora mucronata ranges between 31.5°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 apiculata ranges between 30-30.5°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°C, its salinity is 20.5 ppt, and its humidity level is 87%; the temperature for Rhizophora stylosa is 30.5°C, its salinity is 201 ppt, and its humidity level is 86.5%; and the temperature for Rhizophora mucronata is between 30-30.2°C, its salinity is between 20-20.5 ppt, and its humidity is 87%.

Discussion
Based on the results of data density of trees in the village of Torosiaje Jaya indicate that at the sampling point 3, 2, and 1 has the highest density. This is evidenced, with 36 trees found at sampling points 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, density of all species per hectare, and tree volume at the research site

| Species names     | TS Quadrant | NP | JP (m) | DP (cm) | VP (m³) |
|-------------------|-------------|----|--------|---------|---------|
| B. gymnorrhiza    | I           | 1  | 8      | 82      | 2,566.68 |
| B. gymnorrhiza    | 2           | 12 | 86     | 2,862.65 |
| 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     | 2,862.65 |
| 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      | I           | 2  | 5      | 68      | 1,104.46 |
| R. mucronata      | 3           | 8  | 84     | 2,022.42 |
| R. mucronata      | 4           | 16 | 82     | 1,927.26 |
| R. mucronata      | 5           | 19 | 65     | 1,009.16 |
| R. mucronata      | 6           | 21 | 98     | 3,670.32 |
| R. mucronata      | 7           | 35 | 84     | 1,569.55 |
| R. mucronata      | 8           | 43 | 95     | 3,880.18 |
| R. mucronata      | II          | 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          | 8  | 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 |

Notes: TS: Sampling Point, NP: Tree Number, JP: Tree Distance, DP: Tree Distance, VP: Tree Volume

Table 2. Number of trees in sampling points 300 m² in the village of 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 skills of adaptation 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 mangrove, which is based on the results of further research towards the sea, the salinity or salt content of the higher places. Mangrove is not a plant that needed salt but mangrove is a plant that is 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...
as N, P, S, K, Ca and Mg and micro elements 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 then the growth will be stunted mangrove. According 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 dominant.

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 were 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 results of laboratory analysis, soil dominant mangrove species *Bruguiera gymnorrhiza* is a land that has 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 which 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 that is at the study site ranged from 30-31.8°C. 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 the growth of mangrove. This is confirmed by Kusmana (2010) states that if the temperature is higher than 35°C, it will give 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 influenced by several factors among which salinity, substrate, and temperature. Habitat that affects the growth of mangrove species on the coast of Torosiaje village is mangrove soil which contained sand (<5%), dust (61.1-75.3%), and clay (17.1-47.9%). The soil includes clay because of the combination of dust and clay that forms a good texture. Therefore, the substrate found in 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 with the objective 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 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 release from various sources within Guyana. The total forest coverage of Guyana is 18570000 ha containing over 5 gigatonnes of CO2 in aboveground biomass. Mangrove total coverage in Guyana is 22632.4 ha and locked 0.09gt estimated aboveground carbon which is equivalent to 0.257 gigatonnes of CO2. This is significant taking into consideration the low stature, coverage, and density of mangroves. The phenomenon of global warming has of recent has 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 the understanding of the carbon stored in the mangrove forest and its relevance to carbon dioxide trapping in the standing forest. Such relationship establishes the between holistic approach to mangrove restoration and climate change prevention strategy for Guyana.

Keywords: Mangroves, carbon storage, climate mitigation, conservation

INTRODUCTION

Mangroves are coastal forests at the interface between land and sea. They are highly dynamic ecosystems and 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 across the world (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 condition with varying salinities. With the exception of 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 cutinised 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 results in about 17% of global greenhouse gas emissions. Mangroves play a vital function in preventing and reducing coastal erosion and provides 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 rate of productivity. This means that mangroves occupying only about 0.2% of forest coverage can fix a great deal of carbon their tissues through photosynthesis (NDULP 2013). In addition to the high productivity of mangroves, there is evidence that there are also high levels of carbon being 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 the coastal zone forest area in Guyana for the period 2004 to 2009. The results indicated that coastal zone forest is 22,632.4 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).
Five mangrove species are found along most of the coastlines of Guyana with major 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, *A. 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 mangrove forest ecosystem has started to take the significant economic value as seen with the emergence of carbon markets. Its economic value arises from the knowledge that CO$_2$, a major 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). 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 mangrove ecosystem is a vital carbon sink (Bouillon et al. 2009). The comparatively high aboveground biomass carbon together with carbon-rich soils resulted in the presence of 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 that in Palau the estimated aboveground biomass carbon was 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 Solomon Islands by Albert et al. (2012) also revealed that the aboveground component of mangrove contained the range of 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 effects of 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 a lot of important functions and offer a wide range of services at the local and national levels. Fishermen, farmers and other rural populations depend on mangroves as a supply of wood (e.g. charcoal, fuel wood, timber, poles, posts) and non-wood forest products (food, thatch, fodder, alcohol, sugar, medicine and honey). Mangroves are also used for the production of tannin suitable for leather industry (FAO 2007). Mangrove forests provide many ecological services such as protection of 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, spawing grounds, nurseries and nutrients for a number of animals. Mangroves play a critical role in providing protection of the coastal zone by breaking the force of the wind. Ina 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 thereby lowering of the global temperature (Kridiborworn et al. 2012). Mangroves are known to have high productivity (Spalding et al. 2010) and can, therefore, sequester carbon. Global estimates indicated the mangrove forests have the potential of fixing about 17 metric tons of carbon/hectare/year (NMMAP 2010).

However, no comprehensive study was done to ascertain the amount of carbon that is stored in the mangrove forest in Guyana. This research is intended to estimate carbon storage in the three protected species and also to 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. Will also help to quantify the carbon stored in the mangrove forest as well as help to create an understating and relevance between the carbon and carbon dioxide trapped in the standing forest. Developing such relationship will establish the foundation in fostering 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 W0580 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 W0580 15.6 071) {Plate 4}; Region 4: Coven John (N 090 13.6 421 W 0590 32.2 751) {Plate 5}. (iii) Berbice: Region 5: (N060 36.7 991 W570 36.181) {Plate 6}; Region 6: Borlam (N060 23.781 W0570 14.176). {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 other study areas.

Aboveground trees
Diameter at breast height (1.3 meters above ground) 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 on the basis of species type and categorized into diameter class 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 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 right around the tree. (iii) As the DBH tape 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, always 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, then 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 presences of green leaves.

Tree height. Tree height was determined with the use of 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
Aboveground non-tree vegetation was measured by harvesting techniques. For herbaceous plants, a 30 x 30cm square sample frame made from PVC pipe is sufficient for sampling. For shrubs and other large non-tree vegetation, use larger frames (1m² or 2m²). All vegetation within the frame to ground level was clipped. The frame was viewed as extending vertically and any vegetation falling outside the boundaries of the plot (even if is begun inside the plot) would be excluded. The sample was weighed and a well-mixed subsample was removed for determining 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 defined as 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 dead wood with a diameter of >10cm will be included in the litter layer. Litter was sampled at least the 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 the 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 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. Quadrat
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 be used to 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, stem and, where possible, aboveground roots.

The total harvested fresh mass of each component 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 °C. The subsample dry mass of each component would be calculated from the ratio of dry mass 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 that were 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

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

Region 1: Barima-Waini

Barima-Waini is located in the northwest of the Guyana. This region is heavily forested with total land coverage of 20,339 km² with a population of 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 Cayuni-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 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

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

The study area was Better Hope which is 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 (>5 cm) were 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 mangrove trees measured were 88 while the average among the plots was 29.33 ± 4.16 with the highest mean diameter class distribution of >10-20 cm with 17.67±3.79 and 60.23 % of the overall stand and no tree at >40 cm. The trees density was 1496 tree/ha. 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 fresh water intrusion through a drainage canal that comes from the rice field area. A Large section of the area is deforested which resulted from high tidal energy and movement of the mud flat (Woodroffe 1987; Sherman et al. 2001; Cahoon and Hensel 2006, Adame et al. 2013).

Region 3: Essequibo Islands-West Demerara

Essequibo Islands-West Demerara is bisected by the Essequibo River. 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 Ruimzeght (6°50'31"N 58°13'6"W) which is 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 were measured.
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 mean among the plots of 0.67±0.58. The other diameter classes were consistent with 14.29% distribution and an average of 0.33±0.58. The average number of trees was 2.33±0.20 among the plot while the tree density was 119 trees/ha (Table 3). Minimum DBH of *R. mangle* was 6.0 cm while the maximum being 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 >5 cm at 5.26 % at1.67±0.58 among the plots while 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 the >20-30 diameter class both species. 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 which can prevent the roots from breathing freely. Pollution appeared to have an impact on the growth and development of the mangrove species. Most of the garbage appeared to have floated and deposited there from other places (Sherman et al. 2001; FAO 2007).

**Region 4: Demerara-Mahaica**

Demerara-Mahaica is bordered by the Atlantic Ocean to the north, Mahaiaca-Berbice to the east, Upper Demerara-Berbice to the south and the Essequibo Islands-West Demerara to the west. It land coverage is 4,170 km² with a population of 52,400 (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 were 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 trees density was 1241 tree/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 together with 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**

Mahaica-Berbice is bordered by the Atlantic Ocean 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 km² 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 were measured.

| DBH/cm | *R. mangle* | *A. germinans* |
|---|---|---|
| **Tress** | **Tree Density (ha)** | **Dominance (%)** | **Tress** | **Tree Density (ha)** | **Dominance (%)** |
| **(Mean ± SD)** | | | **(Mean ± SD)** | | |
| 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±0.20** | **119.00** | **100.00** | **31.67±8.50** | **1615.00** | **100.00** |

Table 3. Summary of tree measurement in Region 3

| DBH/cm | *R. mangle* | *A. germinans* |
|---|---|---|
| **Tree** | **Tree Density (ha)** | **Distribution (%)** | **Carbon Density** |
| **(Mean ± SD)** | | | **(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** |

Table 5. Summary of tree and carbon densities in Region 4
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 trees density was 1377 tree/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) at the DBH class interval >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

*East Berbice-Corentyne* is bordered by the Atlantic Ocean 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-Uper Essequibo to the west. Its land coverage is 36,255 km² with a population of 161,412 (Macmillan 2009; Census 2002). The study area was Borlám which is 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 were 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 mean among the plots of 0.67±1.15 whilst the other diameter classes having a consistent distribution of 20% with the average being 0.33±0.58 (Table 7). Minimum DBH of *R. mangle* was 6.0 cm while the maximum being 35.2 cm. The minimum DBH of *R. mangle* was 6.3 with the maximum being 39.0 cm. The tree density was 85 tree/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 minimum DBH of *A. germinans* recorded was 5.3 cm while the maximum being 50.1 cm (Table 8). The mean DBH was 25.86 ± 12.37 cm which indicated normal distribution patterns of the *A. germinans* species in the area. The area is affected by human pressure and influence, especially of recent. 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 which will eventually lead 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 also increases (Stone and Leon 2010).

### Table 7. Summary of tree measurement in Region 6

| DBH/cm | *R. mangle* Distribution (%) | *A. germinans* Distribution (%) |
|--------|-----------------------------|---------------------------------|
| 5-10   | 10.67±3.21                  | 454.00                          |
| >10-20 | 13.00±1.73                  | 663.00                          |
| >20-30 | 2.33±2.31                   | 119.00                          |
| >30-40 | 0.33±0.58                   | 17.00                           |
| >40    | 0.67±1.15                   | 34.00                           |
| Total  | 27.00±1.00                  | 1377.00                         |

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

| DBH/cm | Tree Density/ha (Mean ± SD) | Tree Density/ha Distribution (%) | Carbon Density/Mg/ha (Mean ± SD) |
|--------|-----------------------------|---------------------------------|----------------------------------|
| 5-10   | 10.67±3.21                  | 454.00                          | 91.73±19.91                     |
| >10-20 | 13.00±1.73                  | 663.00                          | 30.77±5.62                      |
| >20-30 | 2.33±2.31                   | 119.00                          | 28.10±19.55                     |
| >30-40 | 0.33±0.58                   | 17.00                           | 7.06±12.15                      |
| >40    | 0.67±1.15                   | 34.00                           | 21.01±36.39                     |
| Total  | 27.00±1.00                  | 1377.00                         | 91.73±19.91                     |

### Table 8. Summary of carbon density Region 6

| DBH/cm | Carbon Density/Mg/ha (Mean ± SD) |
|--------|----------------------------------|
| 5-10   | 0.21±0.28                        |
| >10-20 | 1.01±1.42                        |
| >20-30 | 9.05±12.79                       |
| >30-40 | 17.95±25.39                      |
| >40    | 0.00±0.00                        |
| Total  | 28.21±39.31                      |

### Summary of carbon density Region 6

| DBH/cm | Tree Density/ha (Mean ± SD) | Tree Density/ha (Distribution/%) | Carbon Density/Mg/ha (Mean ± SD) |
|--------|-----------------------------|---------------------------------|----------------------------------|
| 5-10   | 10.67±3.21                  | 454.00                          | 91.73±19.91                     |
| >10-20 | 13.00±1.73                  | 663.00                          | 30.77±5.62                      |
| >20-30 | 2.33±2.31                   | 119.00                          | 28.10±19.55                     |
| >30-40 | 0.33±0.58                   | 17.00                           | 7.06±12.15                      |
| >40    | 0.67±1.15                   | 34.00                           | 21.01±36.39                     |
| Total  | 27.00±1.00                  | 1377.00                         | 91.73±19.91                     |
Riverine forest

Riverine forest type occurs along the floodplain of the river and creek drainages and is flushed by fresh water 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 include 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 between 160 and 320 km from the sea. The Berbice River's mouth is the location of Cabr Island, opposite the mouth of the Berbice 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 (Macmillan 2009; Census 2002). 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 mean among the plots of 8.67±3.06 and the lowest distribution was in the diameter class >40 with a mean of 1.33±1.15. Minimum DBH of R. mangle was 5.2 cm while the maximum is 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 tree/ha (Table 9). The mean DBH for R. mangle in Berbice River was 24.94±12.14. The total 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   | 14.6±16.23            | 2.14±1.86               |
| >20-30   | 33.8±18.48            | 0.00±0.00               |
| >30-40   | 227.29±109.72         | 0.00±0.00               |
| >40      | 61.6±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 | Trees (Mean ± SD) | R. mangle Tree Density/ha | Distribution /% | Trees (Mean ± SD) | A. germinans 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         |
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 which is one of the many islands found 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 were 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 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. mangle 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 Essequibo River was 17.53±7.73 cm. The mangrove forest ecosystem is stable and less affected by human influence. The area is not within close proximity to a residential area and therefore less contact with the inhabitants for usage 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).
Mangroves of all the diameter classes were found in all the study areas. The total distribution of mangroves in Guyana based on the research indicated that for *R. mangle* the maximum distribution existed in the diameter class >10-20 cm while 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 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 not available when estimating the biomass of the tree (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 that there is 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 *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 the penetration of light to allow the growth of forest floor vegetation. Region 6 shows a higher amount of carbon stored in non-tree vegetation. This is because there is more canopy opening and less trespassing of individuals in the area.

**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 litter while Region two shows the least amount (Table 17). The regions with the highest significant amount of litter and consequently carbon being less frequently flooded thereby leaving most of the litter on the floor.

**Soil carbon**

Soil also serve as an important 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 | 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      | 4097.10              | ND        | ND                |
| 3      | 1513.50              | 3.06±0.53 | 4646.41±1.65      |
| 4      | 91.9                 | ND        | ND                |
| 5      | 2082.80              | ND        | ND                |
| 6      | 4685.30              | 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 soil in highest (500 Mg/ha) in Region one while the lowest is in Region 4 (298 Mg/ha) (Table 18). The soil contained a significant amount of carbon that is trapped in mangrove forest, the estimated global average if 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 forest 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 where application in the dead wood also. However, none of the study sites and more 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 forest 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 release from various sources within Guyana. The total forest coverage of Guyana is 18570000 ha containing over 5 gigatonnes of CO₂ in aboveground biomass (MNRE 2012). Mangrove total coverage in Guyana is 22632.4 ha and locked 0.09gt estimated aboveground carbon which is equivalent to 0.257 gigatonnes of CO₂. This is significant taking into consideration the low stature, coverage, and density of mangroves (Spalding 2010). The phenomenon of global warming has of recent 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 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 carbon storage potential in Guyana's mangrove ecosystems reflects a comparatively low (0.12%) level of mangrove forest coverage in relation to other forest ecosystems. In light of Guyana's commitment to a low carbon development strategy, the carbon storage potential of mangrove relative to its small areal extent, underscores the need for strategies, not only to preserve existing mangrove forests but to restore and indeed expand the areal coverage of mangrove. These measures will serve to enhance the carbon storage potential of mangrove ecosystems in Guyana and better synchronized 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) Development of a mangrove expansion/conservation strategy/policy, indicating specific timeframes and benchmarks. (iii) Institute a program for monitoring trends in carbon stock. (iv) Ecological modelling for carbon storage prediction in relation to 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, but especially in primary and high schools. (vii) Conduct a review of mangrove conservation-related policies, programs, regulations in Guyana.

In conclusion, the results indicated that there is 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 Chi-square test there is a significant difference in carbon storage in all the regions (1-6) of Guyana. The maximum storage capacity was observed in region 1 which is statistically significant. This is due to the high mangrove coverage in that region which is 49.9 % of the other 5 regions. The present study proved with all statistical subjugation that mangrove ecosystem contributes significantly towards absorbing carbon dioxide thereby reducing the effects of global warming.

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| Title                                                                 | Pages |
|----------------------------------------------------------------------|-------|
| Two new host for *Caligus bonito* C.B., 1905 (Copepoda, Siphonostomatoida, Caligidae) from Turkey | 1-3   |
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| Recent record of Masked Finfoot *Heliopais personata* in Indonesia after 17 years | 8-10  |
| Distribution and abundance of aquatic plants of Oyan Lake, Ogun State, Nigeria | 11-15 |
| Phytoplankton distribution in Mikawa Bay of Japan in relation to environmental factor | 16-25 |
| Differentiation of soil organisms at different types of peatland in West Kalimantan, Indonesia | 26-30 |
| Macroinvertebrate diversity role in Water Quality Assessment of Winongo and Gajah Wong Rivers, Yogyakarta, Indonesia | 31-37 |
| The density, composition and mangrove forest habitat in coastal areas of Torosiaje Jaya Village, Gorontalo, Indonesia | 38-42 |
| Carbon storage potential of mangrove forest in Guyana | 43-54 |