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The mangrove flora and their physical habitat characteristics in Bunaken National Park, North Sulawesi, Indonesia

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Abstract. *Djamaluddin R. 2018. The mangrove flora and their physical habitat characteristics in Bunaken National Park, North Sulawesi, Indonesia. Biodiversitas 19: xxxx.* The mangrove forests of Bunaken National Park are among the most distinctive and unusual in Southeast Asia because of the species that the forests contain. This study investigated the identity and diversity of mangrove plants as well as physiographic factors and major physical processes of every type of sub-habitats. Seven surveys were conducted to collect and identify mangrove species of the park. Sub-habitats where specimen were found, aspects related to tidal inundation, nature of soil, freshwater influence and topography were observed as well as major physical processes influencing the condition of each sub-habitat. The results suggested that the park was floristically rich with at least 27 plant species and they were distributed over ten recognised sub-habitat types in different composition and diversity. *Ceriops zeppiliana* Blume, *Lumnitzera racemosa* Willd, *Lumnitzera littorea* (Jack) Voigt., *Sonneratia ovata* Backer, and *Camptostemon philippinense* (Vidal) Becc. were found in Bunaken National Park and their presence confirmed the broader distribution limit of these species within Indo-Malesia region. A special notice was for *C. philippinense* as the distribution limit of this is rarely reported.

Keywords: Bunaken, *Camptostemon philippinense*, *Ceriops zeppiliana*, Indo-Malesia, mangrove

INTRODUCTION

Whatever the origin of the term of mangrove, whether it is derived from ‘mangle grove’ which refers to *Rhizophora mangle* Linnaeus or from the old Malay words ‘mangin’ or ‘manggi-manggi’ (Claridge and Burnett 1993), or from the national language of Senegal ‘mangue’ (Vannucci 1998), this term is now applied to those species, a relative small group of higher plants, or the whole community of plants, which have been peculiarly successful in colonising tropical and sub-tropical intertidal habitats at the interface between land and sea (Clough 1979; Duke 1992; Maxwell 2015). Mangrove vegetation includes a range of functional forms, including trees, shrubs, palms and ground ferns (Duke et al. 1998). Mangrove can tolerate salt and brackish waters (Spalding et al. 1997), because the plants have developed complex morphological, anatomical, physiological, and molecular adaptations allowing survival and success in their high-stress habitat (Srikanth et al. 2015).

Global distribution of mangrove have been explained in various reports (e.g. Gieasen et al. 2006; Spalding et al. 2010; Richards and Friess 2015; Hamilton and Casey 2016). Southeast Asia supports the world’s largest area of mangroves, originally extending over 5.1 million ha and representing 33.5 % of the world’s total (Spalding et al. 2010). The largest areas of mangrove in Southeast Asia are found in Indonesia (almost 60 percent of Southeast Asia’s total) (Gieasen et al. 2006). In 2000 total mangrove area was estimated at approximate 2,788,683 ha with the percentage of mangrove loss was of 1.72% between 2000 and 2012 (Richards and Friess 2015).

Indonesia’s mangroves include two biogeographical regions, i.e., Indo-Malesia and Asia, Australasia and the western Pacific (Duke et al. 1992). The lists of mangrove species within these regions have been improved by Duke et al. (1998) in which 50 mangrove species were found in Indo-Malesia and 47 species in Australasia, including several putative hybrids. However, 39 species were overlapped between the two biogeographical regions, thus the total number of species in both biogeographical regions is 57 species. Gieasen et al. (2006) found that mangrove in Indonesia has 48 species and in Bunaken National Park alone, some 32 true mangrove species may be found (Tomlinson 1986), thus Indonesia has the highest mangrove diversity in the Southeast Asia.

Oceanic circulations and climate regime may influence the distribution of mangroves (Thom 1982). The marine environment of Bunaken National Park is under the influence of dominant seawater mass coming from northern Pacific Ocean to Indian Ocean flowing through Makasar Strait that separates Sulawesi and Kalimantan (Van Bennekom 1988). The flow of seawater mass from northern Pacific is strengthened by the Mindanao Current coming from the coastal areas in the southeast of the Philippines Archipelago (Bingham and Lukas 1994). Climatically, the coastal environments of the park is influenced greatly by the equatorial condition which is usually far from extreme climatic conditions with more proportion of wet season and little range of temperature between 25.5°C and 27.0°C.

The mangrove forests of the Bunaken National Park are among the most distinctive and unusual in Southeast Asia because of the species that the forests contain (Davie et al. 1996; Djamaluddin 2004). It is believed that the interplay between geophysical, geomorphic and biological factors has supported the mangrove distribution and diversity in the intertidal environments of the park. This study investigated mangrove species across various sub-habitat types within the park, geographical distribution limits of certain species within Indo-Malesia region, and spatial distribution of mangrove species as the consequences of species adaptation to major environmental conditions.

MATERIALS AND METHODS

Study site and climate

The Bunaken National Park is situated on the North coast of Sulawesi Island. The Park consists of two sections, the northern section ($1^0$34'48.8" N-$124^0$39'27.8" E; $1^0$49'26.8" N-$124^0$51'32.4" E) and the southern section ($1^0$26'24.7" N-$124^0$39'24.7" E; $1^0$16'50.5" N-$124^0$28'54.8" E). The total area covered by the northern sections was 62,150 ha including the five islands of Bunaken, Siladen Manado Tua, Mantehage, Nain and the mainland coast between Tiwoho and Molas. The southern section was restricted to the mainland coast between the villages of Poopoh and Popareng, covering a total area of 16,906 ha. Although the primary conservation concern responsible for the creation of the Park was the coral ecosystem, the reserve also supports about 2,000 ha of mangrove forests that includes 1,000 ha in Mantehage Island (Survey Area A1), about 200 ha between Molas and Tiwoho (Survey Area A2) and 800 ha between Poopoh and Popareng (Survey Area B). A map of the study location and surveyed areas is provided in Figure 1.

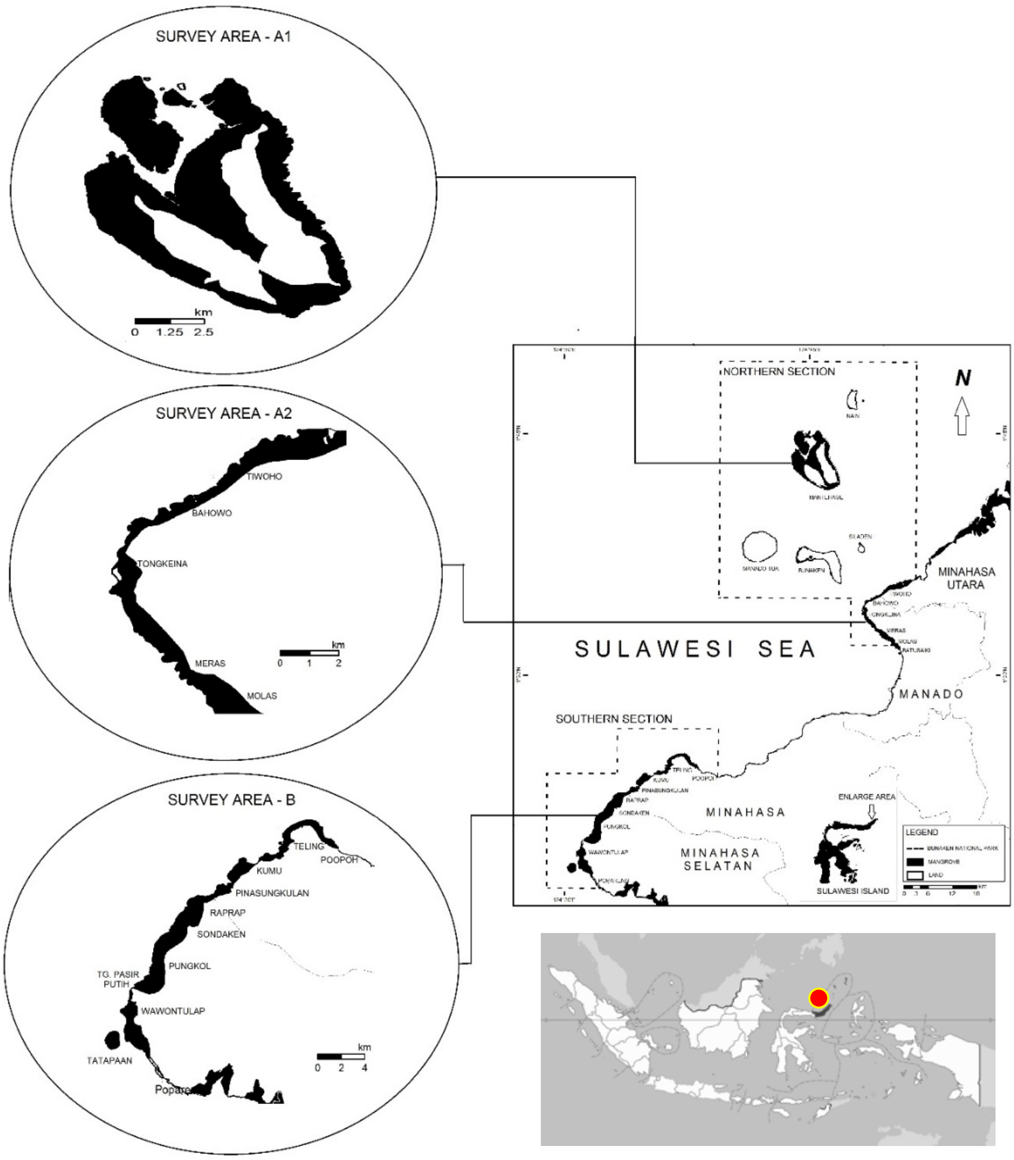

Figure 1. The study areas of Bunaken National Park, North Sulawesi, Indonesia

The rainfall in the study area is strongly affected by the wind systems. The north-westerly winds blow over the South China Sea and bring moisture during September and April. In November these winds arrive in the North Sulawesi via the Sulawesi Sea and to the west coast of south Sulawesi in late of November or early of December. Dry south-easterly winds blow from the wintery Australian land mass towards eastern Sulawesi. These dry winds cause a short dry season in Manado from August to October. The total annual rainfall in northern section of the park reaches 3,000-3,500 mm with 2,200 mm during the wet season (November-April) and 1,100 mm during the dry season (May-October). In the southern section of the park the rainfall is lower and ranges from 2,501-3,000 mm. The timing of the wet and dry season is the same as the north. Based on data of annual temperature during 1973-2016, the annual temperature of North Sulawesi varied little between 25.5 °C and 27.0 °C. The minimum annual mean temperature was 25.5 °C recorded in 1984 and the maximum was 27.0 °C occured in 2015.

Specimen collection

Seven surveys were carried out between November 1995 and September 2016 to collect all mangrove specimens within the Bunaken National Park. The first survey was conducted between November and December 1995 through a community-based survey (i.e., specimens were collected by the local people) resulted in the collection of specimens of all plants recognized by the local people as separate species and for which they had local names. The second survey was carried out in January 1996 and the third survey in June 1999, in 23 locations in Survey Area A1, seven locations in Survey Area A2 and 36 locations in Survey Area B. Specimen collections in the second and third surveys were made after the sub-habitat descriptions were made. The fourth survey was conducted in January 2002 to confirm identification of a number of species which were still uncertain in the previous surveys. The fifth survey was carried out between August 2002 and September 2004 in 10 locations of mangrove around Tiwoho Village (Survey Area A2). The sixth survey was conducted between October 2012 and October 2013 in the mangrove area between two islets in Mantehage Island (four locations in Survey Area A1). This sixth survey was aimed to investigate the massive dieback of mangroves and possible new establishment of mangrove species. Four locations in mangrove areas between Poopoh and Pinasungkulan (Survey Area B) were also visited several times to check the presence of unrecorded species in the previous surveys. The last survey was conducted in September 2016 to check the mangrove species establishment at restored site of Tiwoho (A2). Field determination of the flora were based on morphological characteristics that were compared to a number of references (e.g. Van Stennis 1955-58; Ding Hou 1958; Tomlinson 1986; Mabberley et al. 1995; Noor et al. 2006). All the specimens used for determination of the flora were photographed and documented. All surveyed locations were presented in Figure 2.

Description and classification of mangrove sub-habitat types

A visual analysis of coloured aerial photographs (1:6,000 scale; taken in 1993) was conducted to describe general physical condition of mangrove ecosystems and to identify specific locations that were expected to have different physical conditions. Ground checks were made to ensure a representative sample was taken of all the various types of environmental settings. Description and classification of sub-habitat types were based primarily on dominant physical factors and processes including level of inundation in relation to elevation, local water circulation pattern, freshwater inflow, and specific soil characteristics of texture, salinity and field moisture content. The pattern of seawater circulation was observed visually during ebb and spring tides. The level of tidal inundation was determined using a measuring stake. Soil samples were taken from ten sub-habitat types at three different times. Samples were taken at 0-300 mm depth at five random points in every type of habitat and these were pooled prior to laboratory analysis. Soil texture was determined using the pipette method. Soil salinity was measured using a Hand Refractometer (ARTAGO S/MILL) on the water samples of a known volume eluted through sediment samples. Soil Field Moisture Content (FMC) was determined using the procedure by Gardner (1965) based upon water lost from the weight soil samples oven-dried at 105 °C to constant weight. Biodiversity Professional (Version 2.0) was used for Bray-Curtis Cluster Analysis with Sorensen similarity to group sub-habitats based on species presence. All sampling points for the observation of physical sub-habitat characteristics are shown in Figure 2.

RESULTS AND DISCUSSION

Mangrove flora

There were 27 species from 12 families were found in the mangrove forests of the Bunaken National Park (Table 1).

It was revealed from the Tiwoho survey (Survey Area A2) that one specimen of *C. zippeliana*, formerly recognised as *C. decandra* in the majority of its range (Sheue et al. 2009; Duke et al. 2010), was introduced in early of 2000 but had never been successful in its natural regeneration. *B. cylindrica* that was previously known to occur only at estuarine sub-habitat in Mantehage Island (Survey Area A1) was found in the latest survey at mangrove near Pinasungkulan ($1^0$22’56.4” N; $124^0$34’27.3”-Survey Area B) as young trees under canopy species dominated by *R. apiculata*. One specimen of *S. ovata* was also recorded, at a landward site with freshwater input, in Tiwoho ($1^0$35’31.0” N; $124^0$50’37.9” E-Survey Area A2).

There were five species not found in the mangrove forests of the Park compared with the broader longitudinal biogeographic region between 120^0 and 135^0 E defined by Tomlinson (1986). These species were *Aegialitis annulata* R. Browm, *Aegiceras floridum* Roemer & Schultes, *Bruguiera exaristata* Ding Hou, *Bruguiera hainesii* C.G. Rodgers and *Osbornia octodonta* F. Muell. Later studies reported that species of *A. floridum* occurred in the intertidal environment on Pulau Pondang (0^{0}25’00.3” N; 124^{0}20’59.8” E) and *O. octodonta* in the intertidal habitat within the area of Panua Nature Reserve (0^{0}27’45.3” N; 121^{0}58’54.5” E). Both locations are situated in Tomini Gulf, to the east and south coast of the north arc of Sulawesi Island (Damanik and Djamaluddin 2012; Djamaluddin 2015). In addition to the species in Table 1 there were several major association of species including *Caesalpinia bonduc* (Linnaeus) Roxb. (Fabaceae), *Clerodendrum inerme* (L.) Gaertn. (Verbenaceae), *Hibiscus tiliaceus* Linnaeus (Malvaceae), *Scaevola plumieri* (Linnaeus) Vahl. (Goodeniaceae) and *Terminalia catappa* Linnaeus (Combretaceae).

This study found new distribution of several other species within the Indo-Malesia region since they have not been reported to occur in this region. These included *C. zippeliana* (Ding Hou 1958); *Lumnitzera* sp. (Excell 1954); *S. ovata* (Chapman 1970); *C. philippinense* (Chapman 1976). The occurrence of *S. ovata* in Bunaken National Park represents the northern distribution of this species since it has not been reported here before (e.g. Chapman 1970; Spalding et al. 1997). Compared to the distribution limit of *Lumnitzera* sp. proposed by Excell (1954), the presence of *L. littorea* and *L. racemosa* in the study area confirmed that the broader distribution limit of these species within Indo-Malesia. Special notice was also drawn to the presence of *C. philippinense* in this region since the distribution limit of this species was rarely reported (Chapman 1976; Tomlinson 1986). Individual trees of this species occurred only at one small location in Mantehage Island (1^{0}42’59.4” N; 124^{0}45’31.2” E-Survey Area A1). This location was expected to be the distribution limit of *C. philippinense* since it was common only in the Philippines (Giaesen et al. 2006), although Mukhlisi and Sadiyasa (2014) reported tthe occurance his speciesin Berau of eastern Kalimantan (and in Donggala of western coast of Central Sulawesi (Wahyuningsih et al. 2012), but it was of absent from any reports of mangrove surveys in the south coast of northern Sulawesi (Damanik and Djamaluddin 2012; Djamaluddin 2015) and in the West Papua (Prawiroatmodjo and Kartawinata 2014).

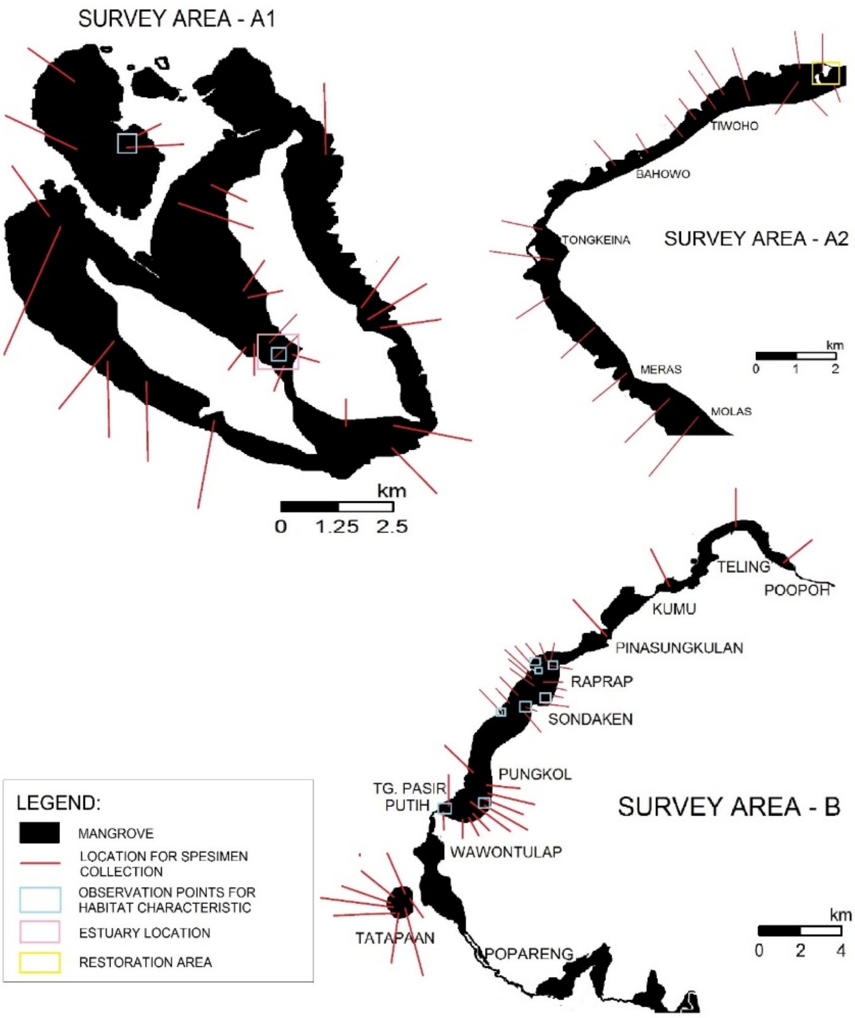

Figure 2. Locations of plants collection and observation for physical sub-habitat characteristics in Bunaken National Park, North Sulawesi, Indonesia

Table 1. The mangrove plants of Bunaken National Park, North Sulawesi, Indonesia

Family	Species	Local name	Common name
Achanthaceae	*Acanthus ilicifolius* Linnaeus[1]	Gahana, Kammunte	Holly mangrove
	Avicennia alba Blume[2]	Api-api	Api-api putih
	Avicennia marina (Forssk.) Vierh[1,2,3]	Api-api	Grey/white mangrove
Bombacaceae	*Camptostemon philippinense* (Vidal) Becc.[1]	Kayu pelompong	-
Combretaceae	*Lumnitzera littorea* (Jack) Voigt.[1,2]	Lolang bajo	Red-flowered black mangrove
	Lumnitzera racemosa Willd[1]	Lolang bajo putih	White-flowered black mangrove
Euphorbiaceae	*Excoecaria agallocha* Linnaeus[1,2,3]	Buta-buta	Milky mangrove, Blind-your-eye
Meliaceae	*Xylocarpus granatum* König[1,2,3]	Kira-kira	Cannonball mangrove
	Xylocarpus molucensis Pierre[2,3]	Kira-kira	Cedar mangrove
Primulceae	*Aegiceras corniculatum* (Linnaeus) Blanco[1,2,3]	Rica-rica, Anting-anting	River mangrove, Black mangrove
Arecaceae	*Nypa fruticans* (Thunb.) Wurmb.[1,2,3]	Bobo	Mangrove palm
Pteridaceae	*Acrosticum aureum* Linnaeus[1,2,3]	Paku pece	Golden mangrove fern
	Acrosticum speciosum Wildenow[1,2,3]	Paku pece	Showy mangrove fern
Rhizophoraceae	*Bruguiera cylindrica* (Linnaeus) Blum[1,3]	Ting putih	Large-leafed orange mangrove
	Bruguiera gymnorrhiza (Linnaeus) Lamk.[1,2,3]	Makurung laut	Large-leafed orange mangrove
	Bruguiera parviflora Weight & Arnold ex Griffith[3]	Makurung	Small-leafed orange mangrove
	Bruguiera sexangula (Lour.) Poir.[3]	Makurung darat	Upriver orange mangrove
	Ceriops zippeliana Blume[2]	Ting papua	Tengat merah
	Ceriopa tagal (Perr.) C.B. Robinson[1,2,3]	Ting biasa	Rib-fruited yellow mangrove
	Rhizophora apiculata Blum[1,2,3]	Lolaro merah	Corky stilt mangrove
	Rhizophora mucronata Lamk.[1,2,3]	Lolaro putih	Upstream stilt mangrove
	Rhizophora stylosa Griffith[1,2,3]	Lolaro putih	Long-styled stilt mangrove
Rubiaceae	*Scyphiphora hydrophyllacea* Gaertn.f.[1,2,3]	Lemong pece	Yamstick mangrove
Lythraceae	*Sonneratia alba* J. Smith[1,2,3]	Posi-posi	White-flowered apple mangrove
	Sonneratia caseolaris (Linnaeus) Engler[2]	Posi-posi	Red-flowered apple mangrove
	Sonneratia ovata Backer[2,3]	Posi-posi	Ovate-leafed apple mangrove
Sterculiaceae	*Herritiera littoralis* Dryand[1,2,3]	Kolot kambing	Looking-glass mangrove

Note: [1)] species found in mangroves of Mantehage Island, Survey Area A1, [2)] species found in mangrove of coastal mainland between Molas and Tiwoho, Survey Area A2, [3)] species found in mangrove between Poopoh and Popareng in the southern section of the Park, Survey Area B

Sub-habitat types and their physical characteristics

Mangroves within the Park were found to occupy at least ten different types of sub-habitat based primarily on physical conditions and processes. Generally these ten sub-habitats could be classified into two main groups, i.e., estuarine and coastal mangrove ecosystems. Based on the elevation relative to the sea level, estuarine mangrove comprised of up and intermediate locations. Whereas coastal mangrove ecosystems comprised of three recognisable elevations i.e., low, intermediate and high elevations. How these ten sub-habitat types were categorised, as well as their relative position across the mangrove forest of Bunaken National Park is presented in Figure 3.

As can be seen from Figure 3 that there was an estuary (sub-habitat 1) in the Park. At low elevation four types of sub-habitat were recognised; seaward fringe (sub-habitat 2), coralline sand berm (sub-habitat 3), tidal water impoundment (sub-habitat 4) and seaward young soil (sub-habitat 5). At intermediate elevation there were two major sub-habitat types of very stable and flat middle zone (sub-habitat 6) and tidal stream edge (sub-habitat 7). But sub-habitat 7 was also found at high elevation. Three other main sub-habitat types comprised of less steep slope and eroding landward fringe (sub-habitat 8), a highly accreting inland fringe (sub-habitat 9) and a seasonal or regular freshwater influenced landward fringe (sub-habitat 10). Characteristics of each sub-habitat type in relation to various conditions of physical environment are presented in Table 2.

Sub-habitat 1 was located in the center of Mantehage Island (Figure 2). This was subjected to sedimentation from nearby land systems and under influence of seasonal freshwater inflow from run-off. There were two deepest parts or undeveloped lagoons located near the center of this sub-habitat. As this was only reached by seawater at high tide, surface substrate of areas around the lagoons might be drier due to excessive evaporation. In contrast, these areas could be inundated by freshwater during wet season.

Sub-habitat 2 was common type in the Mantehage Island and coastal mainland. This was located at about Mean Seawater Level (MSL), being inundated up to 77 times month^{-1}. Its extent depended upon the topography of a mangrove forest. The flatter a mangrove forest the wider the habitat will be. In the Mantehage Island, most of the mangrove forest was narrow with the exception for the mangrove area in the northern side which was subjected to sedimentation and had a relatively flat topography. Another typical characteritic of this sub-habitat was of the absence of freshwater inflow.

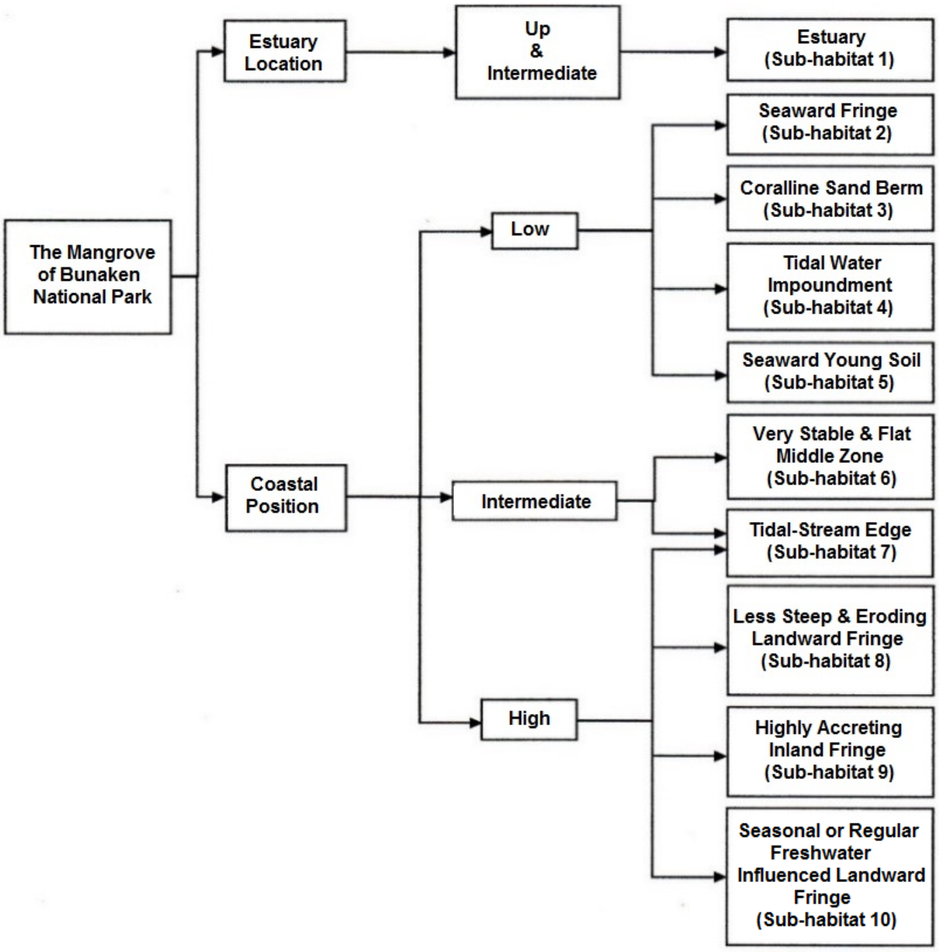

Figure 3. Estuarine and coastal locations of mangrove sub-habitats in Bunaken National Park, North Sulawesi, Indonesia (the terms up and intermediate for sub-habitat ; andlow, intermediate and high for sub-habitat 2-10 refers to the elevation of these habitats relative to sea level)

Sub-habitat 3 was found in the mangrove islands to the north of Mantehage Island and the mangrove island of Tatapaan in the southern section of the Park. This sub-habitat type was characterised by its coral sand berm sediments lying on dead coral reef, convex form of topography and low elevation relative to sea level. Most areas of this sub-habitat were inundated at almost all time and no freshwater supply into this sub-habitat.

Sub-habitat 4 was found at one location, near Tanjung Pasir Putih, in the southern part of the park. Due to its concave topography, this sub-habitat was permanently inundated including during low tide level. The sediment mainly composed of fine and well-draining sand and small proportion of organic matter and the water was mixed with the freshwater from seepage and run-off.

Sub-habitat 5 was another type of mangrove islands. This was located just in the front of the seaward end of tidal channel of the mangrove forest near Sondaken Village in the southern part of the park. Overwash, formed by the accumulation of mostly non organic sediment transported through the tidal channel was in the low elevation. No freshwater was observed to influence this sub-habitat.

Sub-habitat 6 was the most common habitat, comprised up to 50% of the total mangrove forests. This sub-habitat type was located at intermediate elevation relative to sea level and was inundated up to 53 times month^{-1} but freshwater influence was of insignificant. The sediment was dominated by organic matter.

Sub-habitat 7 was common in the southern part of the park where tidal channel components usually dissect the mangrove belt. This sub-habitat type could be found from intermediate to high elevation along a tidal channel in which bank was prograded at one side and eroded at another. Level of tidal inundation varied along the tidal channel depended the position of the sub-habitat at intermediate or high elevation. Seasonal freshwater influence from seepage and run-off was significant at high elevation near the coastline.

Sub-habitat 8 was of common habitat over the mangrove forest in the park. This habitat located at high elevation relative to sea level and was inundated up to 10 times month^{-1}. Topography of this habitat was usually in less steep slope. Freshwater might influence this habitat from seepage and run-off at seasonal period.

Sub-habitat 9 occurred at the inland mangrove area between Rap-rap and Sondaken in the southern part of the park that was subjected to massive sedimentation from the near land. This habitat was at high elevation relative to sea level, the surface of substrate was not smooth as it had many mounds and was inundated only at maximum high spring tide. Freshwater might flowed seasonally from the nearest land through seepage and run-off.

Sub-habitat 10 located at high elevation relative to sea level and had a flat to less steep topography. Surface substrate was always wet and deep. This habitat was inundated up to 10 times month^{-1} and received supply of freshwater at regular basis.

Textural classes of surface substrate seemed clearly different between certain sub-habitats whilst others appeared to be relatively the same (Figure 4). For example, sub-habitat 1 and 6 had a texture dominated by silt particle (silt loam texture). On the other hand, sub-habitat 2, 7 and 10 had loam texture. Sub-habitat 9 was composed of sandy loam clay.

Table 2. Physical characteristics of sub-habitat types in Bunaken National Park, North Sulawesi, Indonesia

Habitat types	Elevation relative to sea level	Local topography	Level of inundation	Sediment feature	Freshwater influence
Estuary (Sub-habitat 1)	Up and intermediate	Basin with isolated lagoon	Frequently waterlogged, inundated at spring tide	Fine and deep clay and poorly drained surface substrate, salinity (21.7±7.4 ppt), textural type (silt), FMC (534.0±4.5%)	Seasonal
Seaward fringe (Sub-habitat 2)	Low	Flat to less steep	Inundated at almost all tide levels (77 times month^{-1})	Sand with small portion of fine sediment, salinity (14.0±0.0 ppt), textural type (loam), FMC (174.0±3.3%)	Absent
Coralline sand berm (Sub-habitat 3)	Low	Convex	Inundated at almost all tide levels (77 times month^{-1})	Coralline sand berm, salinity (8.0±0.0 ppt), textural type (sandy loam), FMC (39.0±4.3%)	Absent
Tidal-water impoundment (Sub-habitat 4)	Low	Concave	Inundated at low tide (up to 107 times month^{-1})	Fine and well-draining sand with little proportion of organic matter, salinity (13.3±0.5 ppt), textural type (sandy loam), FMC (78.3±1.2%)	From seepage and run-off
Seaward young soil (Sub-habitat 5)	Low	Convex	Inundated at all the time (77 times month^{-1})	Subjected to accumulation of mostly non-organic fine sediments, salinity (18.0±0.0 ppt), textural type (sandy loam), FMC (219.3±3.3%)	Absent
Very stable middle zone (Sub-habitat 6)	Intermediate	Less steep	Inundated at normal high tide (53 times month^{-1})	Dominated by organic sediment, salinity (19.7±1.2 ppt), textural type (silt loam), FMC (244.0±3.7%)	Not significant, from seepage and run-off
Tidal-stream edge (Sub-habitat 7)	Intermediate and high	Various (Prograding and eroding banks)	Various depending on local positions (intermediate, high)	Salinity (18.0±0.8 ppt), textural type (loam), FMC (201.0±2.2 %)	Seasonally or regularly from seepage and run-off especially at high position
Less steep and eroding landward fringe (Sub-habitat 8)	High	Less steep	Inundated by tidal water up to 10 times month^{-1}	Shallow surface substrate and in many cases excessively eroded, salinity (19.0±0.0 ppt), textural type (sandy loam), FMC (207.3±2.1 %)	Seasonal from seepage and run-off
Highly accreting inland fringe (Sub-habitat 9)	High	Not smooth surface with many mounds	Inundated at maximum high tide (4 times month^{-1})	Dry and subjected to sedimentation from nearest land, salinity (14.3±0.5 ppt), textural type (sandy loam), FMC (90.7± 2.9 %)	Seasonal from seepage and run-off
Seasonally or regularly freshwater influenced landward fringe (Sub-habitat 10)	High	Flat to less steep	Inundated 10 times month^{-1}	Wet and deep, salinity (6.5±0.5 ppt), textural type (loam), FMC (83.3±2.5 %)	Regular

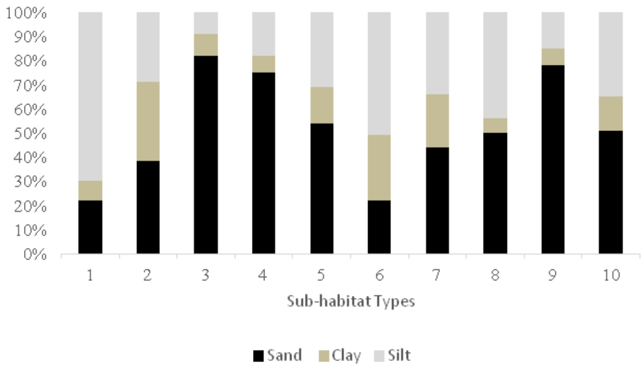

Figure 4. Surface soil texture composition of the sub-habitats in Bunaken National Park, North Sulawesi, Indonesia

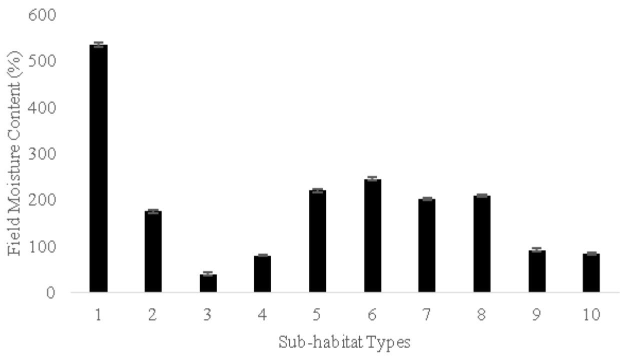

Figure 6. Surface soil field moisture content of the ten sub-habitat types

Based on surface soil salinity the ten sub-habitats could be divided into three groups (Figure 5). The first group of sub-habitats were with high soil salinity varied between 18.0 and 21.7 ppt, including sub-habitat 5, 6, 7and 8. The second group of sub-habitats were with intermediate soil salinity ranging from 13.3 ppt to 14.0 ppt, including sub-habitat 1, 2, 4 and 9. The third group of sub-habitats were with relatively low soil salinity varied between 6.5 and 8 ppt, including sub-habitat 3 and 10. As indicated by the value of standard deviation, surface soil salinity of sub-habitat 1 seemed to be more varied. In mangroves, extreme substrate salinity induces hydraulic failure and ion excess toxicity and reduces growth and survival (Méndez et al. 2016).

Field moisture content measured in the ten sub-habitats varied greatly (Figure 6). The highest value was measured for sub-habitat 1 at 534.0 %. The sub-habitat 2, 5, 6, 7 and 8 had a field moisture varying between 174.0 and 244.0 %. Sub-habitats that had field moisture less than 100 % were measured for sub-habitat 3 (39.0 %), sub-habitat 4 (78.3 %), sub-habitat 9 (90.7 %) and sub-habitat 10 (83.3 %). These differences were probably to be associated with differences in sand composition in which field moisture content tended to decrease with the increased in the number of sand particles (Djamaluddin 2004).

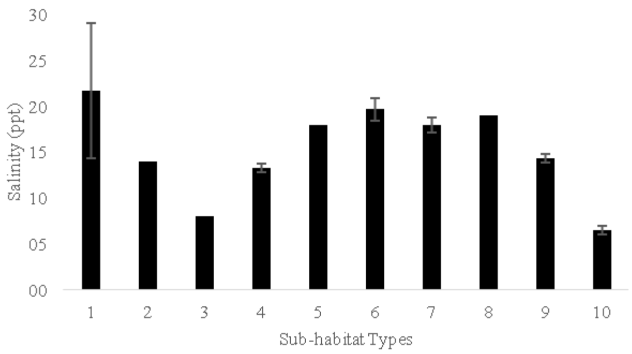

Figure 5. Surface soil salinity of the ten habitat types in Bunaken National Park, North Sulawesi, Indonesia

Species diversity over various sub-habitat types

All ten recognised sub-habitat types had different species diversity (Table 3). Based on the number of species present, sub-habitats could be divided into four categories. The first category included the high diversity sub-habitat which was found on sub-habitat 10 with 14 species. The second category was a group of sub-habitats that contained 9 species including sub-habitat 1, 9, 7 and 10. This category was defined as a moderate species diversity sub-habitat. The third category were the sub-habitat 2, 3, 4 and 5 that contained 4-6 species, and defined as low species diversity. The sub-habitat 6 was the only sub-habitat with two species present, and defined as poor species diversity.

Table 3. Mangrove species within varities of sub-habitat types in Bunaken National Park, North Sulawesi, Indonesia

Species	**Sub-habitat Types**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A. ilicifolius	+								+	+
A. aureum	+							+	+	+
A. speciosum	+							+	+	+
A. corniculatum							+	+		
A. alba								+		
A. marina	+	+	+	+			+	+	+	+
B. cylindrica	+									
B. gymnorrhiza		+	+			+	+	+		
B. parviflora							+		+	
B. sexangula										+
C. philippinense							+			
C. zippeliana								+		
C. tagal							+	+	+	+
E. agallocha	+								+	
H. littoralis								+	+	
L. littorea								+		
L. racemosa	+									
N. fruticans	+									+
R. apiculata	+	+	+	+	+	+	+	+		
R. mucronata		+	+	+	+					
R. stylosa		+	+	+	+					
S. hydrophyllacea								+		
S. alba		+	+	+	+					
S. caseolaris										+
S. ovata										+
X. granatum							+	+		
X. mollucensis							+	+	+	
Total	9	6	6	5	4	2	9	14	9	9

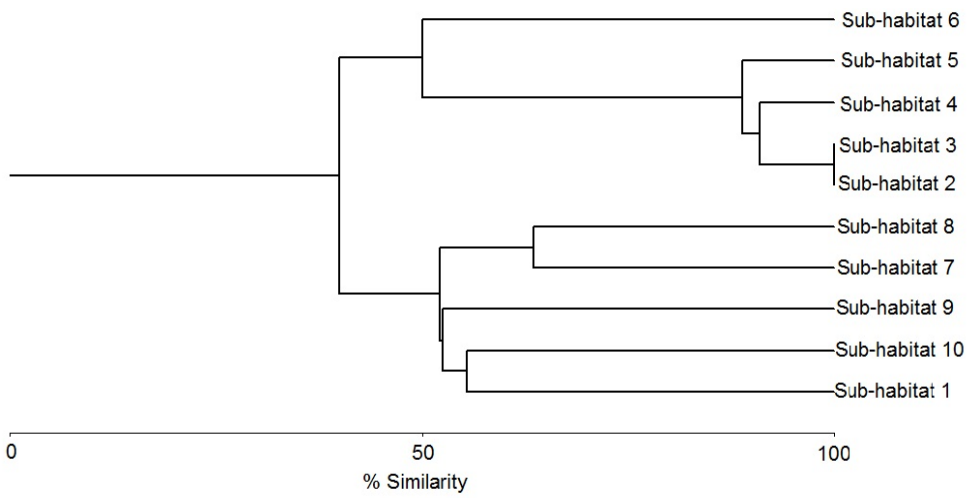

Figure 7. Groups of sub-habitats based on composition of species presence

Based on composition of species present, the ten sub-habitats could also be classified into four groups (Figure 7). The first group consisted of sub-habitat 1, 9 and 10. This group was characterised by the presence of species of *A. ilicifolius, A. aureum, A. speciosum, A. marina* and *N. fruticans.* The second group consisted of sub-habitat 7 and 8 that was characterised by the presence of *A. corniculatum, A. marina, B. gymnorrhiza, C. tagal, R. apiculata, X. granatum, X. mollucensis.* The third group consisted of sub-habitat 2, 3, 4 and 5. The presence of three species of *Rhizophora* (*R. apiculata, R. mucronata* and *R. stylosa*) and *S. alba* were of typical in these sub-habitats. In this group, sub-habitat 2 and 3 were exactly the same in term of the presence of *A. marina* and *B. gymnorrhiza.* The fourth group consisted of sub-habitat 6 that was characterised by the presence of *R. apiculata* and *B. gymnorrhiza*.

Across the intertidal zone of the park the composition of mangrove species appeared to vary with types of sub-habitat. The seaward mangrove areas comprised of sub-habitat 2, 3, 4 and 5. These sub-habitats occupied by *Rhizophora* spp. (*R. apiculata, R. mucronata, R. stylosa*) and *S. alba*. However, *B. gymnorrhiza* was also found on sub-habitat 2 and 3. The low ground slope appeared to be a likely reason for the similarity of these sub-habitats. The middle mangrove areas included sub-habitat 6 and 7 (particularly its intermediate position). *R. apiculata* and *B. gymnorrhiza* dominated on sub-habitat 6. The presence of a high proportion of clay particles in the surface soil seemed to be characteristic of this sub-habitat. The landward mangrove areas had a variety of sub-habitats including sub-habitat 8, 9 and 10. *C. tagal* appeared to be dominant in sub-habitat 8 and 10, but not in sub-habitat 9. Beside *C. tagal*, a number of species such as *A. marina, B. sexangula, N. fruticans* and *S. ovata* usually occurred on sub-habitat 10. The variation in surface soil salinity might be a defining feature of the landward mangrove areas.

The estuarine sub-habitat located in the center between the two islets on Mantehage Island was considered to be different from other sub-habitat types. Physically this sub-habitat was poorly drained, subjected to being frequently waterlogged and inundated by seawater only at high spring tide. Those physical features were predicted to be the most likely factors that supported the growing of two dominant canopy species of *B. cylindrica* and *L. racemosa*. Several species such as *A. marina, E. agallocha,* and *R. apiculata* were also found on some particular points along the tidal streams of this sub-habitat. According to Duke et al. (1998) the physiological tolerance of each mangrove species to salinity influences its estuarine distribution.

Unlike the estuarine sub-habitat, the physical attributes of the tidal-stream edge sub-habitat were largely controlled by seawater flowing through the tidal stream. Surface soil texture was mostly composed of sandy clay loam. This habitat was quite saline as shown by the surface salinity ranged from 17 to 19 ppt. These particular environmental characteristics were probably the factors that supported the survival of *A. marina, B. parviflora, C. tagal*, *Xylocarpus granatum* and *X. Mollucensis* especially the two dominant species of *R. apiculata* and *B. gymnorrhiza*.

Overall, *A. marina* and *R. apiculata* had very broad spatial distribution, while a number of species such as *A. ilicifolius, A. corniculatum, A. alba, B. cylindrica, B. parviflora, B. sexangula, C. philippensis, H. littoralis, L. littorea, N. fruticans, S. hydrophyllacea, S. caseolaris, S. ovata, X. Granatum* had very limited spatial distribution in which each of these species occupied only one or two habitat types. In addition, *Acrosticum aureum* and *A. speciosum*, three species of *Rhizophora* (*R. apiculata, R. mucronata, R. stylosa*), and two species of *Xylocarpus* (*X. granatum* and *X. mollucensis*), often occurred sympatrically. However, the four species of *Bruguiera* (*B, cylindrica, B. gymnorrhiza, B. parviflora, B. sexangula*), two species of *Lumnitzera* (*L. littorea* and *L. racemosa*), three species of *Sonneratia* (*S. alba, S. caseolaris, S.*

ovata), occupied clearly different types of sub-habitat. With particular concern to three species of *Rhizophora*, the most widely distributed mangrove trees in the Indo-West Pacific region (Yan et al. 2016), natural hybridisation was more likely to occur where parental species of *Rhizophora* could occur (e.g. Setyawan et al. 2014; LungNg and Szmidt 2015).

Finally, the mangrove flora in Bunaken National Park was floristically rich with at least 27 species, and the broader northern distribution limit of *L. littorea and L. racemosa*, *C. philippinense*, *S. ovata* was confirmed. The presence of *C. philippinense* was of importance since report of this species was rare. Mangrove species were distributed over at least ten sub-habitat types in different identity and diversity. The low ground slope appeared to be a likely reason for the similarity of four sub-habitat types in the seaward mangrove area. The presence of a high proportion of clay particles in the surface soil seemed to be characteristic of two sub-habitat types (a flat middle zone and a tidal stream edge) in the middle mangrove area. The variation in surface soil salinity might be a defining feature of three sub-habitat types in the landward mangrove area. Poor drainage, being frequently waterlogged and inundated by seawater only at high spring tide seemed to be a characteristic of estuarine sub-habitat. Meanwhile, a sandy clay loam of soil texture and a relatively high surface soil salinity were the physical attributes of a tidal-stream edge sub-habitat.

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