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

Abstract. 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 habitats. Seven surveys were conducted to collect and identify mangrove species of the park. To describe 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 habitat. The results suggested that the park was floristically rich with at least 27 plant species and they were distributed over ten recognised habitat types in different composition and diversity. The presence of *Ceriops zeppiliana* Blume, *Lumnitzera racemosa* Willd, *Lumnitzera littorea* (Jack) Voigt, *Sonneratia ovate* Backer, and *Camptostemon philippinense* (Vidal) Becc. were among the most broadly distributed 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: mangrove, Bunaken, *C. philippinense, C. zeppiliana*, Indo-Malesia

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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, a palms and a ground ferns (Duke et al. 1998). Mangrove is tolerancecan tolerate to salt and brackish waters (Spalding *et al.* 1997), because the plants haves developed complex morphological, anatomical, physiological, and molecular adaptations allowing survival and success in their high-stress habitat (Srikanth et al. 2015).

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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 andwith the percentage of mangrove loss was of 1.72% in between 2000 and 2012 (Richards and Friess, 2015).

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Indonesia's mangroves include two biogeographical regions, includingi.e., Indo-Malesia and Asia, Australasia and the western Pacific (Duke et al. 1992). The listingslists of mangrove species within these regions have been improved, Duke et al. (1998) recordsin which 50 mangrove species were found in Indo-Malesia and 47 species in Australasia, including several putative hybrids. Because there is an overlap ofHowever, 39 species were overlapped between the two biogeographical regions, and because several species specifically occur either in Indo-Malesia or Australasia,thus the total number of species in both biogeographical regions is 57 species. Gieasen *et al.* (2006) claimsfound that mangrove in Indonesia is the more biodiversehas 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 ofin the Southeast Asia countries with 48 species of mangrove. With particular concern to mangroves of Bunaken National Park, some 32 true mangrove species may be found (Tomlinson, 1986).

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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 Malaka Strait that separates Sulawesi and Kalimantan (Van Bennekom, 1988). The flow of seawater mass from northern Pacific is strengthened by the Mindanao cCurrent coming from the coastal areas in the southeast fromof the Philippines Aarchipelago (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 25.5^0 C and 27.0^0 C.

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The mangrove forests of the Bunaken Ppark 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. A long-term investigation on mangrove species across various habitat types within the park provides ample time and opportunity to collect and to record any detailed information of mangrove flora in this specific region of Indo-Malesia. Geographical distribution limits of certain species may also be clarified from this investigation. It is also important that investigation on spatial distribution of mangrove species across different intertidal environments may explain differences in mangrove species adaptation to major environmental conditions.

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MATERIALS AND METHODS

Study site and climate

The Bunaken National Park is situated on the Nnorth coast of Sulawesi Island. The Park consists of ~~mainland~~ coastal mainland and island elements. To manage the Park the area ~~has been~~was divided into 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 ~~is~~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 ~~is~~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 ~~has been~~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.

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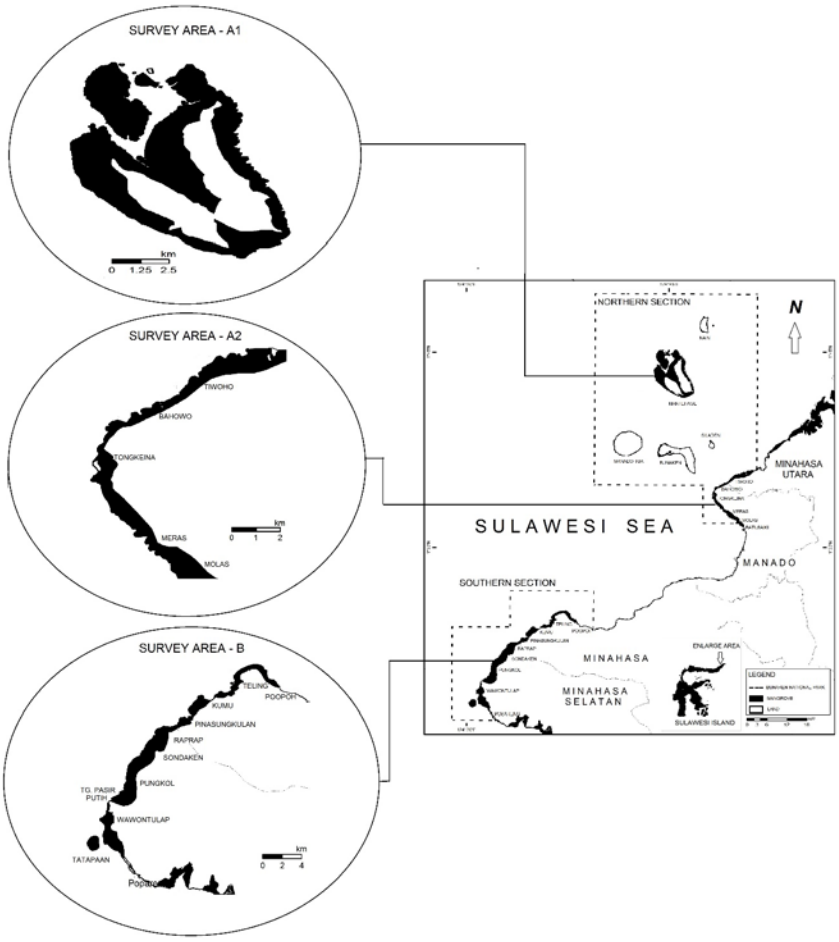

Figure 1. ~~Map~~The study areas of Bunaken National Park ~~and surveyed areas~~.

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 varieds little between 25.5^0 C and 27.0^0 C. The minimum annual mean temperature was~~of~~ 25.5^0 C ~~is~~ recorded in 1984 and the maximum ~~of~~was 27.0^0 C ~~in~~occured in 2015.

Specimen collection

At least seven surveys were ~~undertaken~~carried out between November 1995 and September 2016 to collect all mangrove specimens within the Bunaken Ppark. The first survei was conducted ~~in~~between November and December 1995 through a community-based survey ~~that~~ resulted in the collection of ~~plant~~ specimens of all plants ~~regarded~~recognized by the local

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people as separate species and for which they had local names. ~~T~~In order to obtain more collection of mangrove plants, the second survey was carried out in January 1996 and ~~this was followed by~~ the third survey in June 1999, ~~covering a total of~~ 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 ~~a formal description was made of all~~the habitat descriptions were made~~s present in the park, and care was taken to then visit each of these habitats to ensure each was adequately surveyed~~. 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 ~~to~~in 10 locations of mangrove around Tiwoho Village (Survey Area A2). The sixth survey was conducted between October 2012 and October 2013 ~~to~~in the mangrove area between ~~the~~ two islets in Mantehage Island (four locations in Survey Area A1). This sixth survei was aimed to ~~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 confirmed by reference to arrange of systematic reviews (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. ~~In Figure 2 a~~All surveyed locations were presented in Figure 2~~.~~

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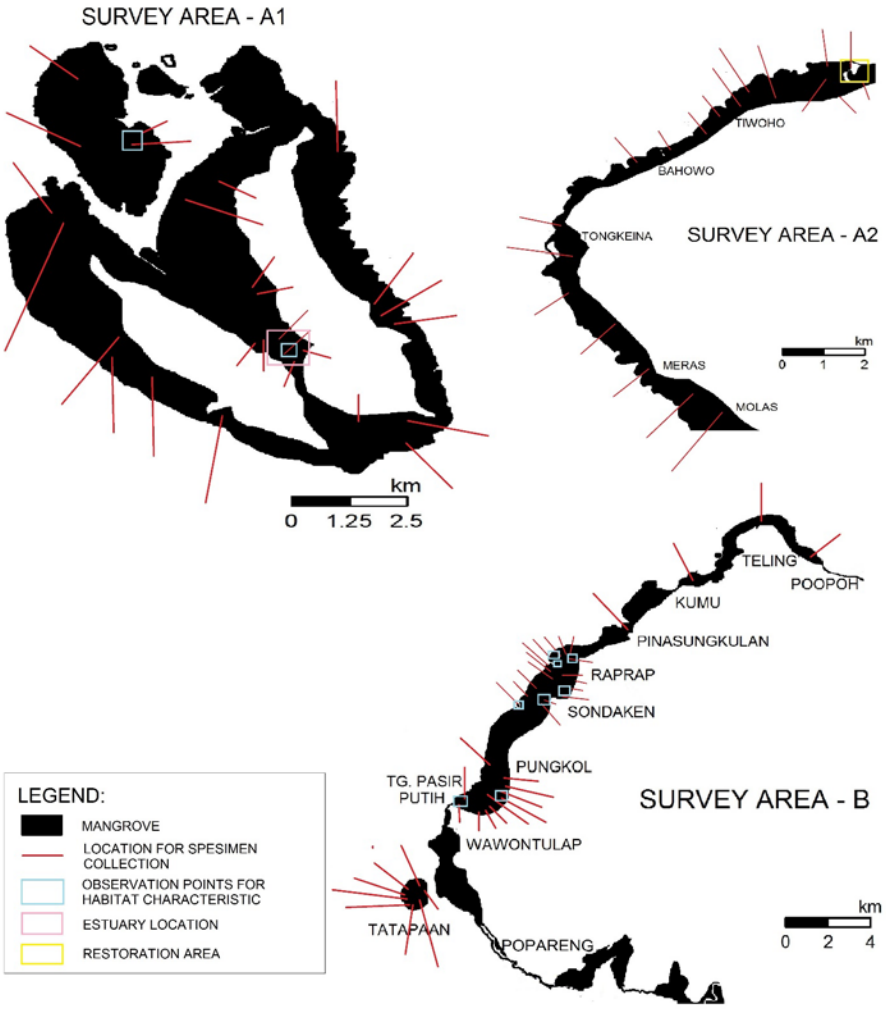

Figure2. ~~Surveyed l~~Locations ~~for~~of plants collection and observation for physical habitat characteristics.

Description and classification of mangrove 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 systems 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 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 ~~nominal~~ habitat types ~~in~~at three different times. Samples were taken at 0 – 300 mm depth at five random points in every type of habitat and pooled prior to laboratory analysis. Soil texture was determine using the pipette method. Soil salinity was measured using a Hand Refractometer (ARTAGO S/MILL) ~~of~~on the water samples of a known volume eluted

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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 105^0 C to constant weight. Biodiversity Professional (Version 2.0)(~~McAleece *et al.* 1997)~~ was used for Bray-Curtis Cluster Analysis with Sorensen similarity to group habitats based on species presence. All sampling points for the observation of physical habitat characteristics ~~can be seen~~are shown in Figure 2.

RESULTS AND DISCUSSION

Mangrove flora

~~After all corrections were made to the previous results of identification, t~~There were 27 species ~~of~~from 12 families ~~confirmed to occur~~ were found in the mangrove forests of the Bunaken National Park (Table 1).~~park~~. Specimens that were identified as species of *Avicennia marina* var. *rumphiana* (Hall. F.) Bakhuizen and *Avicennia officinalis* Linnaeus in the previous surveys were verified as *Avicennia marina* (Forssk.) Vierh and *Avicennia alba* Blume respectively, meanwhile specimen of *Kandelia candel* (Linnaeus) Druce was confirmed as *Bruguiera cylindrica* (Linnaeus) Blum. Identified species of *Ceriops decandra* (Griff.) Ding Hou in the previous study was corrected as *Ceriops zippeliana* in the last identification, as well as the name of *Xylocarpus mekongensis* Pierre was replaced by *Xylocarpus molucensis* Pierre. ~~Table 1 shows all species recorded in the Park, including their local name.~~

Table 1. The ~~scientific, local and common taxonomic names of the~~ mangrove plants of Bunaken National Park

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 mainland mangrove 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.

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. ~~Species of~~ *B. cylindrica* that was previously known to occur only at estuarine habitat in Mantehage Island (Survey Area A1) was ~~then~~ 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 ~~noted~~recorded, at a landward site with ~~regular~~ freshwater input, ~~at~~in ~~mangrove of~~ 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 included *Aegialitis annulata* R.

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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 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 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 is rarely reported (Chapman, 1976; Tomlinson, 1986). Individual tress 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 ~~is~~was expected to be the distribution limit of this species since it ~~is~~was ~~of~~ common only in the Philippines (Giaesen et al., 2006), noted to occur in Berau of eastern Kalimantan (Mukhlisi and Sadiyasa, 2014) and in Donggala of western coast of Central Sulawesi (Wahyuningsih et al. 2012), but it ~~is~~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).

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Habitat types and their physical characteristics

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

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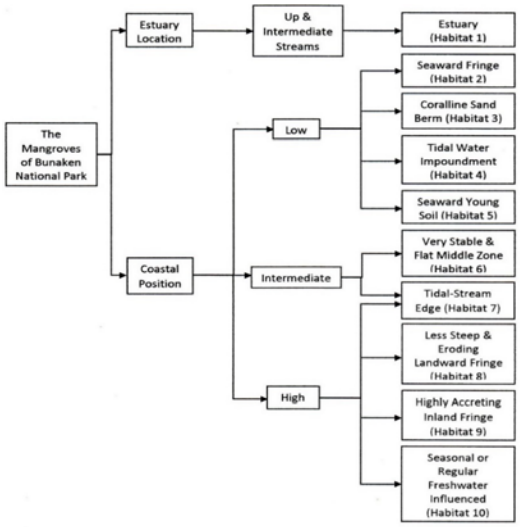

Figure 3. Estuariney ~~location~~ and coastal ~~position~~locations of mangrove habitats in Bunaken National Park (the terms up and intermediate stream for Habitat 1, and low, intermediate and high for Habitat 2 – 10 refers to the elevation of these habitats relative to sea level).

As can be seen from Figure 3 that there was a habitat type of estuary (Habitat 1) in the Park. At low elevation four types of habitat were recognised; seaward fringe (Habitat 2), coralline sand berm (Habitat 3), tidal water impoundment (Habitat 4) and seaward young soil (Habitat 5). At intermediate elevation there were two major habitat types of very stable and flat middle zone (Habitat 6) and tidal stream edge (Habitat 7). ~~This~~ But Habitat 7 was ~~also~~also found at high elevation. ~~as well as t~~Three other main habitat types ~~of~~comprised of less steep and more eroding landward fringe (Habitat 8), a, highly accreting

inland fringe (Habitat 9) and a seasonal or regular freshwater influence (Habitat 10). Characteristics of each habitat type in relation to various conditions of physical environment are presented in Table 2.

Table 2. Physical characteristics of habitat types in Bunaken National Park.

Habitat Types	Elevation Relative To Sea Level	Local Topography	Level of Inundation	Sediment Feature	Freshwater Influence
Estuary (Habitat-1)	Up and intermediate streams	Basin with isolated lagoon	Frequently waterlogged, inundated at spring tide	Fine and deep clay, poorly drained, salinity (21.7±7.4 ppt), textural type (silt), FMC (534.0±4.5%)	Seasonal
Seaward fringe (Habitat-2)	Low	Flat to less steep	Inundated at almost all tide level	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 (Habitat-3)	Low	Overwash	Inundated at almost all tide levels	Coralline sand berm, salinity (8.0±0.0 ppt), textural type (sandy loam), FMC (39.0±4.3%)	Absent
Tidal-water impoundment (Habitat-4)	Low	Concave	Inundated at low tide	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 (Habitat-5)	Low	Overwash	Inundated at all the time	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 (Habitat-6)	Intermediate	Less steep	Inundated at normal high tide	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 (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 (Habitat-8)	High	Lesses steep	Inundated by tidal water up to four times a month	Shallow 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 (Habitat-9)	High	Not smooth surface with many mounds	Inundated at maximum high tide	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 (Habitat-10)	High	Flat to less steep	Inundated several times a month	Wet and deep, salinity (6.5±0.5 ppt), textural type (loam), FMC (83.3±2.5 %)	Regular

Estuary system (Habitat 1) was located in the center of Mantehage Island (Figure 2). This system 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 system, and they remained inundated by seawater at low tide. As this system was only reached by seawater at high tide, surface substrate of areas around the lagoons might be drier. In contrast, these areas could be inundated by freshwater during wet season.

Seaward fringe habitat (Habitat 2) was of common habitat type in the Mantehage Island and mainland mangrove systems. This habitat was located at about Mean Seawater Level (MSL), being exposed to air at approximately 50% and its extent depended upon the topography of a mangrove forest and the trend was that the flatter a mangrove forest the is the wider of

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the ~~this~~ habitat will be. In the Mantehage Island, most of ~~the~~ mangrove forest ~~most of this habitat type~~ was ~~of~~ narrow with the exception for the mangrove area ~~on~~in the northern side ~~that~~which was subjected to sedimentation and had a relatively flat topography. The p~~P~~rotected coast~~al environmental settings, specifically~~especially the one received ~~from~~ direct wave action, had also created a relatively wider area of this habitat. Another typical character~~i~~itic of this habitat was of the absence of freshwater inflow.

Coralline sand berm~~s~~ (Habitat 3) ~~included~~were 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 habitat type was characterised by its coral sand berm sediments l~~a~~ying on dead coral reef, over-wash formation and low elevation relative to sea level. Most areas of this habitat were inundated at almost all ~~tide levels~~time ~~with~~and no freshwater supply into this system.

Tidal-water impoundment (Habitat 4) was found at one location, near Tanjung Pasir Putih, in the southern part of mangrove ~~of the~~ park. Due to its concave topography, t~~T~~his habitat ~~remained~~was permanently inundated including during low tide level ~~due to its concave topography~~. The s~~S~~ediment mainly~~of the habitat is~~ compo~~sed~~ri~~sed~~d~~ of fine and well-draining sand and ~~with little~~small proportion of organic matter and ~~it~~ the water was ~~under influence of~~mixed with the freshwater from seepage and run-off.

Seaward young soil (Habitat 5) was another type of mangrove islands. This habitat was located just in the mouth of tidal channel in the southern part of the park. ~~In its over-wash formation~~Overwash, formed by the accumulation of mostly non organic sediment transported through the tidal channel ~~located at~~was in the low elevation. ~~this habitat had been subjected to accumulation of mostly non organic sediment transported through the tidal channel~~. No freshwater was observed to influence this habitat.

Very stable middle zone (Habitat 6) was the most~~of~~ common habitat, comprised ~~up to 50% of the total mangrove forests over the mangrove forest in the Park with the extent reached up to 50% out of the total mangrove forests~~. This habitat type was located at intermediate elevation relative to sea level and was inundated at normal tide level but~~:~~ freshwater influence was of insignificant. ~~It~~sThe sediment was~~s were~~ dominated by organic ~~sediments~~matter.~~, and freshwater influence was of insignificant~~.

Tidal-stream edge (Habitat 7) ~~is~~was common in the southern section of the park especially along the tidal channels that dissect~~ed~~ the mangrove forests from the land margin to seaward margin. This habitat type could be found from intermediate to high elevation along a tidal channel ~~with its pro-grading~~in which bank was prograded at one side and ~~eroding~~eroded ~~bank~~ at another ~~side~~. Level of tidal inundation varied along the tidal channel ~~depending on local~~depended the position of the habitat at intermediate or high elevation. Seasonal freshwater influence from seepage and run-off was ~~of~~ significant at high elevation near the land margin.

Less steep and eroding landward (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 four times a month. Local topography of this habitat was usually in less steep formation. Freshwater might influence this habitat from seepage and run-off at seasonal period.

Highly accreting inland fringe (Habitat 9) occurred at the margin side such as in the southern mangrove area between Rap-rap and Sondaken that was subjected to massive sedimentation from the near land. This habitat was at high elevation relative to sea level, the~~had not smooth surface~~ substrate substrate was not smooth as it had ~~with~~ many mounds and was inundated only at maximum high tide. Freshwater might ~~supply~~flowed seasonally from the nearest land through seepage and run-off.

Seasonally or regularly freshwater influenced (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 several times a month and received supply of freshwater at regular basis.

Textural types of soil surface seemed clearly disunited between certain habitats whilst others appeared to be relatively the same (Figure 4). For example, the estuary and very stable and middle zone habitats had a texture dominated by silt particle (silt loam texture). ~~Similarly~~On the other hand, the seaward fringe, tidal-stream edge, seasonal or regular freshwater influenced habitats had loam texture. The seaward habitats ~~of seaward~~were characterised by young soil, less steep and eroding, coral sand berm, tidal water impoundment~~., and~~The highly accreting inland fringe ~~had also similar textural class of~~ was composed of sandy loam clay.

Commented [s33]: What does it mean?

Commented [s34]:

Commented [s35]: Of what?

Commented [s36]: Is “estuary” not more popular to readers, unless the river is very small just like a small stream. The term “mouth” usually refers to big channel (river)

Commented [s37]: Is this important? The statement seems not suitable.

Commented [s38]: What does it mean?

Commented [s39]:

Commented [s40]: What does it mean?

Commented [s41]: Which one is the land margin? By defination “land-margin” exist at the interface between the land and ocean and are comprised of intertidal zones, estuaries and bays.

Commented [s42]: Landward is adjective. Thus this phrase has no meaning. Please find the appropriate terminology which suits your description.

Commented [s43]: Is “local topography” different from just “topography”?

Commented [s44]: ???

Commented [s45]: Does not have the name of the system yet. “Influenced” can not become the subject, it should followed by a “ noun”

Commented [s46]: Do you mean “substrat permukaan” or “permukaan substrate”?

Commented [s47]: What does it mean here?

Commented [s48]: What does it mean?

Commented [s49]: “Permukaan tanah” or “tanah permukaan”?

Commented [s50]: What is it in Bahasa?

Commented [s51]: Does it mean rather flat? Or does it mean “”less steep slope”?

Commented [s52]: Eroding substrate or eroding what?

Commented [s53]: This is not paralel with other characteristics

Figure 4. Surface soil texture composition of the ~~ten~~ habitats in Bunaken National Park~~.~~

Commented [s54]: In the .....

Based on surface soil salinity the ten habitats could be divided into three groups (Figure 5). The first group was the habitat with ~~relatively~~ high soil salinity ~~varying~~varied between 18.0 ~~ppt~~ and 21.7 ppt, including habitats of seaward young soil, less steep and eroding landward fringe, very stable and flat middle zone, and tidal-stream edge. The second group of habitats ~~was~~were with intermediate soil salinity ranging from 13.3 ppt to 14.0 ppt, including estuary, tidal water impoundment, highly accreting inland fringe, and seaward fringe. The third group of habitats ~~was~~were with relatively low soil salinity~~, of~~ 6.5 ~~ppt~~ and 8 ppt~~, for the~~these habitats of seasonally or regularly ~~freshwater~~were influenced by freshwater and coral sand berm respectively. As indicated by the value of standard deviation, surface soil salinity ~~for~~of the estuary seemed to be more ~~fluctuated~~varied. In mangroves, extreme substrate salinity induces hydraulic failure and ion excess toxicity and reduces growth and survival (Méndez et al, 2016).

Figure 5. Surface soil salinity of the ten habitat types in Bunaken National Park ~~.~~

Field moisture content measured in the ten habitats varied greatly (Figure 6). The highest value was measured for the estuarine habitat at 534.0 %. The habitats of young soil, less steep and eroding landward fringe, very stable and flat middle zone, seaward fringe, and tidal-stream edge had a field moisture varying between 174.0 and 244.0 %. Habitats that had field moisture less than 100 % were measured for the coral sand berm (39.0 %), tidal water impoundment (78.3 %), highly accreting inland fringe (90.7 %) and seasonally or regularly freshwater influenced (83.3 %). These differences ~~seemed~~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 6. Surface soil field moisture content of the ten habitat types.

Species diversity over various habitat types

All ten recognised habitat types had different species diversity (Table 3). Based on the number of species present, habitats could be divided into four categories. The first category included the high diversity habitat which was found on the less steep and eroding landward with 14 species. The second category was a group of habitats that contained 9 species ~~that included~~including four different habitat types of an estuarine, a highly accreting inland fringe, a tidal-stream edge, and a seasonally or regularly freshwater influenced. This category was defined as a moderate species diversity habitat. The third category ~~included~~were the habitat of seaward young soil, tidal water impoundment, coralline sand berm and seaward fringe that contained 4 – 6 species, and defined as low species diversity. The very stable and middle zone was the only habitat with two species present, and defined as ~~having~~ poor species diversity.

Table 3. Mangrove species within ~~the ten~~varities of habitat types~~.~~ in Bunaken National Park.

No.	Species	Habitat Types									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1.	*A. ilicifolius*	+								+	+
2.	*A. aureum*	+							+	+	+
3.	*A. speciosum*	+							+	+	+
4.	*A. corniculatum*							+	+		
5.	*A. alba*								+		
6.	*A. marina*	+	+	+	+			+	+	+	+
7.	*B. cylindrica*	+									
8.	*B. gymnorrhiza*		+	+			+	+	+		
9.	*B. parviflora*							+		+	
10.	*B. sexangula*										+
11.	*C. philippinense*							+			
12.	*C. zippeliana*								+		
13.	*C. tagal*							+	+	+	+
14.	*E. agallocha*	+								+	
15.	*H. littoralis*								+	+	
16.	*L. littorea*								+		
17.	*L. racemosa*	+									
18.	*N. fruticans*	+									+
19.	*R. apiculata*	+	+	+	+	+	+	+	+		
20.	*R. mucronata*		+	+	+	+					
21.	*R. stylosa*		+	+	+	+					
22.	*S. hydrophyllacea*								+		
23.	*S. alba*		+	+	+	+					
24.	*S. caseolaris*										+
25.	*S. ovata*										+
26.	*X. granatum*							+	+		
27.	*X. mollucensis*							+	+	+	
Total Number of Species		9	6	6	5	4	2	9	14	9	9

Based on composition of species present, the ten habitats could also be classified into four groups (Figure 7). The first group consisted of Habitat 1, 9 and 10. This group was characterised by the presence of species of *A. ilicifolius, A. aureum,*

Commented [s55]: "Habitat types" refers only to the type of vegetation association in an area or to the potential of vegetation to reach a specified climax stage.
This paper contains too many habitat types especially when they are differenciated with numbers , it confuses the readers. Mangrove itself is basically a habitat, any divisions of this habitat is called "sub-habitat"

Commented [s56]: What is "A" stands for? Every abbreviation should be written in full word at the beginning

A. speciosum, *A. marina* and *N. fruticans*. The second group consisted of 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 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 habitats. In this group, Habitat 2 and 3 were exactly the same in term of the presence of *A. marina* and *B. gymnorrhiza*. The fourth group consisted of Habitat 6 that was characterised by the presence of *R. apiculata* and *B. gymnorrhiza*.

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

Across the intertidal environment of the park the composition of mangrove species appeared to vary with habitats. The seaward mangrove areas ~~included~~comprised of four habitat types: seaward fringe, seaward young soil, tidal water impoundment, and coralline sand berm. These habitats occupied by *Rhizophora* spp. (*R. apiculata*, *R. mucronata*, *R. stylosa*) and *S. alba*. ~~Species of~~ However, *B. gymnorrhiza* ~~may~~was ~~-~~also ~~occur~~found on the seaward fringe and coralline sand berm habitats. The low ground slope appeared to be a likely reason for the similarity of these habitats.

The middle mangrove areas includ~~ed~~ing two habitat types of a flat middle zone and a tidal stream edge (particularly its middle sub-habitat). ~~Two species of~~ *R. apiculata* and *B. gymnorrhiza*, occurred in the flat middle zone. The presence of a high proportion of clay particles in the surface soil seemed to be characteristic of this habitat.

The landward mangrove areas had a variety of habitats including a less steep and eroding landward, a highly accreting inland fringe, and a temporarily or regularly freshwater influenced habitats. The variations in the elevation and its consequence on the tidal inundation, the effect of freshwater inflow, and sediments transported from the vicinity land, were significant in these areas. The occurrence of the high intertidal species of *C. tagal* seemed to be characteristic of these habitats. Usually *C. tagal* appeared to be dominant on the less steep and eroding landward habitats. This species could also be dominant on seasonally or regularly freshwater influenced habitat but not on the highly accreting in land fringe. ~~Other than species of~~ Beside *C. tagal*, a number of species such as *A. marina*, *B. sexangula*, *N. fruticans* and *S. ovata* usually occurred on the seasonally or regularly freshwater influenced habitat~~s~~. A strong supply of freshwater from the nearest land that has considerably lower soil salinity might be a defining feature of this habitat.

The estuarine habitat ~~that is situated~~located in the center between the two islets on Mantehage Island ~~were~~was considered to be different from other habitat types. Physically the estuarine 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* ~~could also establish~~were also found on some particular points along the tidal streams of this habitat. According to Duke et al (1998) the physiological tolerance of each mangrove species to salinity influences its estuarine range.

Unlike the estuarine habitat, the physical attributes of the tidal stream edge habitat were largely controlled by seawater flowing through the tidal stream. Surface soil texture was mostly composed of~~a~~ sandy clay loam. ~~The measurement of surface soil salinity proved that this habitat had a relatively high salinity~~This habitat was quite saline as shown by the surface salinity ranged from …to …. These particular ~~circumstances~~environmental characteristics were ~~predicted to be the likely~~probably the factors that supported the survival of *A. marina*, *B. parviflora*, *C. tagal*, ~~and~~ *Xylocarpus* ~~(*X.* *granatum* and *X. mollucensis*)~~ ~~in association with~~especially the two dominant species of *R. apiculata* and *B. gymnorrhiza*.

~~Within the mangrove of the Park there were two species,~~Overall, *A. marina* and *R. apiculata* ~~that~~ had very broad spatial distribution~~. In contrast,~~, 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, ~~the two species of~~ *Acrosticum* ~~(*A. 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 ~~dissimilar~~different types of 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 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 habitat types in different identity and diversity. The low ground slope appeared to be a likely reason for the similarity of four

Commented [s57]: ?

Commented [s58]: ?

Commented [s59]: ?

Commented [s60]: ?

Commented [s61]: Too small to be read.

Commented [s62]: Usually called “intertidal zone”.

Commented [s63]: What does it mean?

Commented [s64]: Dominated?

Commented [s65]: Why this information is important here?

Commented [s66]: What does it mean? Landward is not a noun.

Commented [s67]: What does it mean?

Commented [s68]: I struggle to understand these two sentences, especially the second sentence.

Commented [s69]: This contrdicted the first sentence of this paragraph.

Commented [s70]: What does it mean?

Commented [s71]: What does it mean?

Commented [s72]: What habitat is this?

Commented [s73]: Please provide the number

Commented [s74]: What does it mean?

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 habitat types in the middle mangrove area. A strong supply of freshwater from the nearest land that has considerably lower soil salinity might be a defining feature of three habitat types in the landward mangrove area. ~~Specifically, physical factors of p~~Poor drainage, ~~subjection to~~ being frequently waterlogged~~,~~ and inundated by seawater only at high spring tide seemed to be a characteristic of estuarine 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 habitat.

Commented [s75]: What habitat types?

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REFERENCES

Bingham FM, Lukas R. 1994. The southward intrusion of North Pacific intermediate along the Mindanao coast. J Phys Oceanogr 24: 141-154.
Chapman VJ. 1970. Mangrove phytosociology. Trop Ecol 11: 1-19.
Chapman VJ. 1976. Mangrove vegetation. J. Cremer Publisher, Luterhausen, Germany.
Claridge D, Burnett J. 1992. Mangroves in focus. Marino Lithographics, Queensland.
Clough BF. 1979. Mangrove ecosystem in Australia: structure, function and management. Proceedings of the Australian National Mangrove Workshop. Australian Institute of Marine Science, Cape Ferguson,18-20 April 1979.
Damanik R, Djamaluddin R. 2012. Mangrove map of Tomini Gulf. Sustainable Coastal Livelihoods and Management Program, CIDA, IUCN, Lestari Canada.[Indonesian]
Davie J, Merril R, Djamaluddin R. 1996. The sustainable use and conservation of the mangrove ecosystem of the Bunaken National Park. USAID, Jakarta.
Ding Hou. 1958. Rhizophoraceae. Flora Malesiana I(5): 429-493.
Djamaluddin R. 2004. The dynamics of mangrove forest in relation to die-back and human use in Bunaken National Park, North Sulawesi, Indonesia. [Disertasion]. University of Queensland, Brisbane.
Djamaluddin, R. (2015). The mangrove flora in Tomini Bay. The 5th International Conference on Plant Diversity, Universitas Jenderal Sudirman, Purwokerto 20 – 21 August 2015.
Duke N, Kathiresan K, Salmo III SG, Fernando ES, Peras JR, Sukardjo S, Miyagi T. 2010. *Ceriops zippeliana*. IUCN Red List of Threatened Species Version 2014.3. International Union for Conservation of Nature and Natural Resources.
Duke NC, Ball MC, Ellison JC. 1998. Factors influencing biodiversity and distributional gradients in mangroves. Glob Ecol Biogeogr Lett 7: 27-47
Duke NC. 1992. Mangrove floristics and biogeography. In: Robertson AI, Alongi DM (eds). Coastal and Estuarine Studies American Geophysical Union, Washington.
Excell AW. 1954. Combretaceae. Flora Malesiana 1(4): 533-89.
Fernado S, Pancho JV. 1980. Mangrove trees of the Philippines. Silvatrop Philippine For Res J 5: 35-54.
Gardner, W. H. (1965). Water content. In: Black CA (ed). Methods of Soil Analysis: Part I Physical and Mineralogical Properties. American Society of Agronomy, Wisconsin.
Gieasen W, Wulffraat S, Zieren M, Scholten L. 2006. Mangrove guide book for Southeast Asia. FAO and Wetlands International.
Hamilton SE, Casey D. 2016. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Glob Ecol Biogeogr 25(6):729-738.
LungNg W, Szmidt A. 2015. Introgressive hybridization in two Indo-West Pacific *Rhizophora* mangrove species, *R. mucronata* and *R. stylosa.* Aquat Bot 120: 222-228.
Mabberley CM, Pannel CM, Sing AM. 1995. Flora Malesiana: Seri I Spermathophyata 12(1): 371-81.
Maxwell GS. 2015. Gaps in mangrove science. ISME/GLOMIS 13(5): 18-38.
McAleece N, Lambshead PJD, Peterson GLJ. 1997. Biodiversity Pro. The Natural History Museum, London.
Méndez A R, López PJ, Moctezuma C, Bartlett MK, Sack L. 2016. Osmotic and hydraulic adjustment of mangrove saplings to extreme salinity. Tree Physiol. 36(12): 1562-1572.
Mukhlisi, Sidiyasa K. 2014. Structure and composition of mangrove species in Berau Mangrove Information Centre (PIM), Kalimantan Timur. Indonesian For Rehabil J 2(1): 25-37. [Indonesian]
Noor YR, Khazali M, Suryadiputra INN. 2006. Mangrove introduction guide. Ditjen PPHKA-Wetland International, Bogor. [Indonesian]
Percival M, Womersley JS. 1975. Floristics and ecology of the mangrove vegetation in Papua. New Guinea Bot Bull 8.
Prawiroatmodjo S, Kartawinata K. 2014. Floristic diversity and structural characteristics of mangrove forest of Raja Ampat West Papua, Indonesia. Reinwardtia 14(1):171-180.
Richards DR, Fries DA. 2016 Rates and drivers of mangrove deforestation in Southeast Asia 2000-2012. PNAS 113(2): 344-349.
Setyawan AD, Ulumuddin YI, Ragavan P. 2014. Review: Mangrove hybrid of *Rhizophora* and its parental species in Indo-Malayan region. Nusantara Biosci 6(1): 69-81.
Sheue CR, Liu HY, Tsai CC, Rashid SMA, Yong JWH, Yang YP. 2009. On the morphology and molecular basis of segregation of *Ceriops zippeliana* and *C. decandra* (*Rhizophoraceae*) from Asia. Blumea 54: 220-227.
Spalding MD, Blasco F, Field CD. 1997 World Mangrove Atlas. International Society for Mangrove Ecosystems, Okinawa.
Spalding MD, Kainuma M, Collins L. 2010. World Atlas of Mangroves. Earthscan, London.
Srikanth S, Lum SKY, Chen Z. 2015. Mangrove root: adaptations and ecological importance. Tress 30(2): 451-465.
Thom BG. 1982. Mangrove ecology – a geomorphological perspective. In: Clough BF (ed). Mangrove Ecosystem in Australia: Structure, Function and Management. AIMS with ANU Press, Canberra.
Tomlinson PB. 1986. The botany of mangroves. Cambridge University Press, New York.

Van Bennekom A. 1988. Deep-water transit times in the eastern Indonesian basins, calculated from dissolved silica in deep and interstitial waters. Netherland J Sea Res, 22(4): 341-354.
Van Stennis CGGJ. 1995-1958. Flora Malesiana. Nooordhoff-Kolff NV, Djakarta.
Vannucci M. 1998. The mangrove ecosystem: an overview of present knowledge. Rev Bras Biol 58:1-15.
Wahyuningsih EP, Suleman, SM, Ramadanil. 2012. Structure and composition of mangrove vegetation in Desa Lalombi Kecamatan Banawa Selatan Kabupaten Donggala. Biocelebes 6(2): 84-100. [Indonesian]
Yan YB, Duke NC, Sun M. 2016. Comparative analysis of the pattern of population genetic diversity in Three Indo-West Pacific *Rhizophora* Mangrove Species. Front Plant Sci 7: 1434.