Mangrove Tomini Gulf

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PRESENT CONDITION OF MANGROVE ENVIRONMENTS AND COMMUNITY STRUCTURE IN TOMINI GULF, SULAWESI, INDONESIA

KONDISI LINGKUNGAN DAN STRUKTUR KOMUNITAS MANGROVE DI TELUK TOMINI, SULAWESI, INDONESIA

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ABSTRACT

The mangroves in Tomini Gulf have been exploited for chiefly conversion of mangrove areas into shrimp cultivation and extraction of mangrove wood for various purposes. In this study, interpretation to available map and satellite images and ground check were conducted to describe intertidal environment conditions and general processes of coastal dynamic. At local scale, physiographic factors were used to classify mangrove sub-habitats. A total of 159 sample points were selected to observe structure of vegetation, and the revised two ways classification of Specht was applied to classify structural classification of vegetation. The criterion of mangrove disturbance was developed to classify disturbance level. Interview and field check were conducted to assess the successfulness of implemented rehabilitation programs. Results indicated that there were obvious changes in mangrove vegetation over much the intertidal environments, and these might influence the future development and regeneration of the mangroves. While most rehabilitation programs were unsuccessful, mangrove exploitations still continued. If a sustainable management plan is not developed, the degradation will continue and spread, and the mangrove will lose its ecological functions.

Keywords: disturbance, mangrove, shrimp cultivation, Tomini Gulf

ABSTRAK

Mangrove di Teluk Tomini telah dieksploitasi terutama lahannya dikonversi menjadi tambak udang dan pohonnya ditebang untuk beragam tujuan. Dalam studi ini interpretasi terhadap peta dan citra satelit dilakukan untuk mendeskripsikan kondisi lingkungan intertidal dan proses-proses terkait dinamika pantai secara umum. Pada skala lokal, faktor fisiografik digunakan untuk mengklasifikasikan sub-habitat mangrove. Sebanyak 159 titik sampel dipilih untuk mengamati struktur vegetasi, dan klasifikasi dua-arah Specht yang telah direvisi untuk mangrove digunakan untuk mengelompokkan kelas struktur vegetasi. Kriteria kerusakan mangrove dikembangkan untuk mengklasifikasikan tingkat kerusakan. Wawancara dan pengamatan lapangan dilakukan untuk menilai keberhasilan program rehabilitasi. Hasil studi menunjukkan bahwa telah terjadi perubahan nyata pada vegetasi mangrove di Teluk Tomini, dan perubahan ini dapat mempengaruhi perkembangan dan regenerasi mangrove selanjutnya. Eksploitasi mangrove masih terus berlangsung, sementara kebanyakan program rehabilitasi mangrove tidak berhasil. Jika rencana pengelolaan berkelanjutan tidak dikembangkan, maka dikawatirkan kerusakan akan terus berlangsung dan meluas, dan mangrove di Teluk Tomini akan kehilangan fungsi ekologisnya.

Kata kunci*: kerusakan, mangrove, tambak udang, Teluk Tomini*

I. INTRODUCTION

Mangrove is the term used for 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 (Maxwell, 2015). Global distribution of mangrove have been explained in various reports (Gieasen *et al*., 2006; Spalding *et al*., 2010; Hamilton and Casey, 2016; Richards and Friess, 2016). Southeast Asia supports the world's largest area of mangroves, originally extending over 5.1 million ha (Spalding *et al*., 2010). The largest areas of mangrove in Southeast Asia are found in Indonesia with almost 60 % of Southeast Asia's total (Gieasen *et al*., 2006).

Mangroves provide biomass and contribute to productivity that is of substantial benefit to human populations, primarily fisheries and forestry products (Bandaranayake, 1998). Other critical ecosystem services that mangroves provide include coastline protection (Koch *et al*., 2009) and mitigation of climate change effects (Murdiyarso *et al*., 2015). Despite all the ecological services and economic benefits associated with mangrove ecosystems, about 2.1% (2,834 km^2) of the existing worldwide mangrove area was estimated to be lost each year during the second half of the 20^{th} century (Valiela *et al*., 2001) and a total loss of 1.97% (1,646 km^2) from 2000 to 2012 (Hamilton and Casey, 2016). In Indonesia, mangrove deforestation rate was measured at 0.05 million ha per year (Margono *et al*., 2014).

Mangroves in Tomini Gulf occur along almost all intertidal environments. These ecosystems are unique, growing close to the equator. The total area of mangrove in the Gulf is of some 16,105.40 ha. Unfortunately, within the last two decades the Gulf has lost 10,717.55 ha of its mangrove ecosystems due to mainly conversion the ecosystems into shrimp cultivation that is locally called *tambak udang* (Damanik and Djamaluddin, 2012).

Mangrove environments are of susceptible to both natural and human pressures (Hendrawan *et al*., 2018). Considering the ecological values that the mangroves of Tomini Gulf can provide, and the continuous damage that the mangroves experience, a lot of effort is needed in order to reduce the damage and to restore the ecological functions of these ecosystems. Accordingly, comprehensive baseline data and information are needed to support the development of a sustainable mangrove management plan. This study was conducted to describe intertidal environmental conditions and variation in sub-habitat types of mangroves, to investigate conditions of vegetation structure in relation to patterns of uses and level of disturbances, and to assess any applied mangrove rehabilitation programs in Tomini Gulf.

II. RESEARCH METHODS

2.1. Time and Study Locations

Field observation was conducted during 2009 to 2015 covering all mangrove areas in between 1.5°S and 0.6°N; 120° and 125°E that included Regencies of Bolaang Mongondow Selatan, Boalemo, Pohuwato, and Parigi Moutong. A total of 159 sample points (Figure 1) representing various types and conditions of mangrove were sellected for deep investigation.

2.2. Data Collection and Analysis

2.2.1. Intertidal Habitat Formations and Classification of Sub-Habitat Types

Available maps (Peta Rupa Bumi Indonesia 1:50.000 scale) and data from images (Landsat 4 – 5 TM and Landsat 7 ETM+) were analysed to describe intertidal environment conditions and general processes of coastal dynamic in Tomini Gulf. Results of analysis were confirmed through ground checks. At local scale, all sub-habitat types were classified based primarily on dominant physiographic factors proposed by Clarke and Hannon (1969), including tidal inundation, substrate condition, and freshwater inflow. General characteristics of sediment were observed visually, and a measuring stake was used to determine the depth of surface substrate. The depth of surface substrate was classified into three classes i.e., shallow (less than 30 cm), medium (30 – 50 cm), and deep (more than 50 cm).

2.2.2. Description of Vegetation Structure

A total 159 sample points were visited to investigate growth habit, canopy stratum, canopy form, canopy height, canopy cover, canopy evenness, number of cutting tree in 10 m^2, tree diameter, and distribution of diameter. The mangrove species within 100 m radius around each sample point were recorded to allow a floristic classification. Field identification of the flora was based on specimens' morphology, and these were compared to several mangrove references (Ding Hou, 1958; Percival and Womersley, 1975; Fernando and Pancho, 1980; Blasco, 1984; Tomlinson, 1986; Mabberley *et al*., 1995; Noor *et al*., 2006).

Canopy height was measured directly by means of a fixed stick for a tree with height up to 4 m, and for a tree more than 4 m, it was indirectly measured using the formula (tan a° x d) + h, where a° is the angle between observer and top of tree canopy, d is the distance between observer and tree, h is observer's height. Tree diameter was calculated based on formula of tree's girth divided by 3.14. A tree's girth was measured by means of plastic tape at breast height (a tree with a single stem), above the highest still root (a large *Rhizophora* spp.), about 50 cm from the base (a tree with two main branches sprouting out near the base), and just below the lowest branches (a tree with many branches as in *Scyphyphora hydrophyllacea*).

Foliage Projective Cover (FPC) was assesed using across wire on a free swinging vertical tube with a 45° mirror, developed by Winkword and Goodall (1962). The two ways classification of Specht (1970) which have been revised for mangroves (Walker and Hopkins, 1990; Djamaluddin, 2004) were applied to classify the structural classification of vegetation (Table 1).

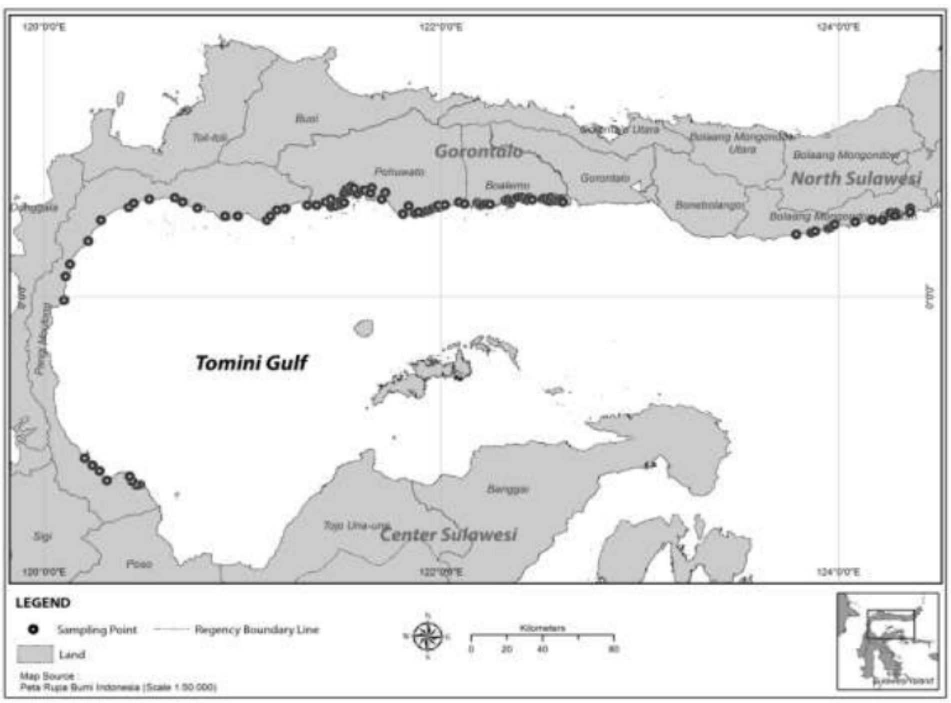

Figure 1. Map of the study location and sample points of observation.

Tabel 1. The most common structural formations of mangrove plant commmunities.

FPC (%)	Life form/Height of Uppermost Stratum				
	Tree[1] >30 m	Tree 10–30 m	Tree 2-10 m	Shrub[2] 2–8 m	Shrub < 2 m
Dense 100-70	Tall closed-forest	Closed-forest	Low closed-forest	Tall closed-shrub	Low closed-shrub
Mid-dense 70-50	Tall forest	Forest	Low forest	Tall shrub	Low shrub
Mid-dense 50-30	Tall open-forest	Open-forest	Low open-forest	Tall open-shrub	Low open-shrub
Sparse 30-10	-	-	-	Tal sparse-shrub	Low sparse-shrub

[1]A tree is defined as larger woody plant usually with a single stem
[2]A shrub is defined as smaller woody plant usually with many stems arising at or near the base

2.2.3. Classification of Forest Disturbance

Structural attributes of diameter distribution, growth habit, canopy stratum, canopy form, canopy cover and number of tree cutting were used to classify forest disturbance as summarised in Table 2.

Table 2. Criterion of mangrove forest disturbance.

Disturbance Level	Indicators					
	Tree Cutting (%)	Diameter Distribution	Growth Habit	Canopy Stratum	Canopy Form	Canopy Cover (%)
Very light	Less than 5 stems	Even	Commonly single-stemmed	Even	From uper third	75-100
Light	5-25 stems	Even	Commonly single-stemmed	Even	From uper third	75-100
Medium	25-50 stems	Uneven	25 % trees with multi-stemmed and latteral coppicing	Uneven	50% from two-third and or base	50-75
Heavy	50-75 stems	Uneven	Commonly tree with multi-stemmed and latteral coppicing	Uneven	Commonly from two-third and or base	25-50
Very heavy	More than 75 stems	Uneven	Commonly tree with multi-stemmed and latteral coppicing	Uneven	Commonly from two-third and or base	25

Note: open mangrove area was categorised in very heavy disturbance.

2.2.4. Assessment of Implemented Rehabilitation Programs

Interviews with people who might have information relavent to assessing rehabilitation programs were conducted. Problems related to implemented rehabilitation programs were also identified in the field. General knowledge of biology and ecology of mangrove species, reports and references of rehabilitation techniques (Lewis, 2005; Priyono, 2010; Hidayat, 2013; Wibisono, 2016; Brown and Djamaluddin, 2017), were all used to identify and explain the identified problems.

III. RESULT AND DISCUSSION

3.1. Coastal Geomorphological Processes and Habitat Types

Differences in oceanography factors mainly wave actions that were generated from different directions and speeds of seasonally winds were expected to be the major controlling factors of coastal geomorphological processes in the Gulf. Coastal environments located near the mouth of the Gulf (areas between Bolaang Mongondow Selatan and part of Boalemo) were under influence by the seasonally strong South, South - east and East winds that could generate strong wave actions in the coastal environments and then active coastal currents. These conditions supported a common coastal formation of narrow and steep littoral zone with hard substrate type (Figure 2 B, C), a rocky cliff coast in certain locations (Figure 2 D), and a very stable small gulf-like coastal formation in sheltered location (Figure 2 A). Within the Gulf to the North (area between Pohuwato and the North part of Parigi Moutong), geomorphological processes were much influenced by the seasonal East and South - east winds that could generate active coastal currents and sedimentation westward. These conditions supported the formations of a broader, shallow, and flat intertidal environment, as well as seaward beaches in several locations (Figure 2 F, G). An area with indication of abrasion was found at Tanjung Panjang (Figure 2 E). The innert side to the West (West part area of Parigi Moutong) received a strong wave surge generated by the seasonal East wind. Coastal environments in this location did not support the establishment of stable mangrove habitats (Figure 2 I, J). Within the Gulf to the South (South part area of Parigi Moutong) there was an inactive wave surge, and this supported the formation of a broad intertidal zone (Figure 2 K, L).

Based on physiographic factors, sub-habitat types of mangrove in Tomini Gulf could be classified into at least nine sub-habitat types (Table 3).

According to Thom (1967, 1982), coastal geomorphological diversity correlates with local mangrove distribution. Previous reports also indicated that identity and diversity of mangroves varied with habitat conditions (Djamaluddin, 2015; Djamaluddin, 2018). Mangroves of Tomini Gulf was floristically rich where at least 27 species were identified, comparing to 32 species listed by Tomlinson (1986) for the broader longitudinal biogeographic region between 120^o and 135^{o}E.

Using the record by Davie *et al*. (1996) and Djamaluddin (2004, 2018) for the mangrove flora in Bunaken Nasional Park (1^{o}35'41" and 1^{o}16'44" N; 124^{o}32'22" and 124^{o}50'50" E), five species (*Avicennia alba, Champtostemon philippinense, Bruguiera sexangula, Sonneratia ovata*, and *Ceriops zippeliana*, formerly recognised as *Ceriops decandra* in the majority of its range (Sheue *et al*., 2009; Duke *et al*., 2010), did not occur in Tomini Gulf. Meanwhile, species of *Osbornia octodonta, Pempis acidula and Heritiera globulus* seemed to be typical species of Tomini Gulf. Figure 3 describes the relative position of mangrove sub-habitats across intertidal environment and the variety of species composition at different sub-habitat types.

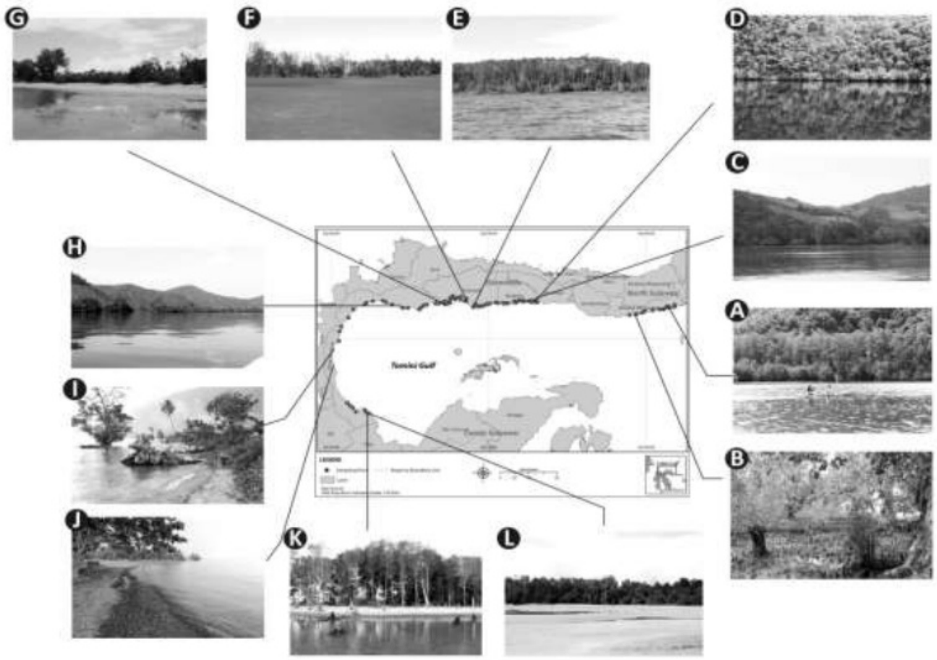

Figure 2. Coastal environment variations in Tomini Gulf: (A) very stable gulf-like coast, (B, C) narrow littoral zone with hard substrate, (D) rocky cliff coast, (E) seaward beach subjected to abrasion, (F, G) broader, shallow, flat coast subjected to sedimentation, (H) estuary, (I, J) unstable coastal environment subjected to abrasion, (K, L) broader intertidal zone.

Table 3. Physical characteristics of sub-habitat types in Tomini Gulf.

Sub-habitat Types	Elevation Relative to Sea Level	Tidal Inundation Level	Sediment Feature	Freshwater Inflow
Estuarine	Low and intermediate	Frequently waterlogged, inundated at low tide	Dominated by fine sediment and deep surface substrate	From rivers
Seaward fringe	Low	Inundated at almost all tide levels	Dominated by sand with small proportion of fine sediments, various depths of surface substrate	Absent
Coralline sand berm	Low	Inundated at almost tide levels	Coralline sand berm	Absent
Seaward young soil	Low	inundated at almost tide levels	fine sediments from river mouth	From river

Sub-habitat Types	Elevation Relative to Sea Level	Tidal Inundation Level	Sediment Feature	Freshwater Inflow
Very stable middle zone	Intermediate	Inundated at neap and spring tides	Dominated by organic materials	Less influence from seepage
Less steep and eroding landward zone	High	Inundated at spring tide	Dominated by fine sand, shallow surface substrate	Seasonally from seepage
Highly accreting inland fringe	High	Inundated only at maximum high tide	Dominated by sediments from the vicinity land	Seasonally from seepage
Seasonally or regularly freshwater influenced landward zone	High	Inundated at spring tide	Dominated by fine sand and subjected to sedimentation from land	From water table and seepage
Seaward beach	High	Dry at almost tide levels	Dominated by coarse sands	Absent

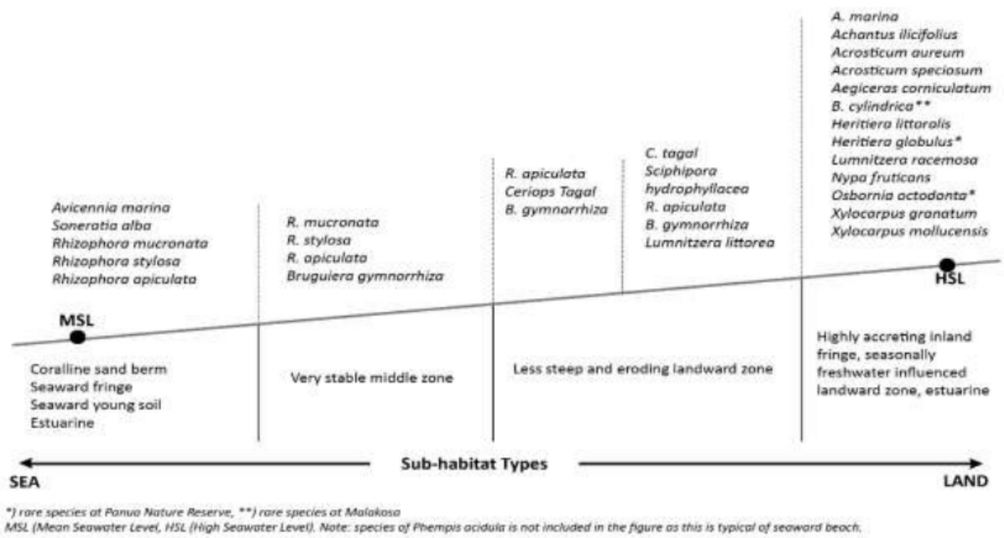

Figure 3. The relative position of mangrove sub-habitats across intertidal environment and species composition over different types of sub-habitat.

As can be seen from Figure 3, two species, *Bruguiera gymnorrhiza* and *Rhizophora apiculata*, seemed to have been common on several habitat types. Other species occured on specific sub-habitats but in large numbers such as *Ceriops tagal, Pempis acidula, Sonneratia alba* and *S. hydrophyllacea*. Meanwhile, three species, *Bruguiera cylindrica*, *O. octodonta, and H.*

globulus, occurred only on specific sub-habitats in small numbers.

3.2. Association Types and Structural Formations

Tomini Gulf mangrove forest exhibited some major changes in habitat conditions over spatial scale. Using the floristic properties in the dominant canopy, types of mangrove assosiaciation were identified, and to classify the plant formation two ways structural classification of Specht (1970) was followed. Tabel 4 summarises ten types of mangrove association with each structural classes over various sub-habitat types.

Trees of *Avicennia marina* occured on two types of sub-habitat of highly accreting inland fringe and seward young soil. On highly accreting inland fringe stands were more likely in the formations of forest and closed-forest. On seaward young soil, they were found in low closed-shrub and closed-forest formations. Forest with dominant canopy species of *B. gymnorrhiza* was uncommon. At Lopon (00º25.722' N; 124º6.203' E), a mono-species stand of *B. gymnorrhiza* was in closed-forest formation with average canopy height of 25 m and diameter varying from 37 - 48 cm. The association of *C. tagal* was common on less steep and eroding lardward where surface substrate water salinity is usually high (Djamaluddin, 2018). At Pinolantungan (00º21'31.8" N; 123º56'29.7" E), stands of *C. tagal* occured in the formation of tall closed-shrub.

It was very common that stands of *N. fruticans* occured in mono-species stands in seasonally or regularly freshwater influenced landward zone. In Tomini Gulf, this association tipe was found, for example at Dagad Dede (00º25'55.6" N; 120º54'22.4" E) and Matandow.

Tabel 4. Mangrove associations and structural formations over various types of sub-habitat.

Association Type	Structural Classes	Sub-habitat Types
Avicennia marina	Closed-forest, forest, low closed-shrub	Highly accreting inland fringe, seaward young soil
B. gymnorrhiza	Closed-forest	Very stable middle zone
C. tagal	Tall closed-shrub, tall open-shrub, tall sparse-shrub, low open-shrub	Less steep and eroding landward
Nypa fruticans	-	Seasonally or regularly freshwater influenced landward zone
Rhizophora spp./B. gymnorrhiza	Forest, closed-forest, low closed-forest	Very stable middle zone
R. apiculata/C. tagal	Closed-forest, Low forest, low open-forest, low closed-forest	Less steep and eroding landward zone
Rhizophora spp.	Forest, low open-forest, low forest, low closed-forest	Seaward fringe, coralline sand berm, seaward young soil
Sonneratia alba	Tall closed-forest, closed-forest, forest, low closed-forest	Seaward fringe, coralline sand berm, seaward young soil
S. alba/B. gymnorrhiza	Tall closed-forest	Very stable middle zone, coralline sand berm
S. alba/ Rhizophora spp.	Forest, closed-forest, low-closed forest	Seaward fringe, coraline sand berm, seaward young soil
S. alba/ A. marina	Forest	Seaward fringe

When *Rhizophora* spp. *B. gymnorrhiza* association type occured, it was most probable that the sub-habitat condition was physically stable (Djamaluddin, 2018). At Patoa (00°19'57,2" N; 123°51'19" E) forest and closed-forest formations were found with canopy height in the range between 15.5 and 23.3 m and tree diameter up to 101 cm. The association of *R. apiculata* / *C. tagal* was encountered in closed-forest, low forest, low open-forest, low closed-forest formations. At Dudepo (00°01'56.6" N; 123°55'09.5" E), canopy trees of *R. apiculata* and *C. tagal* occured in low forest formation.

Stands of *Rhizophora* spp. usually occured on seaward fringe and young soil sub-habitats. In Tomini Gulf this association was encountered in forest, low open-forest, low forest, and low closed-forest formations. Mono-stand of *S. alba* was common on seaward fringe, coralline sand berm, seaward young soil sub-habitats. At Pangia (00°19'16.2" N; 123°47'57.2" E) this association occured in tall closed-forest formation. The *Sonneratia alba*/*B. gymnorrhiza* association occurred only on very stable coastal environment such as at Duminanga (00°19'43.2" N; 123°50'53.6" E). In this location the formation was encountered in tall closed-forest formation. The *S. alba*/*Rhizophora* spp. association occured on seaward fringe. At Dusun Langala (00°30'5.6 N; 122°28'53.5" E) stands consisted of *S. alba, R. apiculata* and *R. stylosa*. The *S. alba*/*A. marina* association was found at Ongka (00°28' 15.9"N; 120°47'35.8"E) on a relatively stable intertidal environment. Canopy trees consisted of two species of *S. alba* and *A. marina* in a forest formation with canopy height of 11.7 m.

3.3. Patterns in Uses and Level of Disturbance

During 1988 to 2010 the Gulf had lost mangrove area of some 42% (10 787.66 Ha or 107.88 km^2) with the average rate of loss at the level of 578.36 ha/year. If this level of degradation would be continual, and there are not any efforts to rehabilitate and conserve the mangroves, the whole remaining area of 16,105.40 ha will vanish in 2038 (Damanik and Djamaluddin, 2012). Although most of shrimp ponds were abandoned, it was revealed in the field that there were new shrimp ponds even in Tanjung Panjang Nature Reserve (Figure 4 A). Most of abandoned shrimp ponds remained unvegetated due to the change in hydrological condition and high soil salinity (Figure 4 B). Moreover, the release of sediments from area of shrimp ponds occured persistently and this resulted in sedimentation on coastal ecosystems such as seagrass and coral reefs.

Figure 4. New established shrimp pond: (a) Tanjung Panjang Nature Reserve (b) Bajo.

Local people exploited mangrove wood for various purposes. Most of big trees of *S. alba* had been cut to meet the need of timber for fishing boat construction (Figure 5 A), resulting in forest with remaining hollow trunk big trees. Unlike wood of *S. alba,* big trees of *B. gymnorrhiza* were cut to provide timber for construction of lift net (Figure 5 B). There was also significant evidence that trees of *B. gymnorrhiza* and *Rhizophora* spp. were subjected to ring-barking to meet the need for fish net preservation and colouring (Figure 5 C). This, however, had left the forest with standing dead trees of both species in certain locations. Wood of these species had also been targeted for firewood (Figure 5 D). Other uses of mangrove were for stakes of fish trap and fence (Figure 5 E, F).

From the total 159 locations surveyed some 40.3% and 35.2% were classified under medium and light disturbed condition respectively, seven location (4.4%) un-disturbed and three locations (2%) at level of heavy and very heavy disturbance. This result of evaluation indicated that almost all types of forest associations had been subjected to mangrove exploitation, and the exploitation had been widespread. If the current level of exploitation continue and spread this ecosystem will experience serious damage and will lose its ecological functions.

3.4. Field Implication of Artificial Plantation

All rehabilitation projects examined in this study applied method of artificial plantation with mostly seedlings of *Rhizophora* spp. from nursery, and facts in the field indicated that most of these projects had been unsuccessful. At Duminanga, seedlings of *Rhizophora* spp were planted in open spaces within a dense forest where the natural regeneration process was most probable (Figure 6 A). At Dudepo, goat grazing had resulted in the loss of almost all planted seedlings (Figure 6 B). At Tanjung Bendera, most of seedlings of *Rhizophora* spp. disappeared due to sedimentation and abrasion and the presence of free-moving logs in the location (Figure 6 C). There were only a few rehabilitation programs that had been sucessful such as at Boila River mouth (Figure 6 D).

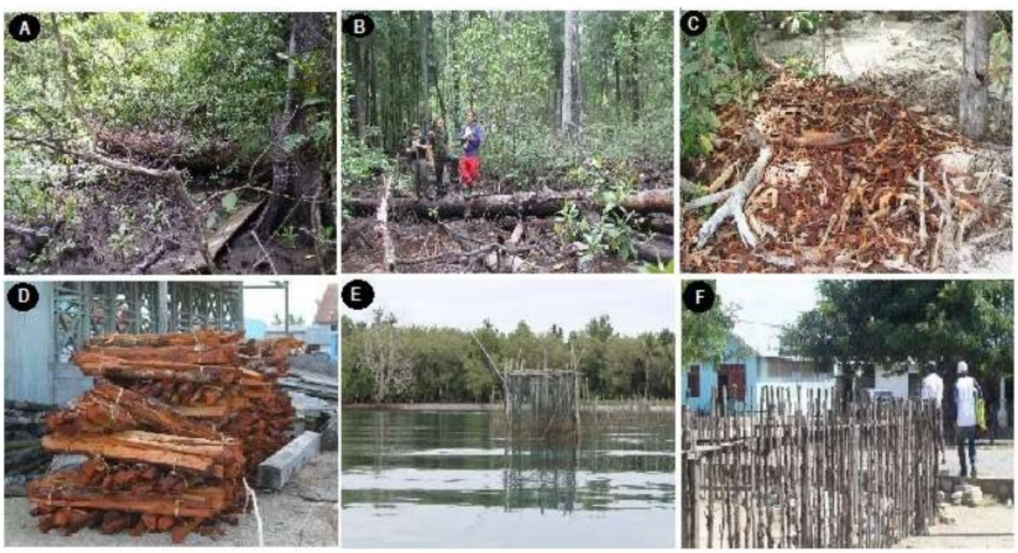

Figure 5. Mangrove uses: (a) logging *S. alba*, (b) logging *B. gymnorrhiza*, (c) mangrove bark, (d) fire wood, (e) fish trap, (f) fence.

Figure 6. Artificial plantation in: (a) Duminanga, (b) Dudepo, (c) Tanjung Bendera, (d) Boila River mouth.

Unsucessful mangrove rehabilitation programs in Tomini Gulf clarify that artificial plantation is not a simple method to be implemented on degraded mangrove areas and areas subjected to active coastal physical processes. Over all, proper procedure and techniques related to artificial mangrove plantation have to be followed, and hydrological restoration may be adopted to rehabilitate physically degraded mangrove areas.

IV. CONCLUSION

Conversion of mangrove areas into shrimp ponds and extraction of mangrove wood for various purposes had changed vegetation structure over various sub-habitats, influencing future development and regeneration of the mangrove. Whilst most of rehabilitation programs were unsuccessful, mangrove exploitations still continued. If management plan would not be developed the degradation will continue and spread, then the mangrove may lose its ecological function.

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