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Mangrove landscaping using the modulus of elasticity and rupture properties to reduce coastal disaster risk

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A B S T R A C T

Hazards in coastal areas such as tsunamis, abrasion and sea level rise may cause ecosystem degradation, building damage, and human death. One strategy to mitigate the possible impacts of such risks is to design mangrove landscaping. This design uses the wood properties of modulus of elasticity (MoE), modulus of rupture (MoR), and other properties. MoE and MoR reflect the strength of wood to reduce the impact of hydrodynamic forces in coastal areas. The destructive method was used to analyze the MoE and MoR of mangrove trees from two stations (West Segara Anakan and East Segara Anakan), which have 20 sampling plots (size 10 m × 10 m) as replicates for each station. The results showed that mangrove species have MoE score ranging from 50.000 kg cm^{-3} to 171.802 kg cm^{-3} and MoR score ranging from 400 kg cm^{-3} to 1503.44 kg cm^{-3}. Accordingly, mangrove landscaping design in West and East Segara Anakan based on MoE and MoR properties were proposed with the following classes: class 1 *Rhizophora apiculata* and *Bruguiera parviflora*, class 2 *B. gymnorrhiza, B. sexangula, R. stylosa* and *R. mucronata,* class 3 *Avicennia alba, Sonneratia alba, Xylocarpus granatum* and *X. moluccensis* and class 4 *Nypa frutican* and *Casuarina equisetifolia.*

1. Introduction

The coastal ecosystem is a dynamic ecosystem (Watson and Byrne, 2009) that is subject to disaster risks that often impact the sustainability of the system (Diposaptono and Budiman, 2008). The potential coastal disasters include abrasion (Hakam, 2013), seawater intrusion (Hilmi et al., 2017a), sedimentation (Sari et al., 2016), organic pollution (Syakti et al., 2013), heavy metals pollution (Syakti et al., 2015; Hilmi et al., 2017c), tidal flooding (Marfai et al., 2008) and tsunamis (Cocharda et al., 2008) and carbon pollution (Hilmi et al., 2017b). Tsunamis are caused by tectonic earthquakes, volcanic eruptions and landslides (Diposaptono and Budiman, 2008; Harada and Imamura, 2003; Harada and Kawata, 2004; Alongi, 2008). The impacts of these hazards are extensive erosion, sediment transport and deposition, land subsidence, building damage, ecosystem degradation and social and economic destruction (Paris et al., 2009; Narayana et al., 2007). Tsunami disasters can cause economic losses of up to US $ 3.482 million (Kathiresan and Rajendran, 2005; Narayana et al., 2007; Vermaat and Thampanya, 2006).

The mangrove ecosystem is an important ecosystem that can reduce the impacts of coastal disasters because it has unique habitats, soil textures, water salinity, water inundation characteristics, root systems, canopies, and strata (Krauss et al., 2008; Kusmana et al., 2000; Krasuss and Allen, 2003). The performances of the roots, growth, strata, zones and wood in mangrove ecosystems are important properties that can potentially reduce coastal disasters from natural hazards such as tsunamis. Mangrove landscaping is an alternative to simply rehabilitating degraded habitats and was developed to reduce coastal disasters by using modulus of elasticity (MoE), modulus of rupture (MoR) as indicators to select mangrove trees and develop landscaping patterns in coastal disaster zones. Previous studies have shown that the design of mangrove landscaping could increase the functions of mangroves that may result in the protection of the area from hydrodynamic forces (Mulidin, 2001; Lugo and Snedaker, 1974; Kairo et al., 2008; Kerr et al., 2006; Kathiresan and Rajendran, 2005) and conservation of habitat for organisms (Kusmana et al., 2000).

The MoE and MoR are the physical properties of wood that indicate the elasticity and strengthen (rupture) of the wood if it receives a load (McIntire et al., 1991; Tsoumis, 1991; Haygreen and Bowyer, 1996; FAO, 1994). MoE and MoR are wood strength and elasticity indicators used to develop mangrove landscaping patterns in coastal disaster classes. The MoE and MoR scores indicate that mangroves can reduce wave energy (Mazda et al., 1995), the effects of tides (Mazda et al., 1995; Massel et al., 1999), the effects of sea currents (Kusmana, 2005)

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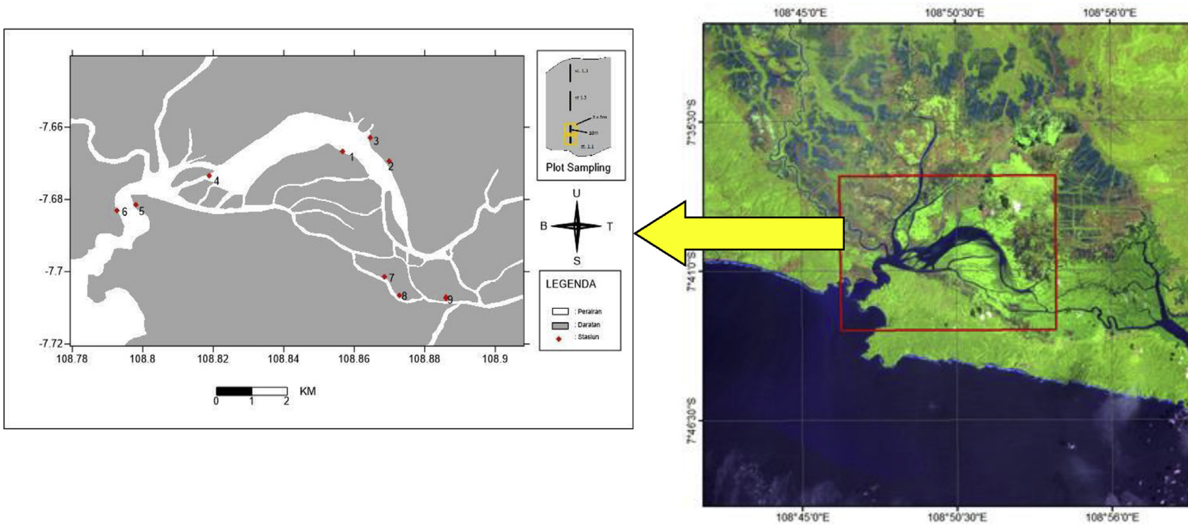

Fig. 1. Site locations in the Segara Anakan Lagoon.

and destruction effect from tsunamis (Barbier, 2008). The design of mangrove landscaping was developed by integrating MoE, MoR and mangrove habitat. The integration of MoE, MoR and mangrove habitat is used as the indicator to select mangrove species in coastal disaster zones. This paper discusses the mangrove landscaping strategy to reduce coastal disasters based on the modulus of elasticity (MoE), the modulus of rupture (MoR), wood density, water-holding capacity and habitat properties.

2. Material and methods

2.1. Site research

This research was conducted in Segara Anakan (Fig. 1). The geographic coordinates of Segara Anakan are 7°35' – 7°46′ S and 108°45' – 109°01' E. Sari et al. (2016) noted that Segara Anakan consists of 1788.7 ha of mangrove ecosystems, 1042.8 ha of lagoon and 11,976 ha of other land use types. In this location, it has been shown that the mangrove ecosystem has the ability to save and protect other ecosystems from many disasters, including tsunamis, high waves and sedimentation.

2.2. Research variables

The variables of the mangrove landscaping pattern used to reduce disaster risks in coastal areas are soil texture, pH and salinity (environment variables), and water content, wood density, MoE and MoR (wood property variables).

2.3. Sampling technique

This research used stratified sampling (Cochran, 1991) of the mangrove species distribution as the main factor. The samples were taken to collect data on the various parameters, namely, wood properties (MoR/species, MoE/species, wood density/species, water content/species), soil texture, soil salinity and pH. The data were collected from two stations (West Segara Anakan and East Segara Anakan). Each station had 20 sampling plots (size 10 m × 10 m) as replicates.

2.4. Research procedure

2.4.1. Environment variables

The environment variables are soil texture, salinity and pH. Soil texture was analyzed by the gravimetric method (Sudjadi et al., 1971; Van Reeuwijk, 1993; Burt, 2004; Rayment and Higginson, 1992). Salinity was analyzed by the conductivity method (APHA, 2005; APHA, 2012) with a handheld refractometer (Atago 2973 Master-53pm United Technology Trade Crop), and pH was analyzed by a pH meter (Horwitz, 2000).

2.4.2. Wood property variables

Wood property variables are water-holding capacity and wood density. They are analyzed by TAPPI T 264 om 88 standards and the ASTM method using the following equations

$$\text{Specific gravity} = \frac{\text{dry weight of wood}}{\text{initial volume}}$$

$$\text{Water content} = \frac{(\text{initial weight of wood} - \text{dry weight of wood})}{\text{tanure dry of wood}} \times 100\%$$

2.4.3. Modulus of elasticity and modulus of rupture

MoE and MoR were analyzed in the Wood Technology Laboratory of Forest Faculty, Bogor Agricultural University. MoE and MoR were also analyzed by determining maximum wood deflection before wood damage. The scores were read by a deflectometer (McIntire et al., 1991; Tsoumis, 1991). The MoR score was analyzed by the formula $\text{MoR} = \frac{3.P.L}{2\,b.h^2}$, and the MoE score was analyzed by the formula $\text{MoE} = \frac{P''.L^3}{4\Delta Y.b.h^3}$, where MoE = modulus of elasticity (kg/cm^2), MoR = modulus of rupture (kg/cm^2), P = pressure until wood breakage (kg), P" = change in load caused by change in deflection (kg), L = distance between wood rafters (28 cm), b = width of the wood sample (cm), h = thickness of the wood sample (cm), ΔY = distance of deflection causing a change (cm).

2.5. Data analysis

The data analyses consisted of (1) classifying the mangrove species based on the MoE and MoR, the water content, and the wood density as indicators of wood strength and ability to reduce coastal disasters, (2) classifying the mangrove ecosystem based on wood properties and mangrove habitat as concepts and strategies for mangrove conservation to reduce the impacts of coastal disasters and (3) determining the pattern of mangrove landscaping based on the mangrove distribution in a coastal disaster area.