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# Crown shape dynamics of dense mangrove *Kandelia obovata* stands in Manko Wetland, Okinawa Island, Japan

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**Abstract**. *Analuddin K, Septiana A, Sharma S, Hagihara A. 2016. Crown shape dynamics of dense mangrove Kandelia obovata stands in Manko Wetland, Okinawa Island, Japan. Biodiversitas 17: 865-872.* The objectives of this study were to elucidate the crown structure dynamics for dense mangrove stands, and to know the crown shape maintenances and its important role for ensuring the stability and vitality the crowded mangrove forest. The growth parameters of *K. obovata* Shue, Liu & Yong stands, such as tree height $H$ (m), height at the lowest living leaves $H_L$ (m), crown length $C_L$ (m) and crown width $C_W$ (m), were measured in the summer from 2004 to 2008. The crown shape dynamics were analyzed. The results showed that the $H_L$ was significantly increased with increasing $H$, which suggests that the crown changed to be dumpy as the stands grew. However, the $C_L$ of young stands increased and then decreased continuously as the stands grew, while the $C_L$ of mature stands decreased from 2004 to 2007 and then increased in 2008. Meanwhile, the $C_L/C_W$ ratio of young stands decreased as the stands grew, while the $C_L/C_W$ ratio of mature stands decreased and then increased, which imply that dense *Kandelia obovata* trees might transform their crown shape for reducing of competition for light among trees. Therefore, these results suggested that the crown shape of dense mangrove treesare dynamics as developing stands.

**Keywords:** Crown length, crown width, crown shape, crown volume, *Kandelia obovata*, stand dynamics

## INTRODUCTION

Mangrove forests are known to play many important roles in the subtropical and tropical coastal areas of the world including nursery grounds and breeding sites for various animals, an essential resource of wood; sites for accumulation of sediment and nutrients in coastal areas (Twilley 1995; Alongi 2002; Manson et al. 2005); maintain the ecological equilibrium in coastal waters and preserve species diversity (Saenger 2002). The exchange of carbon between mangroves and coastal ocean and its fate in the ocean is, therefore, increasingly recognized as potentially important components in the ocean carbon budget. Mangrove ecosystems play important role in the global carbon cycle. The crown structure of mangroves plays an important role for mangrove forest productivity, and the analysis on crown dynamics in mangrove stands is very important to understand the maintenance their productivity and stability.

A tree's crown plays important roles for plant functioning and forest productivity through its effect on light penetration (Kellomaki 1995). The crown of trees influences their competition and survival abilities in the community (Kuulivainen 1992). Crown structure, leaf morphology and photosynthesis are closely related, which influence whole-crown carbon gain (Ellsworth and Reich 1993; Bond et al. 1999; Koike et al. 2001; Pons and Anten 2004). The crown of trees is as a dynamics system, because the leaves composing the crown are dynamic in term of their development and senescence. The leaves arrangement within the crown influences many aspects of whole-plant function including photosynthesis, transpiration and energy balance (Campbell and Norman 1989; Pearcy and Yang 1996).

As the trees grow larger, they produce more precise crown to be sound in their life. In the dense stands, the trees have to maintenance their crown shape to ensure their functioning. This maintenance may be accompanied with the changes in the crown and structure, which are essential for ensuring the life and growth of trees. Therefore, studies on tree crown shape dynamics provide critical information to assess the ecological functioning of mangrove forests.

Several theoretical studies on crown dynamics have been done by models (Mori and Hagihara 1991; Grote 2003; Shaw et al. 2003; Mottus et al. 2006; Weiskittel et al. 2007), but few field data are available (Jimenez-Perez et al. 2006), even there was few studies mentioned crown shape dynamics for mangroves till now. Measurement of a tree crown is often used to study of individual (tree) growth (Kozlowski et al. 1991). Taking into consideration the tree crown as a parameter of the vegetation development, several scientific studies relating to the crown and growth of trees have been undertaken to determine tree growth through models for tree crown profiles (Biging and Gill 1997; Gadow 1999; Gill et al.2000). On the contrary, little information is known about crown shape dynamic on mangrove forests, which are among the most productive ecosystems and play an important role throughout tropical and subtropical coastal areas of the world (Ewel et al. 1998). Therefore, it would be worthwhile to explore the dynamics of crown shape for dense mangrove stands, knowledge of which can improve the understanding of the structural maintenance of mangrove forests.

*Kandelia abovata* is one of among the most dominant mangroves in Okinawa Island, Japan. Although intensive studies have been done in this mangrove *K. obovata* forest including allometric model and mangrove productivity (Khan et al. 2004, 2005, 2007), mangrove photosynthesis capacity (Suwa et al. 2006, 2008; Suwa and Hagihara 2008) and mangrove self-thinning (Analuddin et al. 2009b) and foliage dynamics (Analuddin et al. 2009a), butthe information about how the spatial and temporal maintenances of tree crown shape in dense mangrove forest are scarce. In this study, we monitored the crown shape dynamics of the dense *K. obovata* forest over five years. The dynamics of crown length, width and volume were investigated. The objectives of this study were: (i) to elucidate the crown structure dynamics for dense mangrove stands, and (ii) to know the crown shape maintenance of the dense mangrove forest.

## MATERIALS AND METHODS

### Study site

The present study was carried out at Manko Wetland (Figure 1), which is located along the Kokuba river beside Tomigusuku city of Okinawa Island, Japan (26º11′ N and 127º40′ E). The wetland has been recognized as an important conservation area and has been registered under the Ramsar Convention. The mangrove *Kandelia obovata* (S., L.) Yong was formerly recognized as *K. candel* (L.) Druce. Recently, it was split into two species, one of which is *K. candel* and the other is *K. obovata* distributed in China and Japan (Sheue et al. 200). Tree density of *Kandelia obovata* stands decreased year by year, which ranges from 2.68 to 4.88 (ind./m$^2$) in 2004, and decreased from 1.58 to 3.28 (ind./m$^2$) in 2008 (Analuddin et al. 2009b). *Kandelia obovata* is the dominant species in the study site. Besides, some small groups of *Rhizophora stylosa* Griff., *Bruguiera gymnorrhiza* (L.) Lamk. and *Excoecaria agallocha* L. are also observed, but they grew separately with *K. obovata* stands. The mean annual temperature in the years from 2004 to 2007 was 23.4± 0.1 (s.e.) ºC, while the mean precipitation at the same periods was 2190 ±211 (s.e.) mm yr$^{-1}$.

### Tree inventory

A belt-transect 125 m long and 5 m wide was established in the *K. obovata* forest, whose canopy has been completely closed, perpendicularly to the current river and divided into 25 subplots (5 × 5 m$^2$). All trees in the subplots were recorded. The stem age of trees was determined by ring analysis from sample trees that taken from each subplot. The individual sample tree was taken on the basis of mean stem diameter in each plot. The stem of tree was cut and the annual ring was counted. Stem visualization revealed that tree age continuously increased from 6 yrs near the riverside to 10 yrs near the land (as of 2005), so that trees within a subplot could be assumed as uniformed age. The young and mature trees have been distinguished from their stem age. Trees are having age of

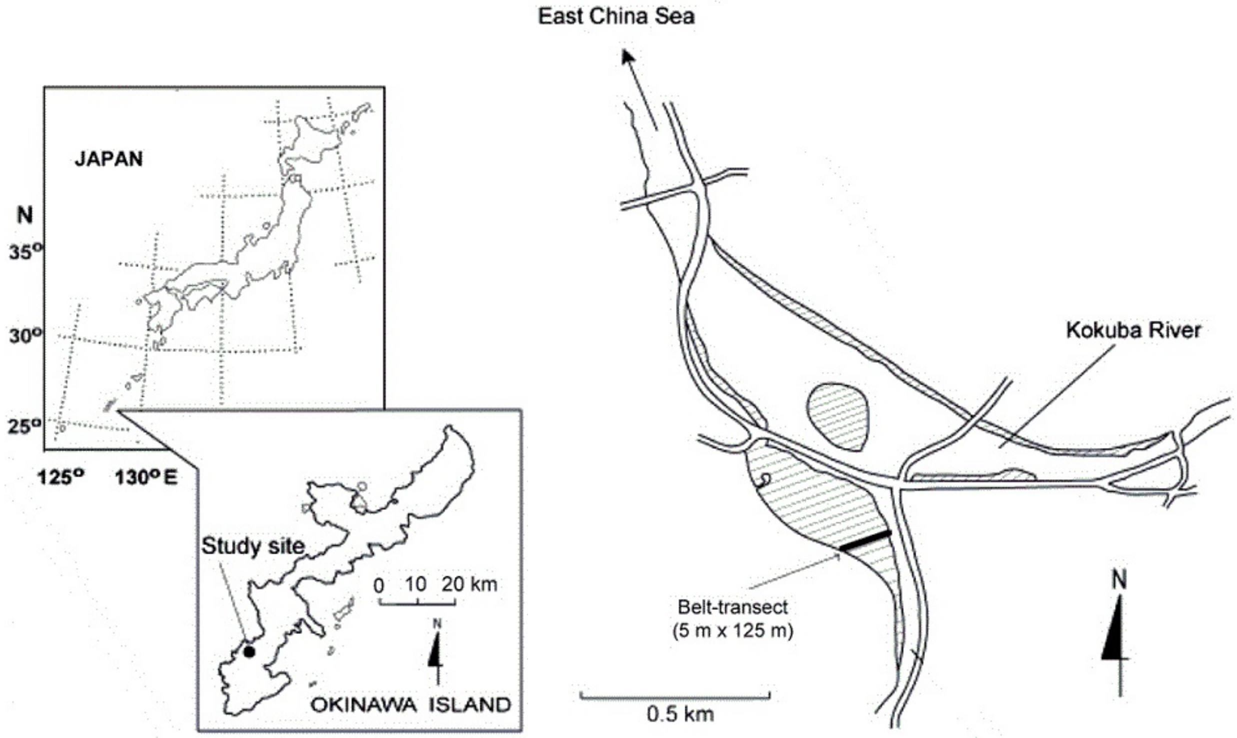

**Figure 1.** Study site at Manko Wetland, Tomigusuku city of Okinawa Island, Japan

less than 7 years assumed as young stands, while the trees are having age of 10 years assumed as mature stands. The young stands are located near the river side and middle area about 25 m and 60 m from the river edge, while mature stands are located near the inland area about 100 m from the river.

Growth parameters of mangrove trees, such as tree height $H$ (m), stem diameter at 10% of $HD_{0.1H}$, height at the lowest living leaves $H_L$ (m), crown length $C_L$ (m) and crown width $C_W$ (m), were measured in the summer of 2004, 2005, 2006, 2007 and 2008. Crown length $C_L$ was defined as the difference between tree height ($H$) and height of the lowest living leaves $H_L$. Crown width $C_W$ of a tree was estimated by the arithmetic mean of two perpendicular directions of the crown, including the widest projection, while crown shape estimated from $C_L/C_W$ ratio. Furthermore, the tree crown volume was estimated according to Frank (2010), i.e. $C_L/C_W$ ratio = 1 assumed as a cylinder, $C_L/C_W$ ratio=0.817 assumed as a sphere, and $C_L/C_W$ ratio = 0.577 assumed as a cone. The growth rate of $H$ and $H_L$ between successively two years was also estimated in each subplot. In addition, scaling between crown structure to stand density, and tree age was performed to verify their effect on the crown shape dynamics.

The relative photon flux density (RPFD)under canopy of *Kandelia obovata* trees was measured in the beginning and end of experimental periods in every subplot by using a data logger (LI-1400, LI-COR, USA) and a pair of horizontally placed quantum sensors (LI-206.8 and LI-151.91, LI-COR, USA). One sensor was mounted at a height of 1.5 m under canopy and the other sensor was placed at above canopy. In this case, a hundred replications were taken in every subplot. The relative PFD (RPFD) from the bottom to the above canopy was calculated on the basis of the stationary sensor that placed above the canopy.

### Statistics

The mean crown length $C_L$, crown width $C_{W,}$ crown shape or $C_L/C_W$ ratio and crown volume $C_V$ were evaluated for all subplots. The $C_L/C_W$ ratio and the age of trees when $C_W$ reaches the higher value were estimated. Scaling the relationships of crown structure to tree density and tree age, as well RPFD were established by Spearman rank correlation, while Kaleida Graph ver. 4.0, Synergy Software was used for best fitting curves (higher $R^2$ value) for non-linear equations.

## RESULTS AND DISCUSSION

### Tree height and height at the lowest living leaves dynamics

Figure 2 shows the dynamics of tree height $H$ and height at the lowest living leaves $H_L$ during the five years. The $H_L$ significantly increased with increasing $H$ (Figure 2a), but the increasing rate of $H_L$ was much higher than that of $H$ except the increasing rate of $H$ in 2008 (Figure 2b). The relationship between $H$ and $H_L$ based on individuals trees showed higher correlation (Figure 2c, $r = 0.90$, $p< 0.05$).These results suggested the decreasing size of crown length of *K. obovata* with increasing tree height.

### Crown length and crown width dynamics

Figure 3 describes the growth dynamics of crown length $C_L$ over five years. The growth of crown length showed spatial and temporal variation (Figure 3a). Mostly trees near the riverside showed small decreasing in crown length as compared to the trees near the land site. The trees grown near the river site (young stands) seemed to increase in the second year then decrease in the third and fourth year, but then increase again in the 2008 (Figure 3b), while the trees grown from the middle to near the landsite tended to decrease from the second up to the fourth year, though they showed small increased again (Figure 3c).The $C_L$ decreased year by year with tree density ($r = 0.39$, $p< 0.05$, Figure 3d). A decreasing trend of $C_L$ seemed to correlate with tree age ($r = -0.549$, $p< 0.05$; Figure 3e). These trends indicated that the $C_L$ of *K. obovata* trees in dense stands are dynamics as the stands grew and correlated with their density and age.

Figure 4 shows the crown width dynamics of dense mangrove *Kandelia obovata* stands over five years. The crown width $C_W$ of trees grown in the middle toward the river side showed increasing size, while the $C_W$ of trees grown near the inland site tended to decrease continuously (Figure 4a). However, the $C_W$ of young stands increased continuously as the stands grew (Figure 4b), while the $C_W$ of mature stands increased and then decreased (Figure 4c). The growth of $C_W$ was not significant correlated with tree density (Figure 4d, $r = 0.23$, $p> 0.05$), and tree age, $r = 0.10$, $p> 0.05$, Figure 4e). Meanwhile, the age of trees when the $C_W$ attain their maximum decreased and increased from the riverside landward (Figure 5), which imply that the trees in the middle area later attains their maximum $C_W$ as compared with trees near the riverside.

### Crown shape and crown volume dynamics

Figure 6 shows the $C_L/C_W$ ratio or crown shape dynamics over five years. The $C_L/C_W$ ratio of *K. obovata* trees is dynamic as stands grew, and showed clearly different trend (Figure 6a). It seemed that the $C_L/C_W$ ratio of young stands decreased continuously as the stands grew (Figure 6b), while the $C_L/C_W$ ratio of mature stands decreased and then increased (Figure 6c). The crown shape showed mostly cylinder in 2004, while other years showed as sphere. However, the dynamics of $C_L/C_W$ ratio showed significantly correlated with tree density ($r = 0.44$, $p< 0.05$; Figure 6d), and tree age ($r = -0.46$, $p< 0.05$; Figure 6e). These results realized that the dense mangrove trees might transform their crown shape to make their life function.

Figure 7 shows the crown volume $C_V$ dynamics of *K. obovata* stands during five years. The $C_V$ increased and decreased in general, though the $C_V$ of young stands located near the riverside still increased as the stands grew (Figure 7a). The dynamics of $C_V$ was positively correlated with tree density ($r = 0.41$, $p<0.05$, Figure 7b), but it was negatively correlated with tree age ($r = -0.554$, $p< 0.05$; Figure 7c) indicating that *K. obovata* trees might have to maintain sound crown volume to sustain in their life.

Figure 8 shows trends of relative photon flux density RPFD under the canopy of *Kandelia obovata* stands. The RPFD under the canopy layer of *K. obovata* stands showed spatial and temporal variations (Figure 8a). The RPPFD seemed to be higher near the landside as compared near the riverside. Many stands showed RPFD were more 10% in 2004, even all stands showed RPFD were more than 5% in 2004, but most of RPFD in all stands showed decreasing trends for less than 5% in 2008,excepting RPFD in two plots of near the river, in the middle and landsite areas. However, the RPFD in 2008 showed negatively correlated with crown volume ($r$ =-0.32, $p$<0.05, Figure 8b), while the RPFD in 2004 was not correlated with crown volume in 2004 ($r$ =-0.017, $p$>0.05, Figure 8b).

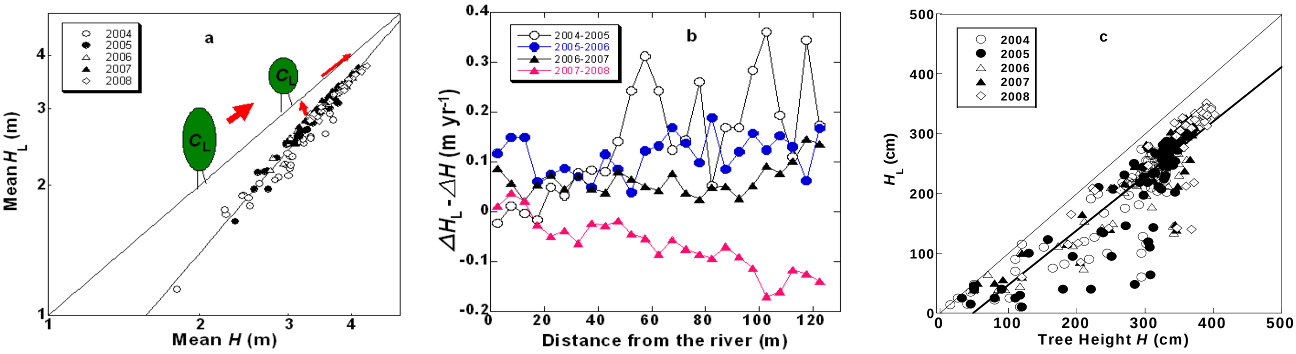

**Figure 2.** The dynamics of tree height $H$ and height at the lowest living leaves $H_L$ during the five years. A. Relationship between tree height $H$ and height at the lowest living leaves $H_L$. Open circles 2004, filled circles 2005, open triangles 2006, filled triangles, 2007, open diamonds 2008. B. Trends of $\Delta H_L$- $\Delta H$ increments from the riverside landward. Open circles 2004-2005, filled circles 2005-2006, filled triangles 2006-2007 (black), filled triangles 2007-2008 (red). C. Example the relationship between $H$ and $H_L$ of individual trees. Symbols are the same as Figure 2.A.

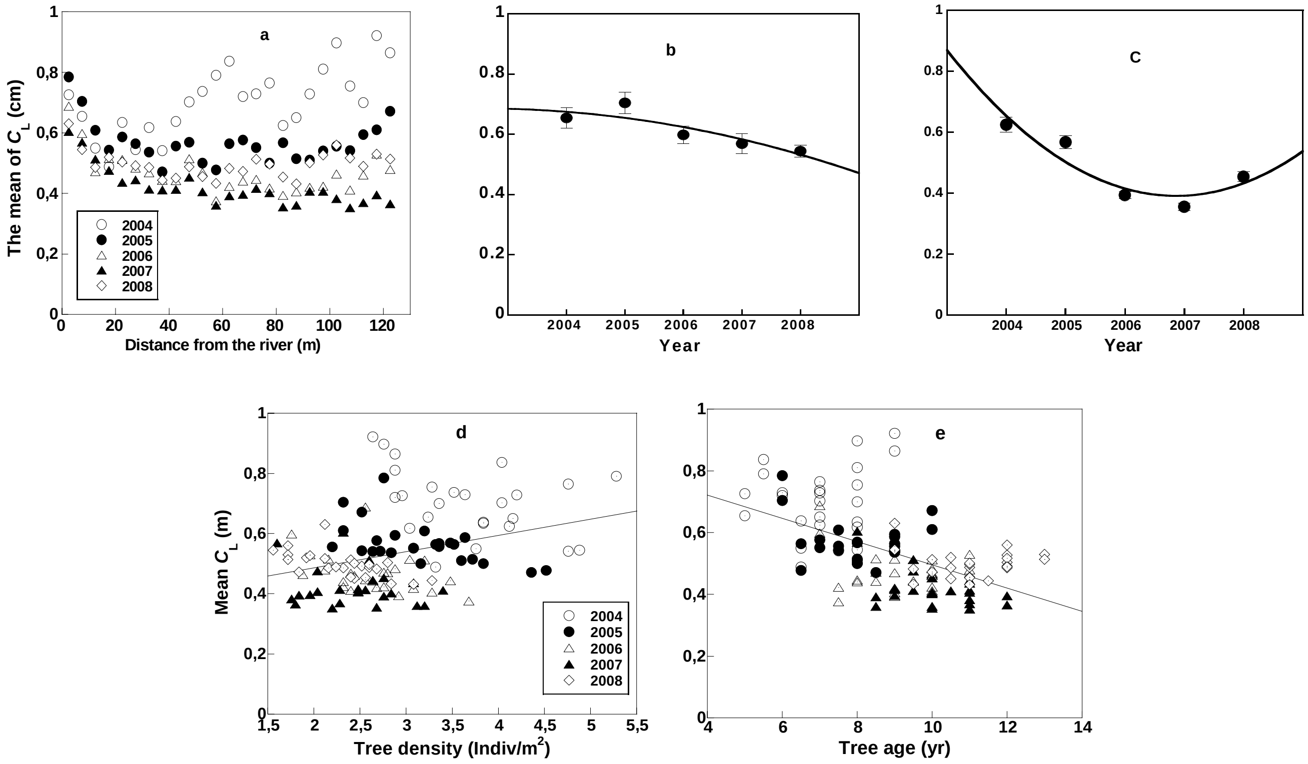

**Figure 3.** A. Spatial trends of crown length $C_L$ dynamics during five years. B. Examples of $C_L$ dynamics for young stand, and C. mature stand. D. Relationships of crown length to tree density, and E. tree age. Open circles 2004, filled circles 2005, open triangles 2006, filled triangles, 2007, open diamonds 2008

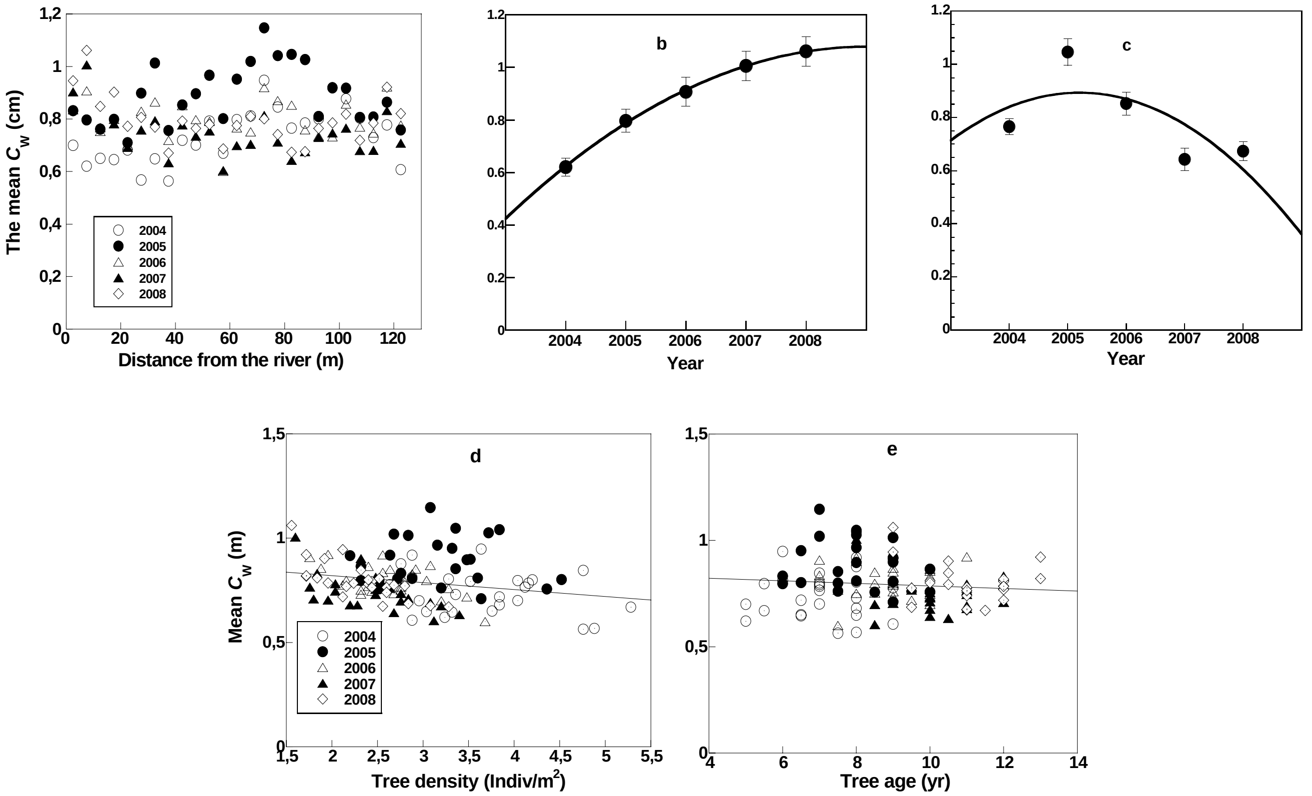

**Figure 4.** Spatial trends of crown width $C_W$ over five years (a). Examples of $C_W$ growth for young stand (b) and mature stand (c). Relationships of crown width to tree density (d) and tree age (e). Open circles 2004, filled circles 2005, open triangles 2006, filled triangles, 2007, open diamonds 2008

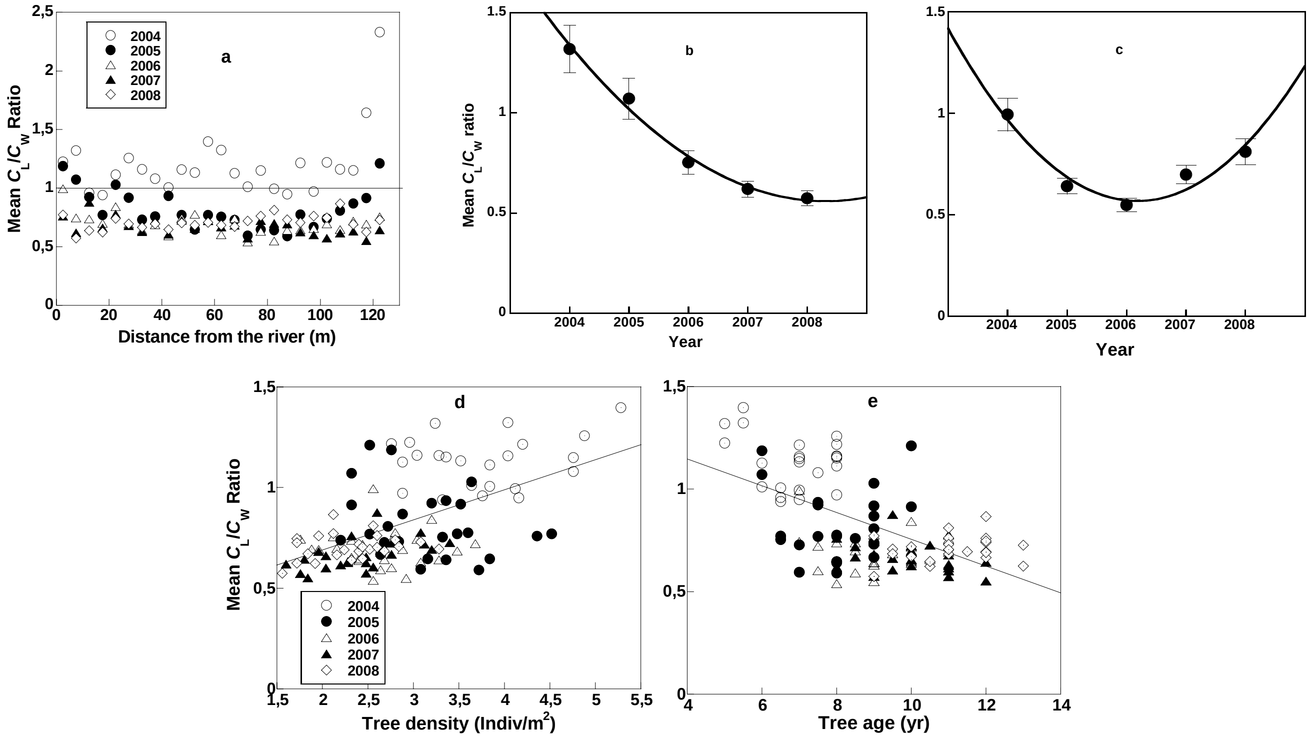

**Figure 6.** A. Spatial trends of $C_L/C_W$ ratio or crown shape dynamics during five years. B. Examples of crown shape dynamics for young stand, and C. mature stand. D. Relationships of $C_L/C_W$ ratio to tree density, and E. tree age. Open circles 2004, filled circles 2005, open triangles 2006, filled triangles 2007, open diamonds 2008

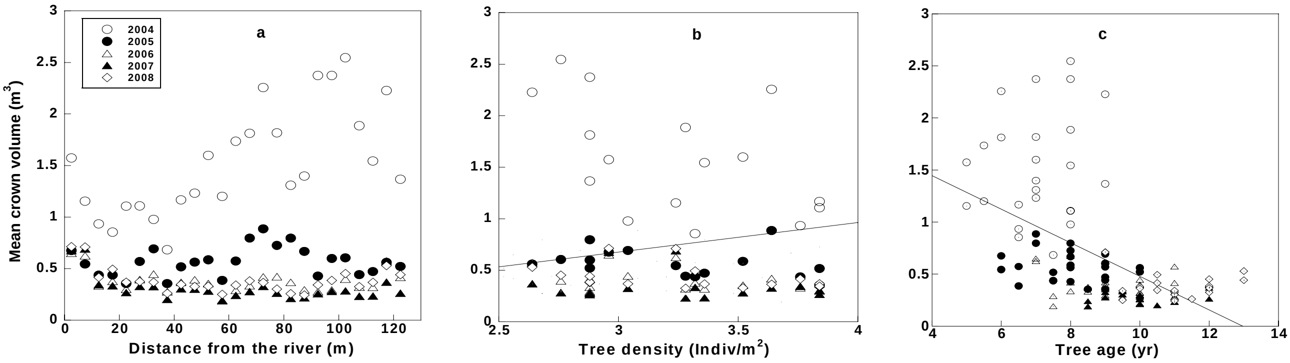

**Figure 7.** A. Spatial trends of crown volume dynamics during five years. B. Relationships of mean $C_V$ to tree density, and C. tree age. Open circles 2004, filled circles 2005, open triangles 2006, filled triangles 2007, open diamonds 2008

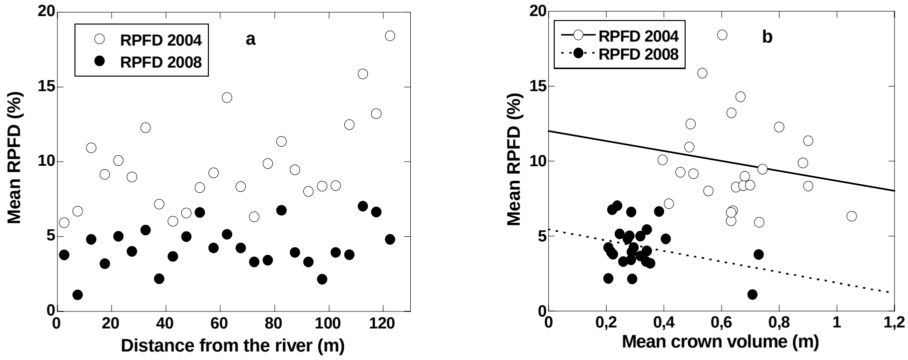

**Figure 7.** Spatial trends in relative photon flux density RPFD under the canopy of *Kandelia obovata* stands (a), and relationship of RPPFD to crown volume (b).Open circles2004 and filled circles 2008

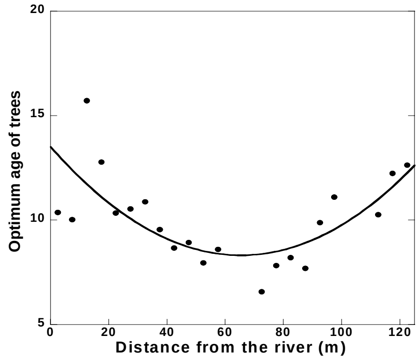

**Figure 5.** Spatial trend of optimum age when trees attain their maximum crown width from the riverside landward

## Discussion

The obtained results confirmed that crown structure of dense *Kandelia. obovata* stands is dynamics. The $C_L$ of the young stand increased and then decreased as the stands grew (Figure 3a), i.e. in the 2004, the $C_L$ of young stand was a little thin then increase in the second year, but then decreased again in the third year and fourth year. This is because high irradiance was found in the first year, which was mostly over 5% for all plots, but it was decreased to less than 5% for most of plots in 2008 (Figure 8a). As the results, $C_L$ tended to increased in the 2004, but then decreased due to reduced RPPDF under canopy of trees. The dynamic of $C_L$ was correlated to tree density (Figure 3d), and tree age (Figure 3e). In contrast, as illustrated in Figure 4, the $C_W$ increased and then decreased as the stands grew (Figure 4a), though the $C_W$ of the young stand increased as the stand grew (Figure 4b), while it increased and then decreased for the mature stand (Figure 4c). The growth dynamic of $C_W$ was not significantly correlated to tree density (Figure 4d), but it was negatively correlated to tree age (Figure 4e). However, the year when crown width attains its maximum decreased from the riverside landward (Figure 5), which indicates that trees near the riverside later attain the year to reach the maximum $C_W$ as compared with trees near the landward. These trends indicate that the tree crown development is not only depending on competition but it also corresponding with their age. Meanwhile, crown shape of dense *Kandelia obovata* stands are dynamics as stands grew though they showed different trends for young and mature stands (Figure 6a). The $C_L/C_W$ ratio decreased for the young stands (Figure 6b) as the stands grew, while it decreased and then increased for mature stands (Figure 6c). Hashimoto (1990, 1991) found that the ratio of crown length to crown width increased with age. Therefore, differences in the tree crown dynamics may reflect how the *K. obovata* trees produce sound crown to function in dense stands.

Although Kohyama et al. (1990) found that the tree crown length of a crowded stand increased as the stand grew, but our results showed that $C_L$ of dense *K. obovata* stands decreased as the stands grew, which implies that crown changes to be dumpy as the stands grow. In fact, as revealed in Figure 6, $C_L/C_W$ ratio decreased significantly as the stands grew, which suggests that the tree crown shape changes with developing stands. The crown volume of dense mangrove *K. obovata* stands are dynamics as stands grew (Figure 7a), and it was correlated with tree age (Figure 7c). This study results suggested that the tree crown shape of the dense mangrove stands is dynamic, and seems to correspond with the developmental stage of the stands. However, this dense mangrove stands were actively self-thinned for small trees (Analuddin et al. 2009b), while foliage in their crown are dynamic as the stands grew (Analuddin et al 2009a). Therefore, there may be existed internal factors (i.e. tree density, competition, and tree age) and external factor such as light intensity for maintenance the crown structures of dense *K. obovata* stands. As the crowded stands grow, the competition for light might be increased among individual trees. It shows that RPFD reduced from more than 5% up to 10% for most of plots in 2004 to less than 5% in 2008 (Figure 8a). The thick crown might result in low light intensity at the bottom canopy layer where leaves could not be doing better photosynthesis. As the results, carbon uptake by bottom leaves may become low. It has been reported by Khan et al (2007) that leaf carbon content of *K. obovata* trees in this forest decreased from the top to the bottom canopy layer. Uemura et al (2006) found on the leaves of winter-deciduous mature trees that leaves chlorophyll content those of trees decreased from the top to the bottom of the canopy. Less photosynthetic ability those of bottom leaves may be influenced their surviving ability, and the death of leaves or branches at the bottom canopy changed the crown shape of mangrove trees. In addition, nutrients from leaves at the bottom of the canopy might be re-translocated to support new leaves flushed in the top of the canopy. Khan et al. (2007) reported that N concentration in the leaves of *K. obovata* decreases from the top to the bottom of the canopy. This decrease might be induced for the rapidly dropped leaves of the bottom canopy or many bottom leaves might die as the stands grew. Therefore, the change in crown shape from a thick type to a thin type may imply that trees might transform their crown shape for reducing the stress of competition. Such change in the crown shape reflects that the dense mangrove stands might need to create sound crown shape to adapt growth and sustain in their life.

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