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Original Article

Seasonal cambial activity of some mangrove trees in Inner Gulf of Thailand in dependence on climate

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Abstract

This study aims to investigate the relationship between the cambial activity of *Rhizophora mucronata*, *Avicennia alba,* and *Avicennia marina* and climatic factors (e.g., rainfall, temperature, salinity, and sea water level) in Samut Sakhon Province, Thailand. Cambial samples were collected once a month from January to December 2009, resulting in total of 18 samples from 9 trees in every month. The samples were prepared by the epoxy technique. The cambial activity was investigated by counting undifferentiated cells in the cambial zone. The relationship between cambial activity and climatic factors were investigated by Pearson's correlation. Correlations among the cambial activity of the three species with rainfall, temperature, and salinity were weak and statistically insignificant. The strongest and most statistically significant relationships were observed with sea water level of *R. mucronata* ($r = -0.67$, $p<0.01$) and *A. alba* ($r = -0.52$, $p<0.05$). Therefore, cambial activity of the three species is not driven by seasonal climatic factors. For *A. alba* and *A. marina*, more than one cambium was found to be simultaneously active.

Keywords: cambial activity, climate, *Rhizophora mucronata*, *Avicennia alba*, *Avicennia marina*, Samut Sakhon, Thailand

1. Introduction

Tree age is a substantial and valuable parameter, for example for sustainable forest management (rotation for forest harvesting), dendrochronology (counting ring-width related to climate data), and forest dynamics. In temperate zones, where the seasons differ more conspicuously, the annual ring formation in trees is a result of periodicity in the type of elements formed by the cambium. However in the tropics, where the climate has a more uniform pattern, it was earlier assumed that the cambium activity seems to be active throughout the year (Bormann and Berlyn, 1981). Investigations on the factors controlling cambial activity are so far contradictory and this question was undertaken by many authors, e.g. trees in the Mediterranean zone were studied by Waisel and Fahn (1965), in temperate zones by Mariaux (1976) and Worbes (2002).

In Thailand, mangrove grow on sheltered muddy shores and low-lying bogs of river and stream estuaries at levels between low and high tides, along the banks of the Gulf of Thailand and on the west side of the east coasts of the peninsula. The climatic conditions of mangroves in coastal areas of Thailand are described in detail here: Rainfall: Average annual rainfall is 1,555.9 mm; monthly rainfall is maximum in September (378.3 mm) and minimum in December (4.6 mm). Temperature: Average annual temperature is 27.6°C, highest in April (29.9°C) and lowest in January (25.5°C).

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Humidity: Average annual relative humidity is 76.1%, highest in October (81.4%) and lowest in January (70.0%) Climatic types: tropical savanna climate with little rainfall and se vere drought during winter and summer (Aksornkoae, 1993).

Researchers from many countries have studied seasonal cambial activity in *Tectona grandis* (Rao and Dave, 1981; Rajput and Rao, 1998; Rao and Rajput, 1999; Rajput *et al.*, 2005), cambial activity in *Pinus sp.* (Murmanis, 1970; Schauer *et al.*, 2001; Gricar *et al.*, 2006; Liang *et al.*, 2009) and seasonal cambial activity in other species, such as *Robinia Pseudacacia* (Waisel and Fahn, 1965), *Pentaclethra*, *Goelthalsia* and *Carapa* (Hazlett, 1987), *Temarindus indica* L. (Rajput and Rao, 2001), *Azadirachta indica* (Rao and Rajput, 2001), *Rosa canina* (Türker *et al.*, 2004), *Machaerium cobanense, M. floribundum*, *Gouania lupuloides* and *Trichostigma octandrum* (Gómez and Ata, 2005), *Fagus sylvatica* (Cufar *et al.*, 2008), and *Araucaria angustifolia* (Oliveira *et al.*, 2009). The cambial activity of species from forests responds to climatic factor like temperature and rainfall. Cambial activity in mangrove trees (*Rhizophora mucronata*) has been studied by Schmitz *et al.* (2006). The study of the relationship between vessel density and salinity showed that the vessel density increases with higher salinity. *Avicennia marina* has been studied by Schmitz *et al.* (2008). This study found that no correlation was observed between radial increment and salinity, while a negative correlation was observed between growth layer width and salinity, with a decrease of the growth layer width corresponding to higher salinity. Change in growth ring is influenced by soil water salinity. Thus, change in growth ring can possibly be influenced by climate, because climatic factors, in particular rainfall, influence the soil water salinity in mangrove forests. However, there is a lack of research on the cambial activity of mangrove trees. In Thailand, most research on cambial activity was done on *Tectona grandis* and *Pinus sp.* (Pumijumnong, 1997; Linasmita and Pumijumnong, 2004; Pumijumnong and Wanyaphet, 2006). Studies of seasonal variation on cambial activity are scarce, especially concerning mangroves. From the studies of mangrove cambial activity, we could gain a better understanding on the factors affecting the tree growth. Knowledge of tree growth, such as the radial growth of trees that affects the increase of wood quantity, is very important in sustainable forest management, because it can dictate the quantities of wood products derived from forests each year. The objectives of the present study are to (i) investigate cambial activity of *Rhizophora mucronata*, *Avicennia marina* and *Avicennia alba* and (ii) investigate the relationship between cambial activity of *Rhizophora mucronata*, *Avicennia marina* and *Avicennia alba* and climatic factors, such as temperature, precipitation, water salinity, and sea water level. The information available might help to better understand the influence of climatic factors on tree growth. This understanding is an important basic knowledge for reforestation development and is also important for further promoting forest management and conservation of natural resources.

2. Methodology

2.1 Sampling site

The sampling site of this study is located at 13° 30′ 10″ N and 100° 16′ 15″ E in a mangrove forest at the Gulf of Thailand, located at the Mangrove Forest Learning and Development Center 2 in Bang Ya Prang, Samut Sakhon Province, Thailand (Figure 1). This area is part of the National Conservation Forest on the westside of the Mahachai Estuary. Plant community in this area was comprised of six species. Among these *Avicennia marina* was dominant with the only exception in the area near the shore that was dominated by *A. alba*. Other species found were *Rhizophora mucronata, Xylocarpus granatum, Bruguiera cylindrical, and Nypa fruticans*. The forest consisted of trees, saplings, and seedlings in numbers 451, 429, and 23,867 per rai (6.25 rai = 1 hectare), respectively. Two zones of plant communities were divided for the survey. From the importance value index (IVI), 10 meters from the coast was the *Avicennia alba* Zone. Up to 30 meters until the inside of the forest was *Avicennia marina* Zone. Characteristics of the climate in the study site are described as following: total annual rainfall is 2,002.4 mm; monthly rainfall is at its maximum in May (409.2 mm) and its minimum in January to February (0 mm); the average annual temperature is 30.2°C, with its highest in April (31.7°C) and lowest in January (27.0°C); and the average annual relative humidity is 63.84%, and is highest in October (71%) and lowest in January (54%). The area has a tropical savanna climate with little rainfall and severe drought during winter and summer.

In order to better understand mangrove forest cambium activities, sediment samples from mangrove forests were analyzed and described. The set of sediment samples of this study included a range of soils from neutral to moderately alkaline. Average pH during the wet season (August, pH=7.62) was lower than the dry season (April, pH=7.71), which may be a result of the amount of rainfall and fresh water intake. The mangrove sediments had a high to very high range (3.36-6.10) of %-organic matter (OM); these high levels in the mangrove sediments are due to decomposition of dead organisms as well as mangrove detritus and anthropogenic inputs. The moderate to high CEC values ranged from 11.15 to 29.03 $cmol_c kg^{-1}$. Sediment samples were clay loam (Buajan and Pumijumnong, 2010).

2.2 Meteorological data

One-year climatic information over the observation period was obtained from secondary data. Data on monthly mean temperature and monthly total rainfall were obtained from the Khlong Toei meteorological station (13° 42′ N, 100° 34′ E) in Bangkok Province near the study site. Salinity data were acquired from the Water Quality Management Bureau, Pollution Control Department at station TC01 (Tha Chin Estuary); the bureau collects data every three months. Sea

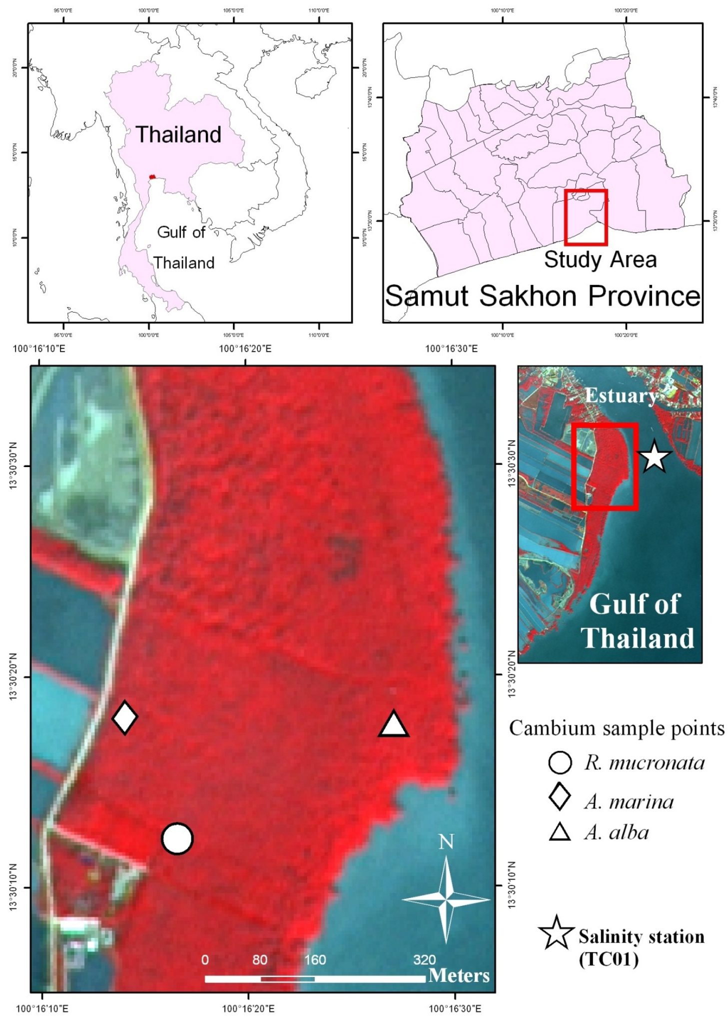

Figure 1. Map of study area showing the location of the study sites; false color composite from spot-5 HM+HJ in 2007.

water level data were acquired from the Hydrology Section Engineering Bureau Marine Department at Samutsakhon Station, Samutsakhon Province. The data were collected every day.

2.3 Cambial activity

Cambial samples were collected once a month from January to December 2009. The specimens included bark, the cambial zone and some parts of wood tissue of the main trunk at breast height (1.3 m). We sampled three trees of each species. The size (GBH) of the sample trees, *Avicennia alba*, *Avicennia marina,* and *Rhizophora mucronata* was 68-86 cm, 51-59 cm, and 25-35cm, respectively. In each tree, two blocks were excised from both contour-parallel sides using a chisel, resulting in total of 18 samples from 9 trees every month. The sample size was about 2 cm × 2 cm with a depth of 1 cm. After the samples were taken from the trunk, they were fixed immediately in 3% glutaraldehyde for preserving the cell fine structure. In the laboratory, the specimens were thoroughly washed with water to remove any remaining chemicals and then dehydrated by passing them through a graded EtOH series starting with 30% and ending with 100% ethanol. Epoxy (Epon 812) was used as the embedding in this study (Bozzola and Russell, 1999). A sliding microtome was used in sectioning the sample. Trimmed sample blocks were sectioned in transverse planes at a thickness of 20 micrometers. Toluidine blue (0.1% in water) was used for staining. Cambial activity was investigated by counting un-differentiated cells in the cambial zone under the light micro-scope with the magnification of 40X.

2.4 Statistical analysis

The correlation among cambial activity, mean, minimum, maximum daily air temperature, total monthly rainfall, water salinity, and sea water level was evaluated by Pearson correlation and F–test. The correlation was made among the data of every tree and between the both sides of each tree.

3. Results and Discussion

During the observation period from January to December 2009, the cambial zones of *Rhizophora mucronata* (Figure 2), *Avicennia alba* (Figure 3), and *Avicennia marina* (Figure 4) seemed to be active throughout the year as indicated by swelling of the fusiform cambial cells. However, two nearly dormant periods of *R. mucronata* occurred in April and December, during which the cambial zones were narrowed to 5 to 6 cell layers. The average number of cambial cell layers during these two months was 6.4 and 5.9 layers, respectively. Differences in cell layers between high-activity and low-

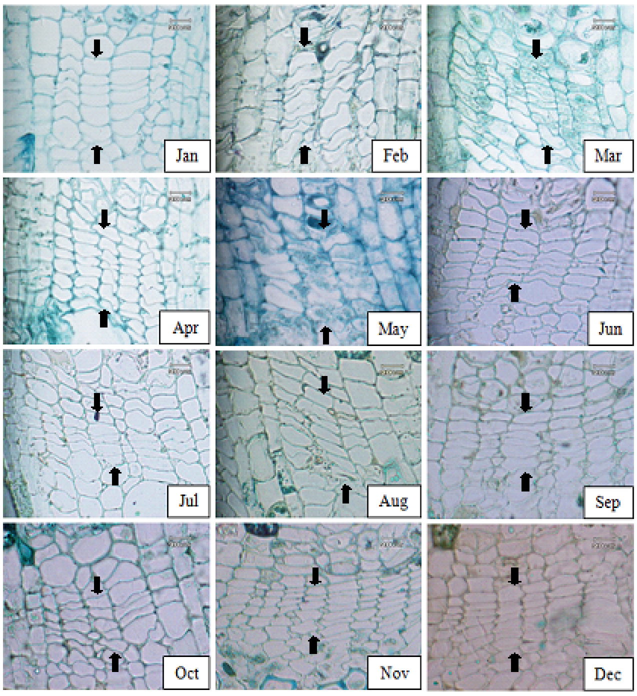

Figure 2. Transverse sections of *R. mucronata* showing cambial activity (arrows) from January to December 2009.

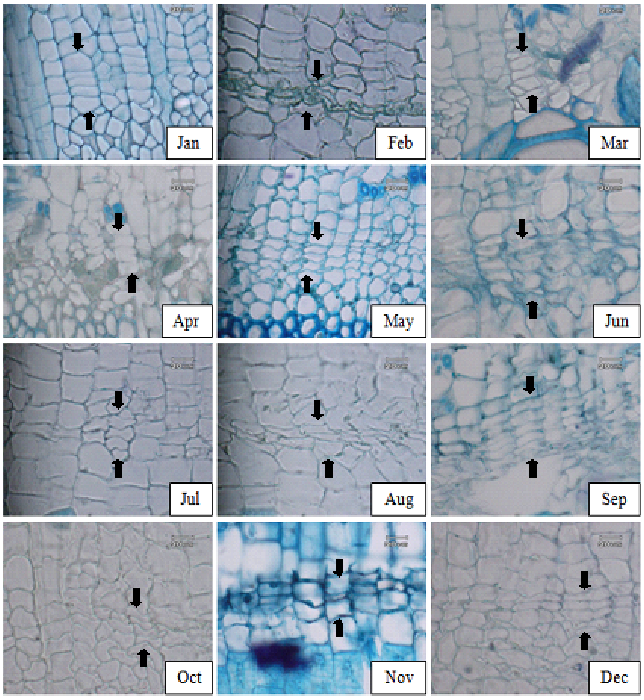

Figure 3. Transverse sections of *A. alba*, showing cambial activity (arrows) from January to December 2009.

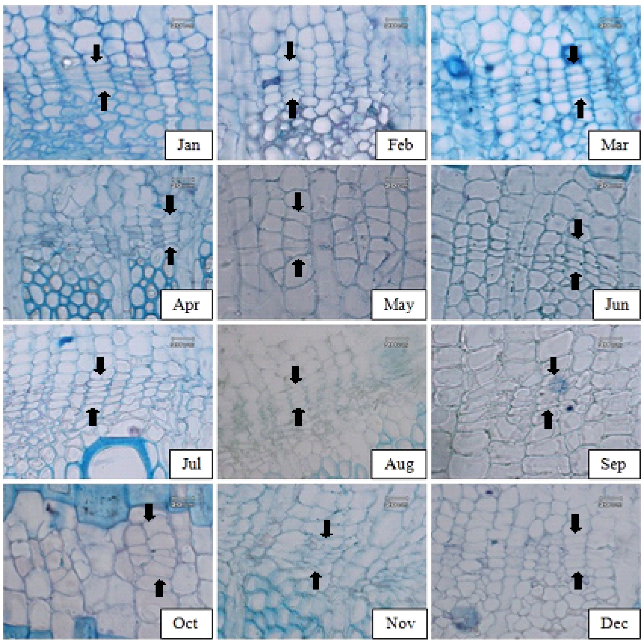

Figure 4. Transverse sections of *A. marina*, showing cambial activity (arrows) from January to December 2009.

activity periods were very distinct. The average number of cell layers of the highest-activity month was 11.9 layers in August. Radial growth in the observed trees occurred in two growth flushes. The first flush appeared in March and almost ceased in April. The second flush started in May, reached its peak in August, and declined in September to December. The highest activity of these two flushes commenced in March and August with 8.9 and 11.9 cambial cell layers, respectively. The second flush, which had a longer duration and more cell layers than the first flush, initiated after the low activity month of April (Figure 5).

Verheyden *et al.* (2004) investigated growth ring formation and age determination of *Rhizophora mucronata* from two forests along the Kenyan coast. Tree samples from natural forests and plantations were marked for four years. They collected 41 stem discs and observed the dark and light growth layer on the polished stem discs. They concluded that the annual indistinct growth ring of *R. mucronata* is defined by a low vessel density earlywood and a high vessel density latewood. Age determination is apparently in trees with radial growth rate above 0.5 mm per year. They found that the low vessel earlywood beginning agrees with the onset of the rainy season. In our study with only one year observation and data we found that there is a second flush onset in May that ceased in September (rainy season). For more clarity and understanding on this issue research should be done for several years.

In *A. alba*, two nearly dormant periods occurred in May and December, during which the cambial zones were narrow, with 3 to 4 cell layers. The average cambial cell layer of the above two months was 3.9 and 3.5 layers thick, respectively. The differences in cell layers between high-activity and low-activity periods were not very distinct. The average number of cambial layers in October, the highest-activity month, was 5.1 layers. Radial growth in the observed trees occurred in two growth flushes. The first flush appeared in April and almost ceased in May to June. The second flush started in July reached its peak in October and declined in November to December. The highest activity of these two flushes commenced in April and October with 4.3 and 5.1 cambial cell layers, respectively. The second flush, which had a longer duration and more cell layers than the first flush, which fell in the low activity months in May and June (Figure 5).

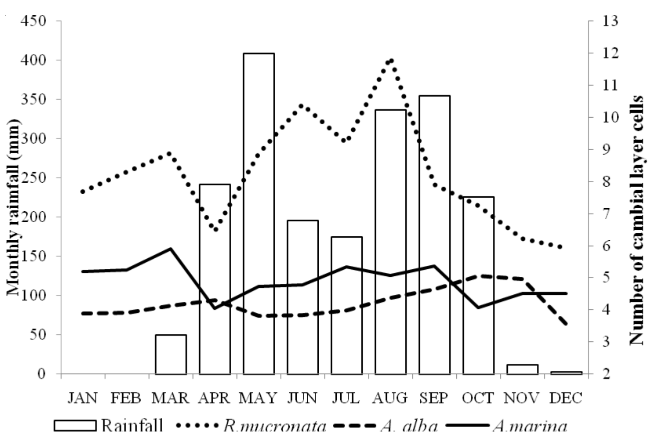

Figure 5. Monthly rainfall and cambial cell layers of *R. mucronata*, *A. alba,* and *A. marina* for the 12 months observation period.

Finally, in *A. marina*, two nearly dormant periods occurred in April and October, during which the cambial zones were narrow with 4 to 5 cell layers. The average number of cambial cell layers of the above two months was 4.0 and 4.1 layers, respectively. The difference in cell layers between high-activity and low-activity periods was not distinct. The average number of cell layers in March, the highest-activity month, was 5.9 layers. Radial growth in the observed trees occurred in two growth flushes. The first flush appeared in March and almost ceased in April. The second flush started in May, reached its peak in September, and declined in October. The highest activity of these two flushes commenced in March and September with 5.9 and 5.4 cambial cell layers, respectively. The second flush had a longer duration but fewer cell layers than the first flush (Figure 5).

Analysis of the cambium layers of the tree different species using the F–test statistics revealed that during January to February there was a significant difference ($p<0.05$) *between R. mucronata* and *A. marina* and between *A. marina* and *A. alba*. During May to July, there was a significant contrast ($p<0.05$) between *R. mucronata* and *A. marina.* In October, a significant difference was found ($p<0.05$) between *R. mucronata* and *A. alba* and between *R. mucronata* and *A. marina*. Finally, in November, there was a significant difference ($p<0.05$) between *R. mucronata* and *A. marina* and between *A. marina* and *A. alba*. Differences during the other months were not statistically significant.

3.1 Relationship between cambial activity and climatic variables

Table 1 demonstrates simple correlation analysis among cambial cell layers of *R. mucronata, A. alba* and *A. marina* and climatic factors as well as the inter-correlations among the climatic factors themselves. No significant correlations between cambial layers of *R. mucronata* and climatic factors were found except that the mean lower low water was negatively correlated with cambial layers of *R. mucronata* (r = -0.676, $p<0.01$). No significant correlation between cambial layer of *A. alba* and climatic factors were found except that mean higher high water was negatively correlated with cambial layers of *A. alba* (r = -0.523, $p<0.05$). In mangrove forest, tidal fluctuation is an essential factor for tree growth. The abundance and distribution of mangroves is also effected by tidal fluctuation. Therefore, the activity of cambium can be controlled by tidal fluctuation. Espinosa *et al.* (2008) studied the effect of prolonged flooding on the bark of mangrove trees and found that each type of tissue responded differently. *Annona glabra* L., *Laguncularia*

Table 1. Simple correlation among cambial cell layer of *R. mucronata, A. alba* and *A. marina* and certain climatic factors during the 12 monthly intervals from January to December 2009.

	R.mucronata[a]	*A.alba*[b]	*A. marina*[c]	Rainfall[d]	Max[e] Temp	Min[f] Temp	Avg[g] Temp	M.H.[h] H.W	M.L[i] W
R.mucronata	1								
A.alba	-.181	1							
A. marina	.475	-.294	1						
Rainfall	.439	.212	-.145	1					
Max Temp	.231	.130	-.166	.575*	1				
Min Temp	.263	.110	-.106	.574	.627*	1			
Avg Temp	.310	.087	-.065	.479	.872**	.794**	1		
M. H.H.W	-.362	-.523*	.147	-.752**	-.514*	-.749**	-.548*	1	
M .L.W	-.676**	.263	-.085	-.661**	-.449	-.498*	-.384	.596*	1

** Correlation is significant at the 0.01 level (n = 12)
* Correlation is significant at the 0.05 level
a. Average cell layers from 3 *R. mucronata* trees (6 samples)
b. Average cell layers from 3 *A. alba* trees (6 samples)
c. Average cell layers from 3 *A. marina* trees (6 samples)
d. Monthly average rainfall
e. Monthly maximum temperature
f. Monthly minimum temperature
g. Monthly average temperature
h. Mean Higher High Water (M.H.H.W.): Usually high water occurs two times a day with the height of high water not being equal. The higher full high water is called Higher High Water. The average of higher high water is called Mean Higher High Water.
i. Mean Lower Low Water (M.L.W.): Usually low water occurs two times a day with the height of low water not being equal. The lower full low water is called Lower Low Water. The average of Lower low water is called Mean Lower Low water (see Marine Department, 2009).

racemosa (L.) Gaertn f. and *Hibiscus tiliaceus* L. developed rythidome. *Avicennia germinans* (L.) Stearn developed rythidome only in the submerged stem portion. *Phyllanthus elsiae* Urb. developed one periderm in both stem portions. Species that developed rythidome also developed aerenchyma between periderms and in the phellem. *H. tiliaceus* and *P. elsiae* showed the highest values for anatomical phloem and periderm characteristics below water surface while an inverse tendency was observed in *A. glabra* and *L. racemosa*, suggesting that prolonged flooding modifies vascular cambium and phellogen differently.

The coefficients revealed that the cambial activity of *A. marina* did not have any significant relationship with any of the climate factors examined. That result was related to Schmitz (2007) who studied successive cambia development in *Avicennia marina*. Growth layer development in *A. marina* is not driven by the seasonal climate at Gazi Bay. For the cambial activity of *A. marina* and *A. alba*, we found that a new cambium has been formed while the early cambium is still activating (Figure 6). The efficiency of this mechanism can improve tree growth under appropriate environment conditions (Schmitz *et al.*, 2008) Simultaneous activity of two cambia has previously been reported in *A. germinans* and *A. resinifera* Forst.f. (Zamski, 1979).

Table 2 demonstrates a simple correlation analysis among cambial cell layers of *R. mucronata, A. alba* and *A. marina* as well as salinity. No significant correlations between cambial cell layers of the three species and salinity were found. We know that our study area is located at an

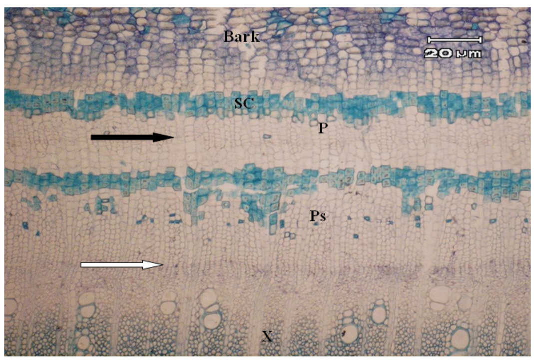

Figure 6. Transverse section of the outermost wood of *A. marina*. A new cambium (black arrows) has been formed while the early cambium (white arrows) is still activating. (SC) = Sclereids, (P) = Phloem, (Ps) = Phloem strands, (X) = Xylem.

Table 2. Simple correlation among cambial cell layer of *R. mucronata*, *A. alba*, *and A. marina* and salinity data collected in three month intervals from January to December 2009.

	Salinity[a]	*R. mucronata*[b]	*A. alba*[c]	*A. marina*[d]
Salinity	1			
R. mucronata	.207	1		
A. alba	-.116	.031	1	
A. marina	.516	.865	-.379	1

(n = 4)
a. Salinity data were acquired from the Water Quality Management Bureau, Pollution Control Department at station TC01 (Tha Chin Estuary) collected every three months.
b. Cambial layers of *R. mucronata,* average every three months.
c. Cambial layers of *A. alba*, average every three months.
d. Cambial layers of *A. marina,* average every three months.

estuary. It has been significantly influenced by fresh water intake, so the salinity levels are not very high. However, salinity was an important factor to tree growth in mangroves (Menezes *et al.*, 2003). Schmitz *et al.* (2006) studied the influence of a salinity gradient on vessel elements of the mangrove species *Rhizophora mucronata*. A significant positive relationship between vessel density and salinity was found for the rainy season (earlywood) as well as for the dry season (latewood), but no significant effect of salinity on the radial and tangential diameter was found in either rainy or dry season wood. Other factors possibly affecting cambial activity may be phenology.

Recently, Robert *et al.* (2011) investigated six mangroves species growing in Gazi Bay, Kenya, *Sonneratia alba*, *Heritiera littoralis*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, *Xylocarpus granatum,* and *Lumnitzera racemosa*. Cambial marking technique was applied for a 1-year period. They concluded that growth ring formation in mangrove trees was controlled by more than one condition. In addition site-specific and tree species effects have to be taken into consideration.

4. Conclusion

This study presented here is the first to examine cambial activity of mangrove trees in Thailand. The results revealed that cambial activities of the three observed species were not influenced by seasonal climate. Nevertheless, cambial activity of *Rhizophora mucronata* and *Avicennia alba* had a significant correlation with the sea water level. Salinity had no significant correlation with cambial cell layers of the three species. It could be assumed that salinity levels were not suitable for this study. Hence, further investigations should examine a larger area where the level of salinity and inundation are different from the area investigated here.

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