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Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia

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Abstract. *Surbakti H, Nurjaya IW, Bengen DG, Prartono T. 2023. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. Biodiversitas 24: 1502-1510.* The Banyuasin Estuary receives much freshwater, which transports low-salinity water from upstream to the sea through the rivers that flow along the area. The interaction between the freshwater mass from the river and the highly saline seawater mass moving toward the estuary will affect the condition of the mangroves in the region. This study aims to estimate the freshwater runoff from the two main rivers (Musi River and Banyuasin River) into the Banyuasin Estuary in different seasons, at high and low tides, and their impact on the mangroves present in both estuaries. The interaction between the freshwater and seawater masses can be explained using the freshwater fraction and transect methods used for mangrove zonation analysis. This research focuses on the mouth of the Musi River and the Banyuasin River. The present study showed the influence of freshwater fraction at the mouth of the Musi River is very strong in all seasons, dominated by oligohaline and mesohaline conditions. In contrast, the mouth of the Banyuasin River is dominated by mesohaline and polyhaline conditions. Altogether, ten species of mangroves have been found in the Banyuasin Estuary. Of which, low saline tolerant species, namely *Nypa fruticans* and *Sonneratia caseolaris,* are predominant, whereas salt tolerant species, namely *Avicennia marina,* are predominant in the mouth of the Banyuasin River.

Keywords: Banyuasin, estuary, freshwater, mangrove, salinity

INTRODUCTION

An estuary is a partially enclosed coastal body of brackish water with one or more rivers or streams and a free connection to the open sea (Pritchard et al. 1967). This condition causes seawater with high salinity to mix with freshwater from upstream, which changes periodically (Mitchell et al. 2017; Nayak and D'mello 2018; Ralston and Geyer 2019). This mixing means that the environmental zone in the estuary is very unstable. The dynamics of sea tides control the mixing of freshwater and seawater in the estuary, the amount of freshwater and residual currents, and the estuary's bathymetry (Nayak and D'mello 2018). The combined influence of seawater and freshwater will produce a distinctive community with distinct environmental dynamics. For example, mangroves are tidal forest ecosystems in sheltered saline to brackish environments (Alongi et al. 2015; Cherukuru et al. 2017; Nelson 2014; Sassi and Hoitink 2013).

The Banyuasin Estuary is one of the areas with the largest mangrove ecosystem on the east coast of the island of Sumatra. Berbak-Sembilang National Park in the Banyuasin Estuary keeps mangroves more pristine than in other areas. The total mangrove area in Berbak-Sembilang National Park for South Sumatra is 94,622.05 ha (Ulqodry et al. 2021). Like other estuaries, the Banyuasin Estuary receives much fresh water, transporting low-salinity water upstream to the sea through the river flow along the area. The flow pattern in the Banyuasin Estuary tends to be dominated by tidal influences. When the water level is at mean sea level towards the highest tide, the water mass moves towards the estuaries. The direction of the water mass turns towards the Bangka Strait when the mean sea level conditions go to the lowest ebb, where the water mass movement from the estuaries to the Bangka Strait is 0.21 m/s (Surbakti 2012). The interaction between the freshwater mass from the river and the highly saline seawater mass moving toward the estuary will affect the condition of the mangroves in the region.

Several studies have shown a correlation between mangrove zonation and mangrove tree adaptation to low soil oxygen levels with a characteristic root shape, high and low tides, flood frequency, salinity, and a close association with soil type (mud, sand, or peat) (Ellison 2021; Froilan et al. 2020; Mughofar et al. 2018; Radabaugh et al. 2021). Previous research has also attempted to explain the relationship between mangroves and environmental conditions and salinity in the Banyuasin Estuary. However, most of these studies describe relationships based on instantaneous measurements without considering daily and seasonal influences. The interaction between the freshwater mass originating from the river and the seawater mass is not described in detail regarding the mangrove ecosystem and the dynamics occurring in the estuary.

Therefore, this study was conducted to estimate the amount of freshwater runoff from the two main rivers (Musi River and Banyuasin River) into the Banyuasin Estuary during different seasons and conditions related to high and low tides and the impact on the mangroves in both estuaries. The freshwater fraction method explains how much freshwater enters the marine area and mixes with seawater masses in the Banyuasin estuary waters. The interaction between the freshwater mass originating from the river and the seawater mass flowing to the river mouth can be explained using the freshwater fraction method. Freshwater fraction is calculated by comparing the mean salinity of estuary water, which has a lower value, to seawater salinity and using salinity as an index to describe the mixture of these water masses, i.e., the amount of freshwater runoff stored in estuary water (Chen and Bowen 2022; Haddout et al. 2022).

MATERIALS AND METHODS

Study area

The study was conducted from October 2018 to October 2019 on water mass and mangrove ecosystems in the Banyuasin Estuary, South Sumatra, Indonesia (Figure 1). The study area in the Banyuasin Estuary is limited to the Banyuasin and Musi River areas.

Procedures

Data collections

Tide observation data for 2000-2012 was obtained from PT Pelindo II Palembang Branch using the AOTT Kempton Tide Observation Tool and an observation time interval of 1 (one) hour. Precipitation data as an indicator of seasonal influences were obtained from the Palembang Kenten Station Climatology Agency. Current measurements were carried out continuously over 15 days with the RCM 106. The observation time interval was 1 (one) hour.

Salinity and temperature measurements at each location and depth were made using the Valeport Midas CTD+ Model 606. The used CTD (conductivity, temperature, depth) has three main sensors: a pressure sensor, a temperature sensor, and a sensor for determining the electrical conductivity of seawater (salinity). Pressure measurement on the CTD uses a strain gauge pressure monitor or quartz crystal. The collection of salinity data was conducted for three different seasons, in which there were differences in precipitation in each period. The data obtained from the field is also used to represent the condition at high and low tides.

Data collection on the structure of the mangrove vegetation was carried out along the streams of the two rivers (Banyuasin River and Musi River). Twelve stations represent the Banyuasin River, while 16 represent the Musi River.

Data analysis

Tide and current data were analyzed using the least squares method. The tide data analysis results in the form of harmonic components of the tides. The least squares analysis of the current measurement data was performed to separate tidal generated and residual currents. Furthermore, the results of the current separation are described in the form of a current vector diagram (stick plot diagram).

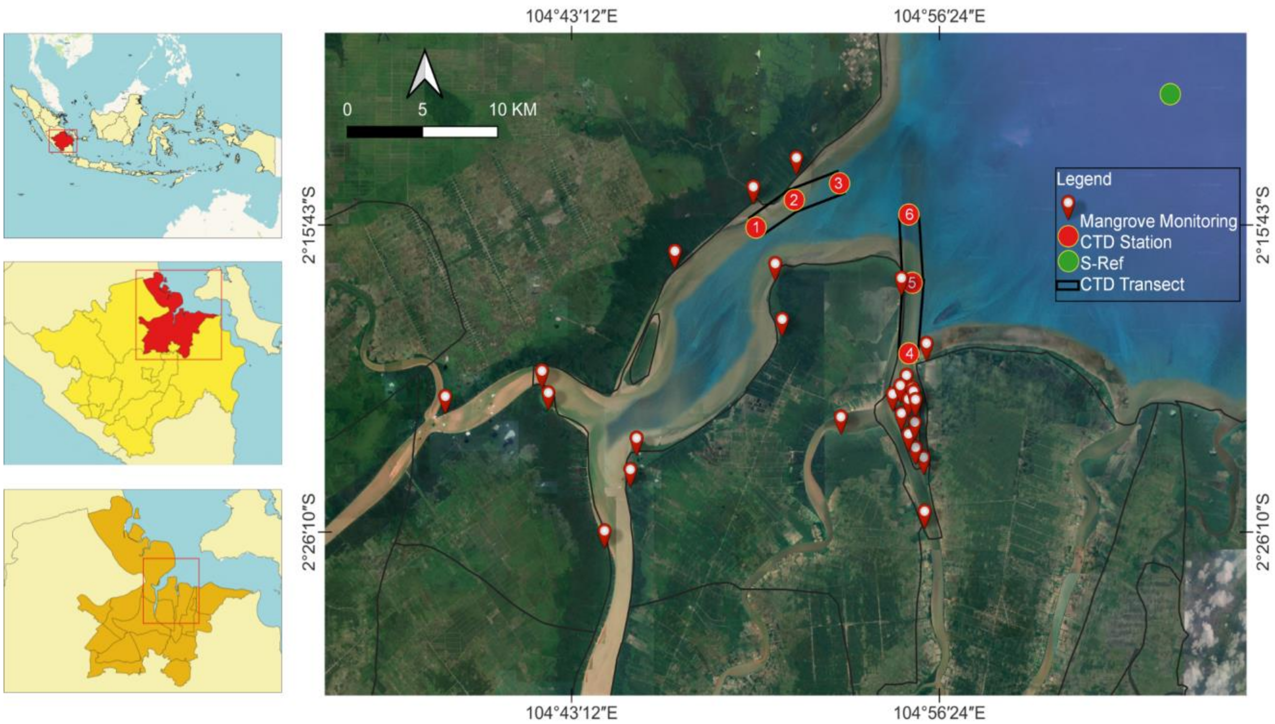


Figure 1. Research location map in Banyuasin Estuary, South Sumatra, Indonesia. The dotted box is the transect for the water mass analysis

The salinity distribution values obtained from the measurement results are then classified according to the Venice system classification (Alves et al. 2009; Pratiwi et al. 2022) as follows: Freshwater: salinity < 0.5; Oligohaline: 0.5 < salinity < 5; Mesohaline: 5 < salinity < 18; Polyhaline: 18 < Salinity < 30; Euhaline: salinity > 30.

Freshwater fraction analysis is used to quantitatively describe the freshwater mass that infiltrates the seawater and then mixes with the seawater mass. This analysis uses a reference value for salinity (salinity of seawater distant from the estuary and assumed unaffected by the inflow of freshwater from the estuary) and the salinity measured at each observation station point. The freshwater fraction calculation is based on the following equation (Chen and Bowen 2022; Nurjaya 2001):

$$F(x,h) = \frac{S_{ref}(h) - S(x,h)}{S_{ref}(h)}$$

Where, *F (x, h)* is the freshwater fractions, *S(x, h)* is the salinity measured at site x (PSU) and S_{ref} *(h)* is the reference salinity.

The reference salinity used in this study is 32.46 PSU; this is the salinity of the research station far from the coast and estuaries. It is not affected as much by the inflow of freshwater from estuaries and coastal currents.

The mean freshwater fraction along the transect is defined as follows (Chen and Bowen 2022; Nurjaya 2001):

$$F_r = \frac{1}{h}\int_h^0 \frac{S_{ref} - S}{S_{ref}}\,dz$$

Where, F_r is the average value of freshwater fractions along the transect, and h is the water depth of the station (m).

In addition, the structure analysis of the mangrove community was conducted to see the impact of freshwater in the Banyuasin estuary.

RESULTS AND DISCUSSION

Tides in Banyuasin Estuary

The analysis of the tidal data showed 68 harmonic components of the tides at the Tanjung Buyut site, Banyuasin II. Based on the determined value of the harmonic tidal constant, the Formzahl number (F) is 3.54, showing that with the diurnal tide type where a high and a low tide occur in one day, the tides in the study area shift approximately 48 minutes. The tidal type obtained is consistent with that reported in previous studies where the research area has a diurnal tidal type (Heltria et al. 2021; Wei et al. 2016; Surbakti 2012).

The results of tidal data analysis also provided a picture of tidal asymmetry (asymmetric tides) in the tides. The time it takes to reach the highest tide is much faster than the time to reach the lowest tide. The required time from the highest water level to the lowest water level is 14 to 15 hours, while the required time from the lowest water level to the highest water level is about 9 to 10 hours (Figure 2A). This asymmetry makes the inflow of freshwater from the river longer compared to the inflow of seawater from the Bangka Strait into the estuary and will affect the amount of freshwater fraction in the water column in the Banyuasin estuary (Surbakti 2012).

The field measurements, the separation of tidal and residual currents, show that the current velocity is much larger and more regular at full moon tide (Figure 2B and Figure 2C). At high tide, the current velocity tends to weaken with a less regular pattern. This condition is caused because the system's power at high tide increases, so the volume of water carried is much greater than at high tide, so the current speed increases. Figure 2C also shows the dominant current at the study site with a larger current value than the residual current (Figure 2D). The mean velocity of the measurement current was 21.4 cm s^{-1}, the tidal current was 19.3 cm s^{-1}, and the mean velocity of the residual current was 10.1 cm s^{-1}. Residual currents are smaller than tidal currents but play an important role in material dispersal, including salinity in estuarine waters (Shen et al. 2022; Xiong et al. 2021).

Seasonal and diurnal variability in salinity

Salinity values obtained at the survey site for all measurement periods ranged from 0.01 to 30.22 PSU, with an average salinity value of 16.05 PSU. An overview of the average salinity values at the two transect locations and the data retrieval period is shown in Figure 3A. The average salinity at the mouth of the Musi River is much lower (12.13 PSU) compared to the average salinity at the mouth of the Banyuasin River (19.97 PSU) for all data collection periods. The salinity difference in each estuary is due to the differential inflow of freshwater into the upstream waters, affecting the estuary's salinity reduction. In addition to the influence of freshwater input from upstream, estuary salinity distribution is generally also influenced by other factors such as water circulation patterns, evaporation, and precipitation (Abiy et al. 2022; Snedden et al. 2022).

The average salinity in December has a lower value at both mouths of the Musi River and the Banyuasin River when the conditions of seasonal variation are considered (Figure 3A). The average December salinity at the mouth of the Musi River is 7.20 PSU (Figure 4), while it is 18.69 PSU at the mouth of the Banyuasin River (Figure 5). Overall, the average salinity in December was 12.94 PSU, followed by May (15.40 PSU) and July (19.80 PSU). The low salinity in December is due to the month's high rainfall of 323.6 mm (Figure 3B).

Daily fluctuations in salinity values are displayed based on the magnitude of the salinity values in high and low tide conditions. Average results over the entire observation period showed significantly lower salinity values in low tide (11.22 PSU) compared to high tide conditions (20.87 PSU). This condition is caused by the large flow of water from the low-salinity river at low tide, reducing the estuary's salinity. The two rivers' daily variation conditions showed significant differences for all data collection periods. The average salinity in the Musi River reaches 17.43 PSU at low tide and 6.82 PSU at low tide (Figure 4), while the average salinity in the Banyuasin tends to be higher at low tide, 24.31 PSU and 15.63 PSU at low tide (Figure 5). This image shows that the Musi River receives fresh water from upstream based on the more dominant diurnal variations, so the salinity is lower.

Differences in the entry of freshwater from rivers and seawater into estuaries lead to salinity stratification at different depths of the study area. Tidal changes and the amount of freshwater runoff strongly influence the vertical stratification pattern formed at the study site. This condition is visible in the transects in the Musi River area, and vertical stratification is weak in the Banyuasin River area. The salinity of seawater tends to be higher, so this condition results in seawater generally moving at the bottom of the water and freshwater at the surface. This phenomenon leads to a mass circulation of water in the estuary (Hormann et al. 2019; Loganathan et al. 2021). The results of the cross-sectional images (Figure 4 and Figure 5) show that the salinity stratification is vertical and horizontal. Stations far from the river mouth have higher salinity than stations at the mouth.

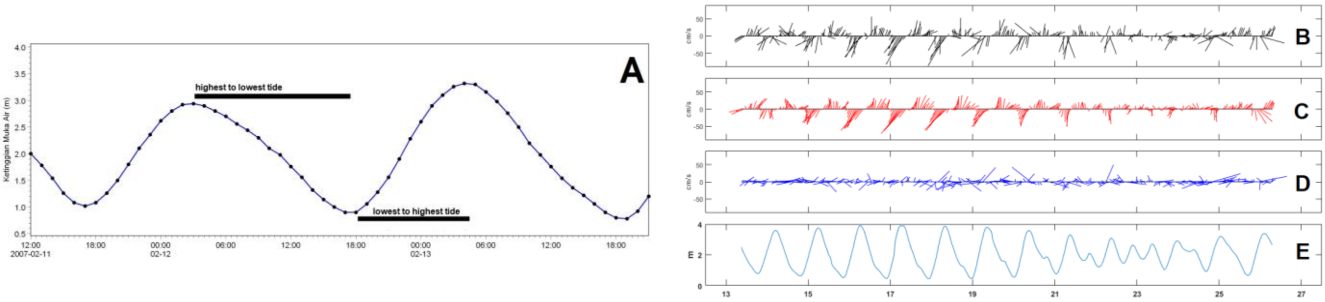
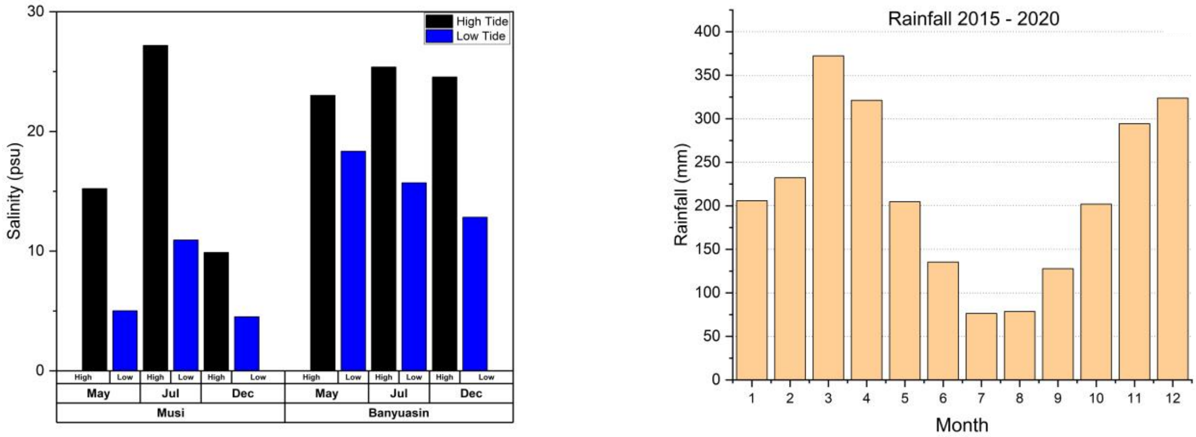


Figure 2. A. The state of asymmetry of the tidal period, B. total current, C. tidal current, D. residual current, and E. Tide conditions at the time the current data was recorded



A **B**

Figure 3. A. The average salinity in each data collection period, B. average rainfall for the period 2015 to 2020

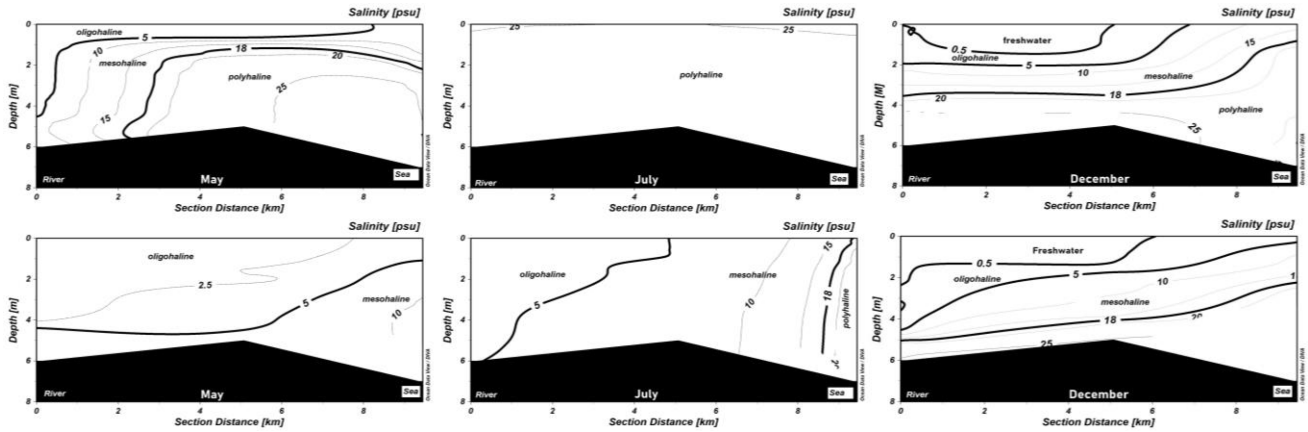


Figure 4. The cross-sectional profile of salinity from the estuary to sea in the Musi River, South Sumatra, Indonesia in different seasons. Flood period (*above*) and ebb period (*bottom*)

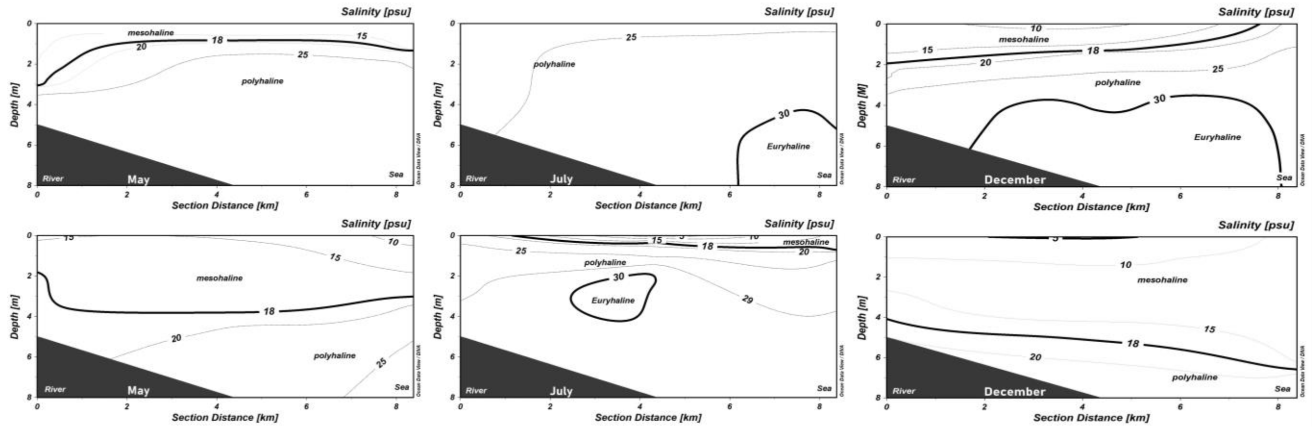


Figure 5. The cross-sectional profile of salinity from the estuary to sea in the Banyuasin River, South Sumatra, Indonesia in different seasons. Flood period (*above*) and ebb period (*bottom*)

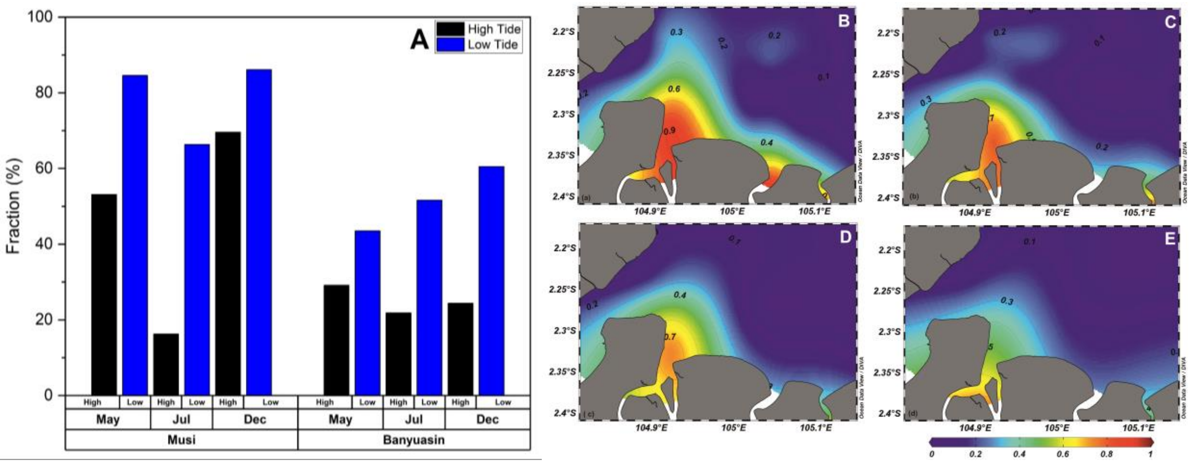


Figure 6. A. The mean fraction of freshwater in each sampling period, B. the cross-sectional profile of the freshwater fraction from the estuary to the sea in the surface layer, C. depth of 2 meters, D. depth of 3 meters E. depth of 4 meters

Overall, the received salinity analyses show that low-salinity water masses predominantly influence the Musi River with dominant oligohaline and mesohaline conditions. Indeed, a freshwater layer forms in December at both low and high tide. Meanwhile, the Banyuasin River has higher salinity and is dominated by mesohaline and polyhaline.

The freshwater fraction in the Banyuasin Estuary

The results of the freshwater fraction analysis performed based on the salinity measurement data showed that the freshwater fraction entering the water column ranged from 0.07 to 0.99 for all seasons, with an average freshwater fraction value of 0.51 (Figure 6). Figure 3A shows the average freshwater content at all locations during the survey period. The freshwater fraction in the Banyuasin River transect ranged from 0.07 to 0.97, with an average value of 0.38 for all data collection periods (Figure 6 and Figure 8). The value of this freshwater fraction shows the fraction of the freshwater mass that has passed station 1 to station 3. The freshwater fraction from the Musi River with a lower salinity (12.13 PSU) results in a higher freshwater fraction of 0.09 to 0.99. with a mean of 0.63 (Figure 6 and Figure 7).

The value of the seasonal variation of the freshwater fraction shows that in December, when the salinity in the mouths of the Musi River and the Banyuasin River is lower, a higher value of the freshwater fraction occurs than in other months. The freshwater fraction in December was 0.07 to 0.99, with an average freshwater fraction of 0.60. The average value of freshwater content in December at the mouth of the Musi River was 0.78, while it was 0.42 at the mouth of the Banyuasin River. High rainfall in December leads to a high inflow of freshwater from the river into the Banyuasin Estuary, increasing the value of the freshwater fraction. The opposite condition in July, where rainfall is low (Figure 3B), with the average fraction of freshwater entering the Banyuasin Estuary being only 0.39. The level of freshwater fraction entering the Banyuasin Estuary follows the rainfall pattern at the study site. The highest amounts of precipitation fall in December (323.63 mm), followed by May (204.63 mm) and July (76.36 mm) are shown in Figure 3B.

The averaging results over the entire observation period showed that the value of the freshwater fraction at low tide (0.65) was significantly higher than at high tide (0.36). The daily variation conditions in the two rivers show significant differences for all data collection periods. Musi River's average freshwater fraction value reaches 0.46 at high tide and 0.79 at low tide. In contrast, the average freshwater fraction value in the Banyuasin River tends to be lower, 0.25 and 0.52 at high and low tide, respectively. The dominant state of the freshwater fraction from the Musi River is visible from the surface layer to 4 meters based on the horizontal distribution at each depth (Figure 6B-6E).

Differences in the value of freshwater fraction at each site are influenced by the process of mixing of water masses due to tidal variations, channel shapes, and bathymetric slopes, differences in currents leading in and out of estuaries, and variations in the mass of freshwater entering the region (Snedden et al. 2022; Sulaiman et al. 2021; Talke et al. 2021; Wisha et al. 2022). The results of previous research conducted at the research site show that the energy of water movement at the mouth of Musi River in response to tidal oscillations, channel shape, and bathymetric tilt is much higher than that at the mouth of Banyuasin River. Therefore, it is strongly suspected that the magnitude of the water momentum at the mouth of the Musi River is the dominant factor causing the site to contribute a higher average fraction of freshwater.

Based on the salinity and freshwater fraction analysis results, the tidal effect will cause large diurnal variations in salinity and freshwater fraction. The seasonal influence, meanwhile, is evident in the high levels of rainfall, which vary each month, causing seasonal fluctuations in salinity and freshwater content in the Banyuasin Estuary. Overall, the influence of the freshwater fraction at the mouth of the Musi River is very strong in all seasons. Therefore, it is strongly suspected that the differential contribution of freshwater mass causes differences in the region's composition and distribution of mangroves.

Composition and distribution of mangroves in the Banyuasin Estuary

The composition and distribution of mangrove species in the Banyuasin Estuary and Musi River estuary are shown in Figure 9. Altogether a total of 10 mangrove species have been found in the present study, namely, *Avicennia alba*, *Avicennia marina*, *Bruguiera gymnorrhiza*, *Bruguiera sexangula*, *Excoecaria agallocha*, *Kandelia candel*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Sonneratia caseolaris* and *Nypa fructican*. Of the ten species found in the Musi River estuary and Banyuasin River estuary, five species are found in both places, namely *A. alba*, *A. marina*, *R. apiculata*, *S. caseolaris*, and *N. fructican*. Two species found only in the Banyuasin River estuary are *B. gymnorrhiza* and *R. mucronata*. While the species found only in the Musi River estuary are *B. sexangula*, *E. agallocha*, and *K. candel*.

Based on species distribution observed that *A. marina* is the predominant species in the Banyuasin estuary (found at 8 out of 12 observation stations) and *N. fructican* is the least common species (found in only one location). Whereas, in Musi River Estuary, *N. fructican* is the predominant species (found at 7 out of 16 observation stations) followed by *A. alba* (found in 5 observation stations) and *S. caseolaris* (found in 4 observation stations).

Site-wise mangrove species composition is shown in Figure 9. It is observed from the species composition that Station 4 on the Banyuasin River and stations 14, 15, 16, 17, 18, 19, and 26 on the Musi River are dominated by *N. fructican*. Likewise, Station 7 on the Banyusin River and station 25 at the mouth of the Musi River are dominated by *S. caseolaris*. From this observation, it is evident that the influence of the freshwater inputs at both sites from rivers affects mangrove species composition in the region relative to other stations.

Mangrove zonation in the Banyuasin Estuary

Mangrove vegetation typically exhibits a zoning pattern concerning salinity stratification along the estuary. The zonal pattern overview of mangroves at the mouth of the Banyuasin River and the mouth of the Musi River is shown in Figure 10. The mangrove species are often found at both locations in the front area of the mangrove zone, namely *Avicennia* sp. The composition of mangrove species on the Banyuasin River coast is dominated by *A. marina*, while on the Musi River estuary dominated by *A. alba*. *Avicennia* sp. is a mangrove species that usually lives in groups in one place. It has a good survival tolerance and prefers areas with high salinity. Therefore, it is often found in coastal areas directly facing the sea where the area has high salinity. It is known from several research results that *A. marina* has a fairly high tolerance limit for waters with extreme conditions such as high salinity, coarse sand, fine sand, or muddy substrate conditions. These findings are supported by the root system of *A. marina*, namely the respiratory root system, while *A. alba* is the dominant species in heavily flooded coastal areas, and the substrate tends to be sandy (Froilan et al. 2020; Halidah and Kama 2013; Sreelekshmi et al. 2020).

The results of previous studies indicate that the type of sediment fraction dominates the bottom substrate around the mouth of the Musi River in the form of medium silt to sand. This is due to higher energy water movement at the mouth of the Musi River, so the sediment grains of the clay and silt fractions are always in suspension. While at the mouth of the Banyuasin River, the sediment fraction is more dominated by silt; since the area is relatively sheltered and the energy of water movement is much lower, this causes the silt/clay sediment fraction to be deposited in this area (Affandi and Surbakti 2012). This condition of the substrate is also one reason why *R. mucronata* was found at the mouth of Banyuasin River, while it was not found at the mouth of Musi River. *A. marina* and *R. mucronata* tend to dominate the muddier area (Froilan et al. 2020; Sreelekshmi et al. 2018, 2020)

Salinity is a factor that causes *Avicennia* sp. to be in the foremost zonation. At the same time, the bottom substrate is the distinguishing feature for mangrove species in the front zone of the coastal areas in both estuaries. The bottom substrate in the form of silt at the Banyuasin River estuary causes *A. marina* to dominate in this zone. In contrast, a sandy substrate causes *A. alba* to dominate the feature of the leading zone in the Musi River estuary.

Another result shows that the mangrove species in the Musi River are dominated by species that can live in low-salinity habitats (Figure 10). *Nypa fructican* and *S. caseolaris* grow mainly along small tidal streams and in parts of low-salinity mangroves, estuaries that prefer low salinity with freshwater inflow. The *Sonneratia* species found in both estuaries is *S. caseolaris*. Based on its habitat and the salinity of the aquatic environment it grows, each species has its saline zone; *S. caseolaris* was found at 0 to 15‰ salinity, *S. ovata*; at 6 to 15‰ and *S. alba* at 11 to 20‰. *S. caseolaris* grows in oligohaline and limnetic/freshwater zones with a low salinity range of 6-7‰ (Marisa and Sarno 2015; Telave 2015). The analysis of water mass properties in the previous discussion supports this condition. Low-saline water masses predominantly influence the Musi River with dominant oligohaline and mesohaline conditions. Even freshwater layers are formed in December (with heavy rainfall) at high and low tides. Meanwhile, the Banyuasin River has higher salinity and is dominated by mesohaline and polyhaline.

Mangrove zonation reflects the eco-physiological response of plants to one or more environmental parameters. Mangroves generally grow in 4 zones: open areas, central areas, areas with brackish water to almost freshwater, and areas towards the mainland with fresh water. The open area is the mangrove area in part facing the sea, and the middle or middle mangrove is the mangrove area behind the open zone. The next zone is the brackish mangrove zone, namely mangroves along rivers with brackish water to almost fresh water. This zone is usually dominated by the *Nypa* or *Sonneratia* communities. The last is the inland mangrove zone, namely mangroves located in the brackish or almost freshwater zone behind the green mangrove belt (Alongi 2009; Froilan et al. 2020; Sreelekshmi et al. 2020).

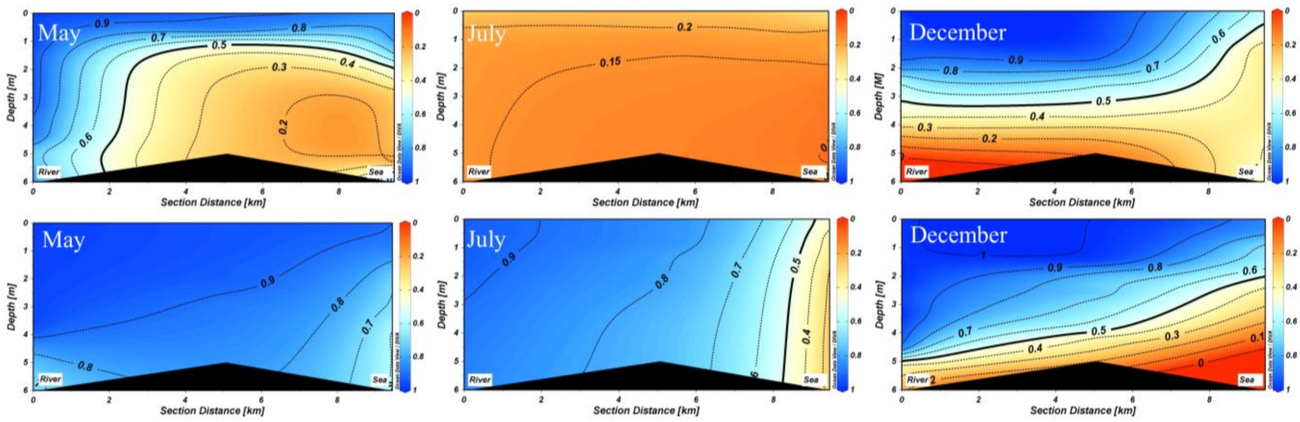


Figure 7. The cross-sectional profile of the freshwater fraction from the estuary to the sea in the Musi River, South Sumatra, Indonesia in different seasons. Flood period (*top*) and ebb period (*bottom*)

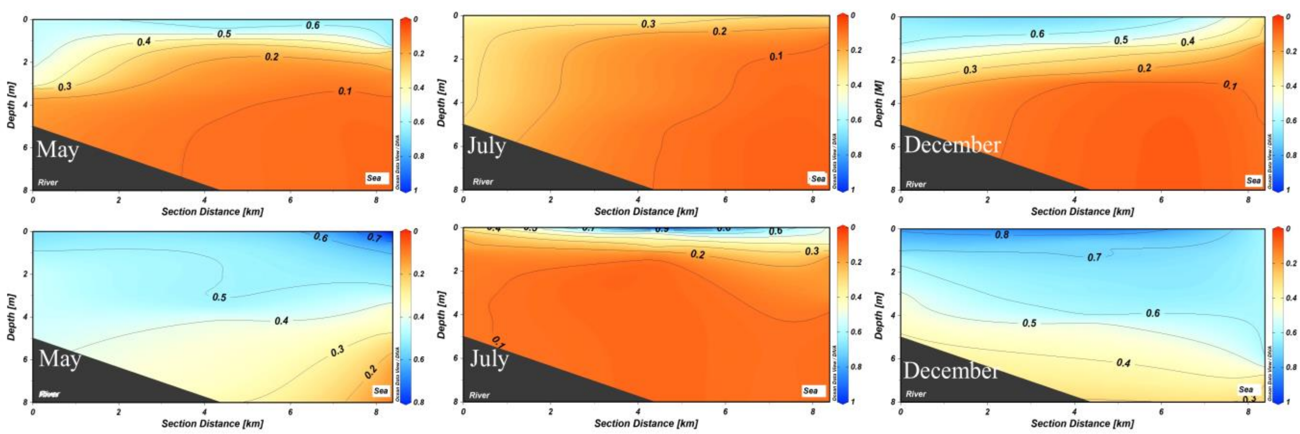


Figure 8. The cross-sectional profile of the freshwater fraction from the estuary to the sea in the Banyuasin River, South Sumatra, Indonesia in different seasons. Flood period (*top*) and ebb period (*bottom*)

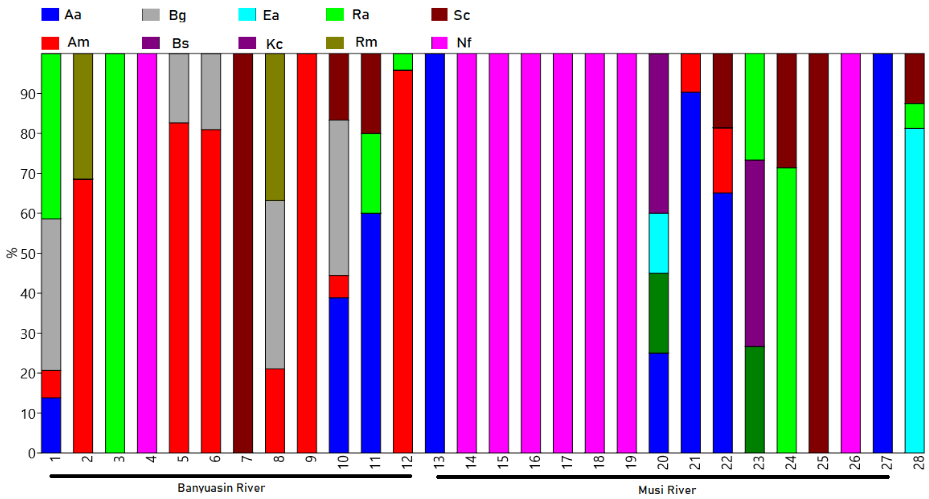
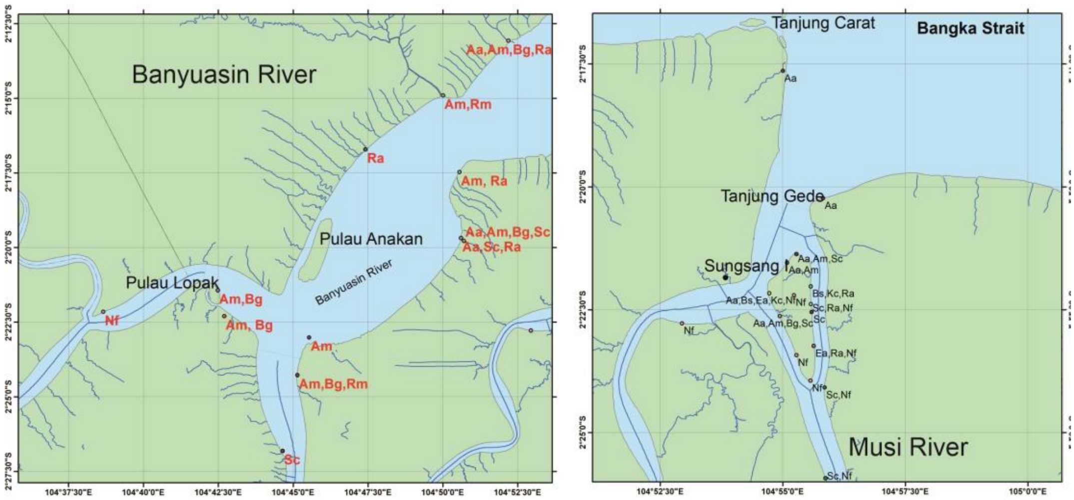


Figure 9. Composition of the mangroves in the Banyuasin Estuary, South Sumatra, Indonesia. Aa: *Avicennia alba; Am*: *Avicennia marina;* Ac: *Aegiceras corniculatum;* Bg: *Bruguiera gymnorrhiza*; Bs: *Bruguiera sexangula*; Ra: *Rhizophora apiculata*; Rm: *Rhizophora mucronate*; Sc: *Sonneratia caseolaris* and Nf: *Nypa fructican*



A B

Figure 10. Zonation mangroves in the Banyuasin Estuary, South Sumatra, Indonesia. A. Banyuasin River; B. Musi River. Aa: *Avicennia alba; Am*: *Avicennia marina;* Ac: *Aegiceras corniculatum;* Bg: *Bruguiera gymnorrhiza*; Bs: *Bruguiera sexangula*; Ra: *Rhizophora apiculata*; Rm: *Rhizophora mucronate*; Sc: *Sonneratia caseolaris* and Nf: *Nypa fructican*

In conclusion, the Banyuasin Estuary is heavily influenced by tides and inputs from rivers flowing into the estuary. The dominance of a single type of tidal effect is reflected in the region's large diurnal variations in salinity and freshwater fraction. The daily fluctuations in salinity and freshwater fraction are very strong in all seasons at the mouth of the Musi River, where there is a very significant vertical difference between low and high tide. The effect of different rainfall each month causes differences in freshwater flow from rivers to estuaries, reducing salinity and increasing the fraction of freshwater in the estuary. This condition strongly impacts the distribution and zoning of mangrove species. The vegetation at the mouth of the Musi River is dominated by species that can adapt to low salinity, which differs from the mouth of the Banyuasin River.

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