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Evaluation of Influence of River Inflow Discharge and Tidal Level to Spatial-temporal Distribution of Salinity in Can Gio Area, South of Vietnam by Two Series of Field Observations

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This study assesses the influences of river inflow discharge and tidal levels on the spatial–temporal distribution of salinity along the main rivers in Can Gio mangrove forest in the south of Vietnam. Field observations were conducted to collect salinity time series, spatial salinity distribution, and vertical profiles of salinity during two periods in the 2017 and 2018 wet seasons. Period I (2018) experienced a high discharge from upstream rivers as well as at middle tide, while Period Ⅱ (2017) had a regular discharge from the upstream rivers and at spring tide. The results showed that salinities in Can Gio area changed depending not only on the tidal regime from the East Sea, but also on river discharge resulting from rainfall runoff. Most of the freshwater flows into Can Gio area through Phu Xuan, which is located at the upstream end of the observed area. The salinities at Phu Xuan changed significantly in Period Ⅱ, with the practical salinity unit (psu) ranging from 1.6 to 6.0, while in Period I salinity only ranged from 0.1 to 0.4 psu. The salinities along the main rivers in the area, Long Tau River and Soai Rap River, changed depending on their respective distances to the sea, i.e. sites closer to the sea had a higher salinity. Conspicuously, the salinities along Thi Vai River were very high, approximately 20psu, even though the distances to the sea were relatively large. This unusual salinity prevalence can be explained by the location and surrounding topography of Thi Vai River, as its upstream inflow is relatively small. Furthermore, this narrow inlet is combined with peculiar topography and a river intersection, causing an unmixing water area.

Key words: salinity, field observation, spatial–temporal distribution, vertical profile, tidal regime

INTRODUCTION

Estuaries are considered environmentally pressured areas due to their high interaction level between tide and river flow, or high dynamic nature (Elliot and Quintino, 2007). Vietnam is considered to be one of the areas most vulnerable to natural disasters in Asia (Yusuf and Francisco, 2009). Specifically, coastal areas suffer the most environmental degradation.

Mangroves are essential ecosystems at the boundary of an estuary. They have a beneficial effect on the surrounding environment because they supply essential food for humans, protect the land from erosion, facilitate alluvium deposition, and mitigate the impacts of typhoons and floods. Can Gio area is located in the South of Vietnam. It includes a mangrove forest, which was considered an international biosphere reserved zone (UNESCO, 2000) and commonly considered as one of the most beautiful mangrove forests in Southeast Asia (Blasco *et al.*, 2001). Mangrove is an ecological term referring to communities of various plants in diverse environments. Mangroves may include trees, palms, ferns, and shrubs in coastal areas and river estuaries of tropical and subtropical zones. Having physiologically adapted to overcome extreme conditions, such as anoxia, frequent tidal inundation, and high salinity, mangroves can develop in saline inter–tidal coastal habitats. Furthermore, mangrove ecosystems represent a transition area between marine and terrestrial communities, receiving both daily saltwater from the sea depending on tidal regimes, and freshwater from upland rivers. The integrality of the mangrove ecosystem is multi–fold. It is an ideal environment for many aquatic organisms, as well as a home to numerous non–aquatic species. Moreover, mangroves are as a cleansing system for water and sediments in estuaries while simultaneously providing buffer zones against typhoons and floods. Furthermore, due to climate change including sea level rise, mangrove ecosystems become an increasingly essential duty to prevent shoreline erosion as an natural protection. Mangroves naturally complete their life cycles under salinity conditions (Flowers *et al.*, 1986). The optimal salinity for growth in mangroves varies for different plants. For example, the optimal salinity for the growth of A. marina is substantially lower, ranging from 10–25 psu seawater (Downton 1982; Clough 1984). The mangrove forest area of Can Gio Biosphere Reserve has an extremely high biodiversity with various kinds of fauna and flora. There are approximately 77 mangrove species, wherein 42 are mangrove associates including both saltwater and brackish water varieties, and 35 are true mangroves that solely occur in mangrove forests

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(UNESCO/MAB Project 2000). In the southern part of Can Gio Reserve, there are three dominant species, namely: Avicennia alba, Rhizophora apiculata, and Phoenix paludosa, with optimal salinities between 10 and 35 psu. The most common mangrove species is Rhizophora apiculata. Avicennia alba often grows in areas of high salinity. Phoenix paludosa usually appears on elevated ground, mixing with other kind of mangrove species such as Acrostitum aureum and Nypa fruticans, forming mixed communities. Other species found in Can Gio area are Avicennia alba, A. officinalis, A. lanata, Aegiceras majus, Sonneratia alba, Sonneratia ovata, Sonneratia casedar, Bruguiera gymnorrhiza, Bruguiera parviflora, Ceriopssp, Kandelia candel, Rhizophora mucronata, Thespesia populnea, Hibiscus tiliaceus, Lumnitzerara cemose, Excoecaria agallocha, and Xylocarpus granatum (Truong *et al.*, 2008). The appearance of different mangrove species, with different optimal salinity conditions, can suggest the salinity characteristics of the surrounding environment.

Currently, the Can Gio area faces many environmental issues. Particularly, changes in salinity affect the mangrove forest (Thu *et al.*, 2018b). Changes in salinity in Can Gio area are primarily affected by the flow of the main rivers and the tidal regime from the East Sea. Accordingly, this study investigates salinity changes along the main rivers in Can Gio area, Southern Vietnam. Field observations provided data for both salinity time series and spatial–temporal distribution of salinity with regards to river depth and the impact of tidal regimes and season.

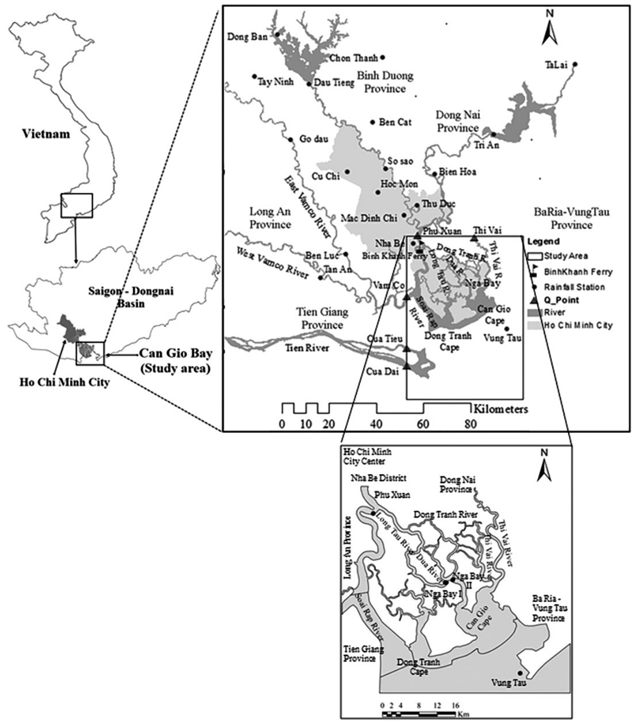

Fig. 1. Location of the Can Gio area and the main rivers, namely: Soai Rap, Long Tau, Dua, Dong Tranh, and Thi Vai rivers in Can Gio area. HOBO U24 Conductivity Loggers were set up at the locations marked Phu Xuan and Nga Bay I, II in two periods to record salinity time series.

MATERIALS AND METHODS

Study site

Figure 1 shows the location of these rivers in the context of the broader region. Can Gio is a coastal district with a deltaic confluence of the Dong Nai– Saigon and Vam Co rivers, which drain into the East Sea (Thu *et al.*, 2018a). Freshwater from the Dong Nai – Saigon river system is carried toward the East Sea through its two main branches and through its subordinate branches. Its two main branches are the Soai Rap and Long Tau rivers, which include many smaller branches and creeks, such as Dua and Dong Tranh rivers, and subordinate branches include the Thi Vai River and others. Most of the water in Can Gio is brackish from the mixing of freshwater and seawater.

In the mouth of the river, tides are typically semi–diurnal with a half–daily inequality of varying significance. The tidal range is about 1 m during neap tide and up to 4 m meters during spring tide. Tidal amplitudes are highest from October to November and lowest in April and May.

The main rivers of Can Gio area are Nha Be, Soai Rap, Dong Tranh, Long Tau, Dua, Nga Bay, Go Gia, and Thi Vai rivers. Nha Be River is one branch of Dong Nai Saigon River system. It begins at the confluence of Saigon River and Dong Nai River. At Binh Khanh ferry terminal, the two branches are Soai Rap River flowing west and Long Tau River flowing east. Soai Rap River begins from Phu Xuan Commune, in the upstream of Can Gio area, southbound spilling to the East Sea at Soai Rap Estuary. The length of Soai Rap River is about 40 km with the largest width approximately 3 km. The eastern branch is the Long Tau River flowing to Ganh Rai Bay, which flows around Sac Forest before flowing into the East Sea. Long Tau River flows to Phuoc Khanh Commune, Nhon Trach District, and Dong Nai Province, via two branches. The eastern–most branch continues to be called Long Tau flowing down to Nga Bay where the Dua River flows in. The other branch to the east and southeast is called Dong Tranh River.

Thi Vai River is situated in the East side of the mangrove forest. The length of the river is approximately 37 km before entering the East Sea. This river is immensely affected by the tide with a tidal range of about 3 m (Karen *et al.*, 2014). Therefore, the water in Thi Vai River is brackish with high salinities of up to 30 psu in the lower area during the dry season. Its water cannot be used for irrigation, industrial, or domestic purposes because of its naturally high salinity. The tide strongly impacts the middle and lower parts of the river. In the upper reaches, the salinity varies and depends on the tide and freshwater inflow.

This study focuses primarily on the following rivers of Can Gio area: the Soai Rap, Long Tau, Dua, Dong Tranh, and Thi Vai rivers. The Soai Rap and Long Tau rivers run along the left side and through the middle of the forest, respectively. Dua River is a branch of the

Long Tau River. Can Gio mangrove forest is located on the left side of the Thi Vai River. Due to their geographical proximity, salinity in these rivers directly affects the environmental health of the Can Gio mangrove forest.

Field Observations

The field observation was conducted at the middle of the rainy season, from September 13 to 14, 2018 (Period I), and compared with the previous study at the end of the rainy season from December 7 to 10, 2017 (Period II) (Thu *et al.*, 2018b). Period I had a high discharge from the upstream rivers. The rainfall and middle tide in this period is shown in Fig. 2. Period II had a regular discharge from the upstream rivers. The rainfall and spring tide in this period is shown in Fig. 3. To assess the salinity along these rivers, salinity time series were collected at two fixed stations. Phu Xuan Station is located in the upstream of Can Gio area; this is the area influenced most directly by the discharge from the upstream rivers. This station recorded time series for both Periods I and II. The next point was in Nga Bay I for Period I and Nga Bay II for Period II. These stations were located in the middle of the mangrove forest. They were essential for assessing changes in salinity with reference to the tidal regime and upstream discharge in this region. HOBO U24 Conductivity data loggers (U24–002–C) (Thu *et al.*, 2018b) were used to collect salinity time series at these three stations, as shown in Fig. 1.

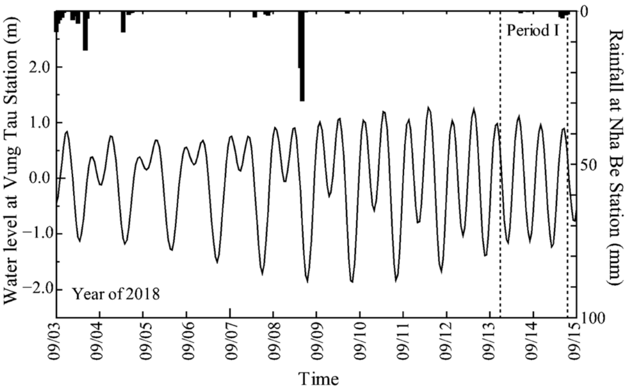

Fig. 2. Period I: Observed water level at Vung Tau Station and observed rainfall (September 3 to September 15, 2018).

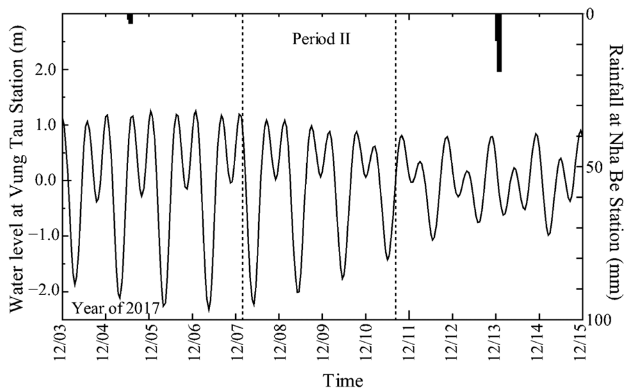

Fig. 3. Period II: Observed water level at Vung Tau Station and observed rainfall (December 3 to December 15, 2017).

These instruments were set up approximately 2 m beneath the water surface, recording electric conductivity and temperature at 10 min intervals. The HOBO U24 Conductivity Logger was set up at Phu Xuan from December 7 to 8, 2017 (Period II), and Nga Bay II stations from December 8 to 10, 2017 (Period II). From September 13 to 14, 2018 (Period I), the loggers were set up at both Phu Xuan and Nga Bay I stations. Additionally, the salinities at the surface water were continuously observed in 5 min intervals by the HOBO U24 Conductivity logger that was towed by an observation boat along two pathways. Figure 4 shows Pathway I on September 13, 2018 (Period I) – from Phu Xuan Station through the upstream of Long Tau River, to Dua River,

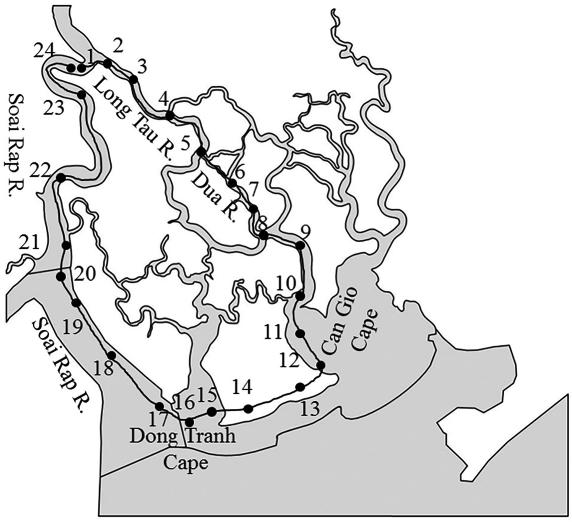

Fig. 4. The observation line (Pathway I) for the continuous salinity time series by the HOBO U24 Conductivity logger. The line follows the marked observation points for vertical profiles of salinity by the CastAway CTD data logger along Long Tau, Dua, and Soai Rap rivers (September 13, 2018).

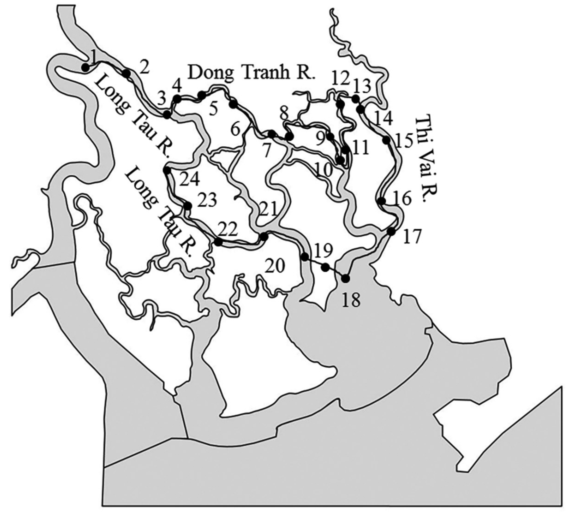

Fig. 5. The observation line (Pathway II) for continuous salinity time series by the HOBO U24 Conductivity logger. The line follows the marked observation points for vertical profiles of salinity by the CastAway CTD data logger along Long Tau, Dong Tranh, and Thi Vai rivers (September 14, 2018).

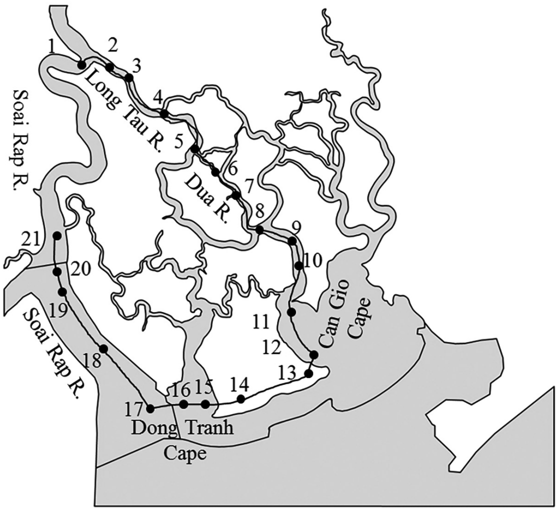

Fig. 6. The observation line (Pathway Ⅲ) for continuous salinity time series by the ProDSS data logger, following the observation points for vertical profiles of salinity by the CastAway CTD data logger along Long Tau, Dua, and Soai Rap rivers (December 10, 2017).

and downstream of Long Tau River to Soai Rap River. Figure 5 depicts Pathway Ⅱ on September 14, 2018 (Period I) – from Phu Xuan Station to the upper part of Long Tau River, to Dong Tranh River, to Thi Vai River, back to the lower part of Long Tau River, and to the end point in Tac Ong Tranh Creek. In the previous study in 2017, the ProDSS data logger towed by an observation boat was used for measuring salinity continuously (Thu *et al.*, 2018b) along nearly the same pathway (Pathway Ⅲ) to Pathway I, as shown in Fig. 6.

Furthermore, CastAway CTD data logger was used (Thu *et al.*, 2018b) to collect vertical profiles of salinity along the Soai Rap, Long Tau, Dua, Dong Tranh, and Thi Vai rivers and some small branches in those three periods, as shown in Figs. 4, 5, and 6.

RESULTS AND DISCUSSIONS

Field observations for Period I took place in the middle of the rainy season. With frequent heavy rain, the upstream discharge from rivers was especially high.

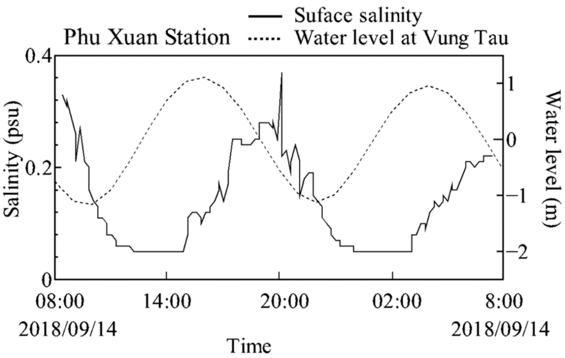

Fig. 7. Observed tidal level at Vung Tau Station overlaid with the observed time series of surface salinity at Phu Xuan Station (Period 1, 08:00 September 13 to 08:00 September 14, 2018).

This significantly diminished the salinity at Phu Xuan Station in this period. Figure 7 shows that the range of salinity at Phu Xuan Station in this period was between 0.1 and 0.4 psu. Salinity also varied depending slightly on the tide. However, despite peak tides, the salinity was still minimal. Phu Xuan is located on the upper stream, which is the main drainage water path from the city center. Combined with the particularly high rain volume during this measurement (September 14, 2018), the topography of the drainage path instigated a large discharge of freshwater to be released into Phu Xuan.

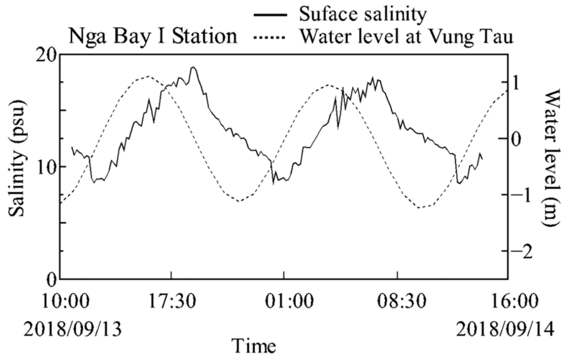

Fig. 8. Observed tidal level at Vung Tau Station overlaid with the observed time series of surface salinity at Nga Bay Station from (Period 1, 10:00 September 13 to 16:00 September 14, 2018).

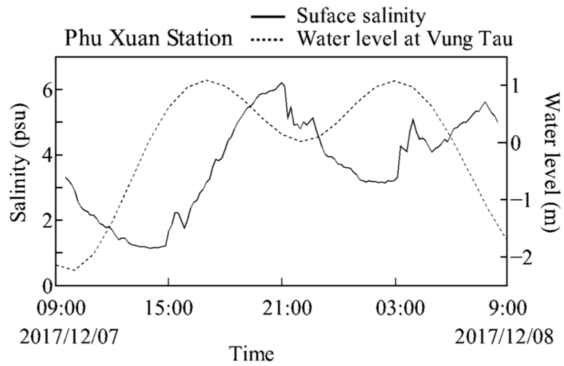

Fig. 9. Observed tidal level at Vung Tau Station overlaid with the observed time series of surface salinity at Phu Xuan Station (Period Ⅱ, 09:30 December 7 to 08:30 December 8, 2017).

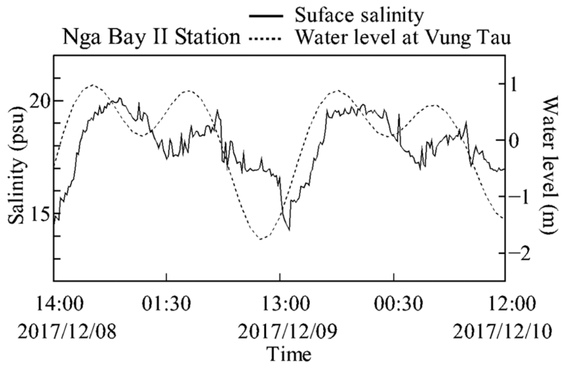

Fig. 10. Observed tidal level at Vung Tau Station overlaid with the observed time series of surface salinity at Nga Bay Station (Period Ⅱ, 14:00 December 8 to 12:00 December 10, 2017).

This led to significant freshwater dilution, causing the salinity to decrease dramatically as seen in Fig. 2. Compared with the data obtained from Period II, the surface salinity ranged from 1.6 – 6.0 psu at Phu Xuan Station as shown in Fig. 9. This significant discrepancy in the salinity ranges of Period I and II can be explained by each period's differing relation to the rainy season. While Period I took place at the height of the rainy season, Period II took place at the end of the rainy season, implying that more freshwater inflow was present in Period I.

Though, salinity was low at the Phu Xuan station in Period I, salinity at Nga Bay in Period I was much higher, reaching 18.9 psu at the peak tide on September 14, 2018, as shown in Fig. 8. Maximum salinity at Nga Bay during Period I was nearly 2 psu less than maximum salinity at Nga Bay during Period II (December 10, 2017). Figure 10 shows the salinity of Nga Bay II Station during Period II, which reached 20 psu at peak tide. This showed that the upstream flow affected the salinity at Nga Bay lesser than it did at Phu Xuan. However, the observed minimum salinity decreased significantly across the two periods, from approximately 15 psu in Period II to approximately 8 psu in Period I. This decrease can be explained by the division of the upstream river flow from Phu Xuan into two parts: the majority flowed to the Saigon River through Soai Rap before emptying to the sea; the remainder flowed through Long Tau River, to Nga Bay, and then entered into the Can Gio Cape. Thus, the upstream flow from Phu Xuan entered into Nga Bay, contributing to the salinity's decrease to 5 psu at low tide, and stretching the salinity amplitude to a range of 8.5 to 18.9 psu, as shown in Fig. 8. Still at a sizeable distance of 20 km from Phu Xuan, where the influence of the upstream flow is faded, the smallest the salinity at Nga Bay reached was 8.5 psu.

In the surveys of both periods, the salinity peak at Phu Xuan Station occurred 4 hours later than the water level peak at Vung Tau Station. At Nga Bay Sation the salinity peak occurred 2.5–hours after the water level peak at Vung Tau. This peak latency is caused by distance between the respective upstream river and the sea. Phu Xuan is located about 40 km from the sea, while the distance of Nga Bay is 20 km.

Figure 11 shows the continuous observed salinity time series on September 13, 2018 (Period I) by the HOBO U24 Conductivity logger along Pathway I: Phu Xuan, Long Tau, Dua, Can Gio Cape, Dong Tranh Cape, connecting Dong Hoa River to Dong Tranh Cape, then, going through Soai Rap River, and terminating at Phu Xuan Station. Along this pathway, salinity concentration tendencies varied according to the spatial location and river network characteristics. Salinity decreased at river flow intersections and at greater distances from the sea.

Specifically, salinity increased from nearly 0 psu at Phu Xuan Station to around 14 psu at the end point of Dua River. A sudden drop in salinity occurred at Nga Bay from 14.5 psu to 10.5 psu, where six branch rivers were confluent before entering into Can Gio Cape. However, the salinity tended to increase to around 20 psu at Can Gio Cape. Near Can Gio Cape, the salinity remained high due to the large river section and the main water–exchange gate on the right of the Can Gio mangrove forest. Contrastingly, salinity at Dong Tranh Cape only reached 15 psu at most, reducing to approximately 5 psu according to observed data along the river connecting Can Gio Cape to Dong Tranh Cape. This is the consequence of more freshwater rushing from Phu Xuan into Soai Rap River than into Long Tau River. The salinity of Soai Rap River decreases in the direction of Phu Xuan, to Vam Co, to Dong Tranh Cape, in line with the expected reduction of salinity with greater distance from the sea. The observed salinity at Phu Xuan was around 0 psu and gradually increased to 15 psu in Dong Tranh Cape. However, the increasing trend of salinity in

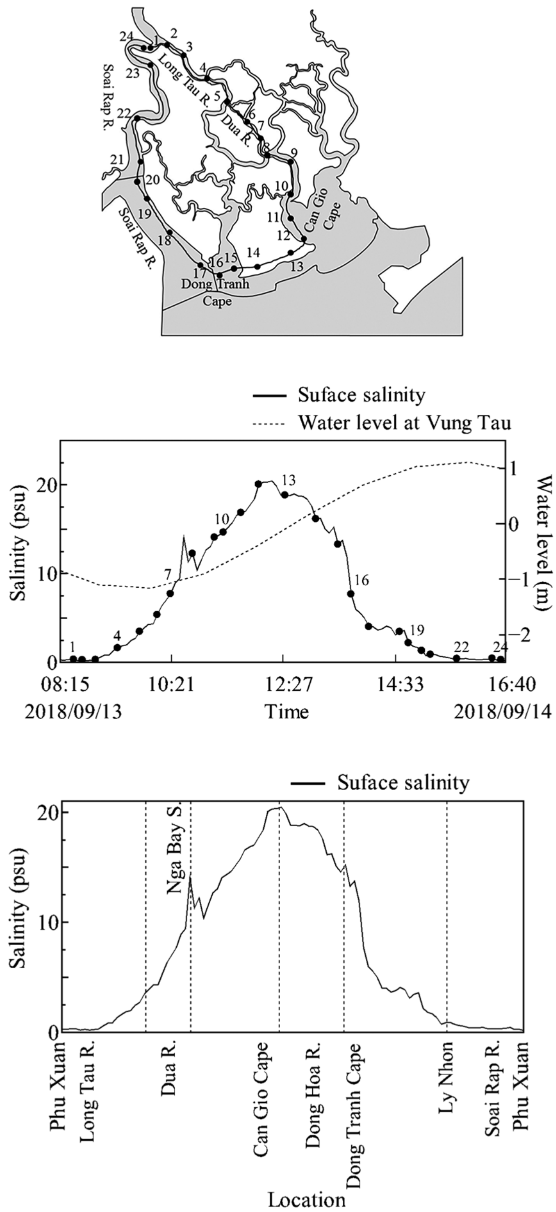

Fig. 11. Continuous observed salinity time series along Pathway I by the HOBO U24 Conductivity logger (Period I, September 13, 2018). A black circle shows an observation time of the vertical profile of salinity using the CastAway CTD data logger.

the stretch from Phu Xuan to Vam Co was extremely slow, only increasing from 0 to 4 psu. At the Vam Co intersection, the salinity remained close to 4 psu due to the addition of freshwater from the Vam Co upstream branch river. In the stretch from Vam Co to Dong Tranh Cape, where there are no connecting upstream rivers to the sea and no confluent rivers, salinity increased faster, from 4 to 15 psu.

Comparing the observed salinity time series in December 2017 (Period Ⅱ, Pathway Ⅲ) with September 2018 (Period I, Pathway I), the saline in Period Ⅱ was 3–6 psu higher than those in Period I for the entire Can Gio Area. Particularly, the salinity at Phu Xuan recorded about 6 psu in Period Ⅱ, while it was nearly fresh water in Period I.

Figure 12 follows Pathway Ⅲ: Phu Xuan, Long Tau, Nga Bay, Can Gio Cape, Dong Hoa, and finishing at Dong Tranh Cape. The salinity in Period Ⅱ was approximately 4 psu higher than that in Period I. In Period Ⅱ, the salinity at Can Gio Cape remained at a high concentration of 24 psu. This high value of salinity continued via Dong Hoa River to Dong Tranh Cape for approximately 2.5 hours before reducing following the tidal regime. However, the salinity at Dong Tranh Cape was observed to be 20 psu, 4 psu lesser than at Can Gio Cape in Period I, as shown in Fig. 11. Observed data in September 2018 (Period I) was at the middle of the rainy season with an ebb tide and tidal levels lower than those in December 2017 (Period Ⅱ) at the end of the rainy season. Period I received large amounts of freshwater from upstream, thus, reducing the salinity for the entire Can Gio man-

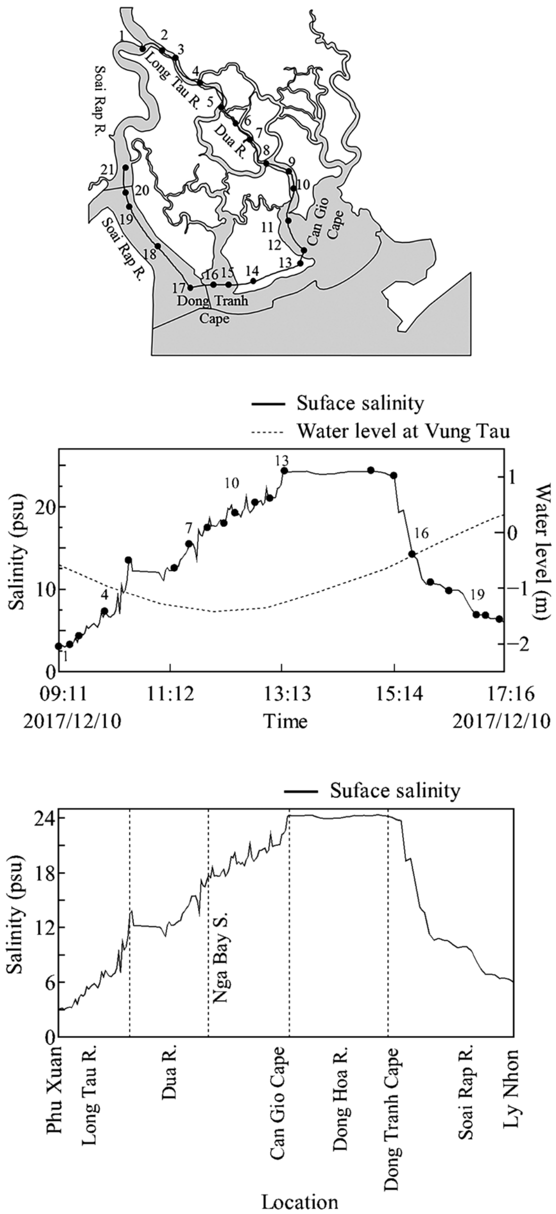

Fig. 12. Continuous observed salinity time series along Pathway Ⅲ by the ProDSS data logger (Period Ⅱ, December 10, 2017). A black circle shows an observation time of the vertical profile of salinity using the CastAway CTD data logger.

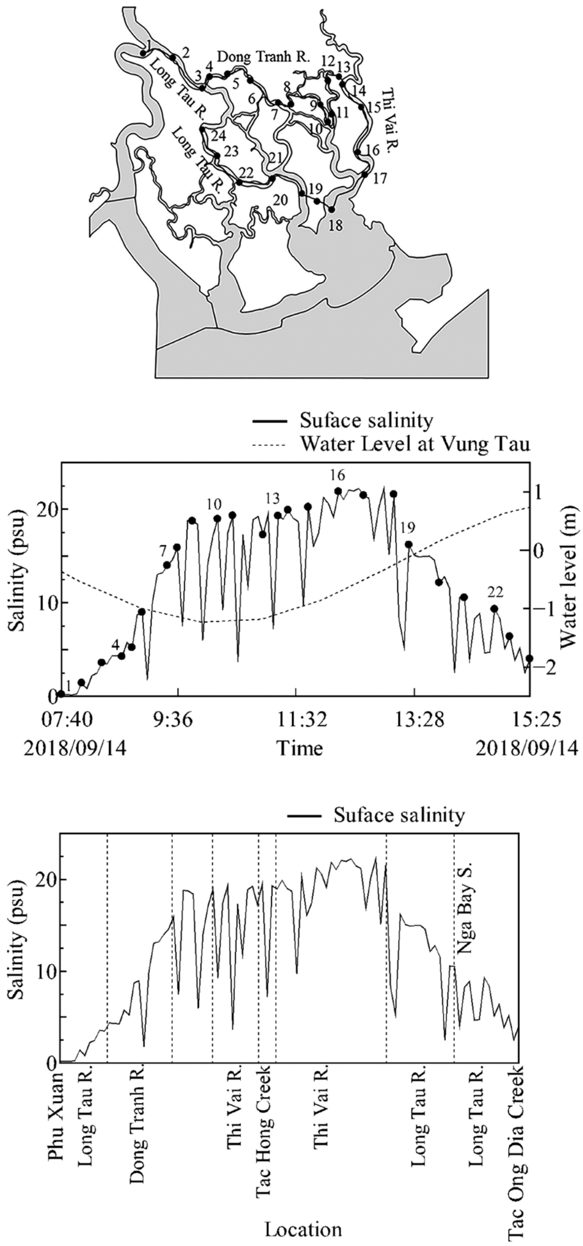

Fig. 13. Continuous observed salinity time series along Pathway Ⅱ by the HOBO U24 Conductivity logger (September 14, 2018). A black circle shows an observation time of the vertical profile of salinity using the CastAway CTD data logger.

grove forest. Soai Rap River received large discharges from the Dong Nai– Saigon river system, combining with Vam Co River, which resulted in the 4 psu lesser salinity at Dong Tranh Cape than at Can Gio Cape.

Figure 13 shows the saline change along Pathway Ⅱ: Phu Xuan, Long Tau, Dong Tranh, Tac Hong Creek, Thi Vai, Ganh Rai, back to the downstream of Long Tau via Ganh Rai Estuary, and then terminating at Tac Dong Dia Creek. In the stretch between Phu Xuan and Thi Vai, the saline dramatically increased from approximately 0 psu at Phu Xuan to around 10 psu at Dong Tranh, then reaching 20 psu at Thi Vai upstream river. The river maintained approximately 20 psu along Thi Vai River (points 13 to 17 in Fig. 13). Above results revealed that in the stretch of Long Tau from Phu Xuan to Dong Tranh, freshwater at Phu Xuan entered Long Tau, causing dilution of salt–fresh water in this area and leading to a trend of quick reduction from Dong Tranh to Long Tau, ultimately reaching 0 psu in Phu Xuan. When the salinity achieved around 20 psu at Point 13 (Fig. 13), the saline almost always remained at this level in Thi Vai River. It showed that the influence of the upstream flow at Phu Xuan was no longer available, the upstream flow at Thi Vai was too small, and the tidal regime could not significantly impact the salinity due to a far distance from the sea. However, there were some points of sudden decreases in salinity along the pathway. These were not determined by explicit saline measurements, but by observations during navigation. For example, a heavy rain occurred during the field observation. The freshwater created by rainfall–runoff at the drylands entered the pathway through small creeks. Thus on the pathway, alternating bodies of saltwater and freshwater remained unmixed due to the sudden freshwater inflow, visually identifiable as bands on the water's surface.

Additionally, the vertical profiles of salinity were observed by the CastAway CTD data logger at selected points along the pathways in Can Gio area. Figures 14 and 15 show the vertical profiles of salinity along Long Tau, Dua, and Soai Rap rivers in September 2018 (Pathway I, Period I) and December 2017 (Pathway Ⅲ, Period Ⅱ), respectively. In general, water depth directly affected salinity levels along the pathways; salinity had lower values at the water surface and highest values at the bottom. The salinities in Period I were lower than those in Period Ⅱ at both the surface and the bottom of the water. According to observations in the Period I, the profiles of salinity from point 1 to point 5 were quite similar. There was no change between the surface and bottom water. The change from the surface to the bottom

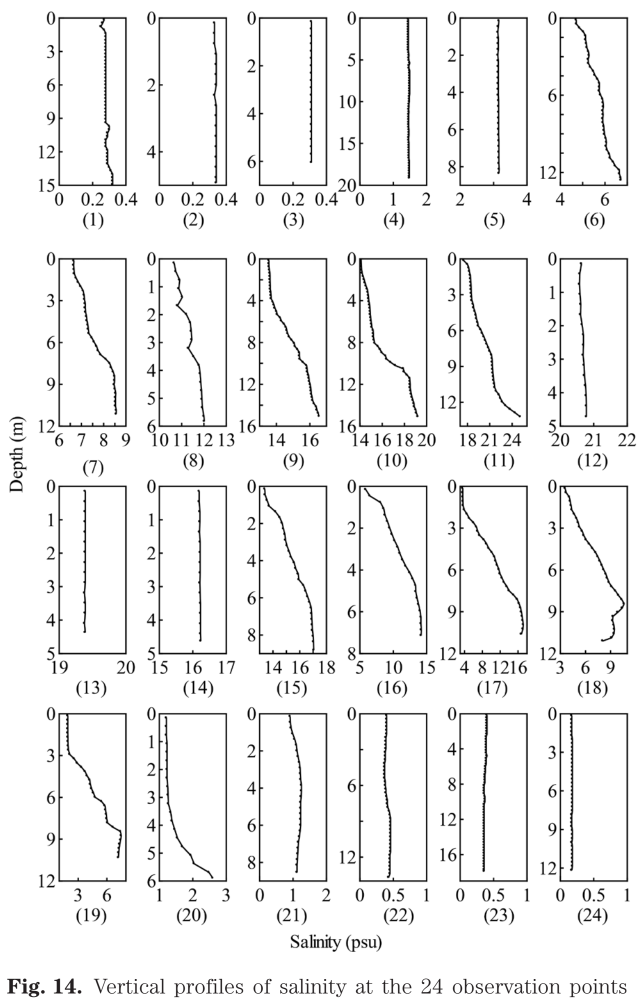

Fig. 14. Vertical profiles of salinity at the 24 observation points along Pathway I recorded with the CastAway CTD data logger (Period I, September 13, 2018). (See also Figs. 4 and 11.)

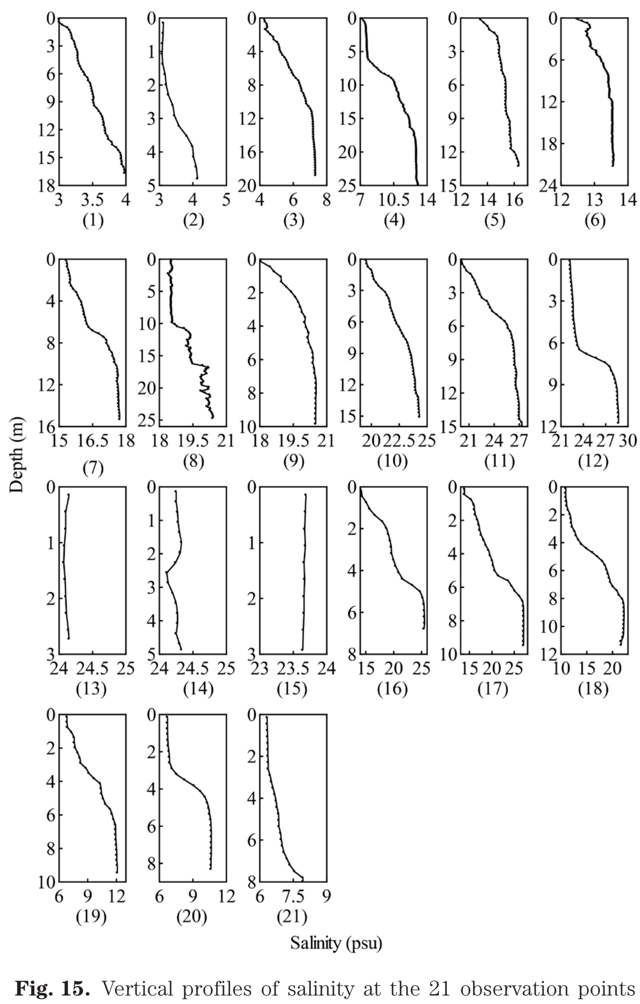

Fig. 15. Vertical profiles of salinity at the 21 observation points along Pathway Ⅲ recorded with the CastAway CTD data logger (Period Ⅱ, December 10, 2017). (See also Figs. 6 and 12.)

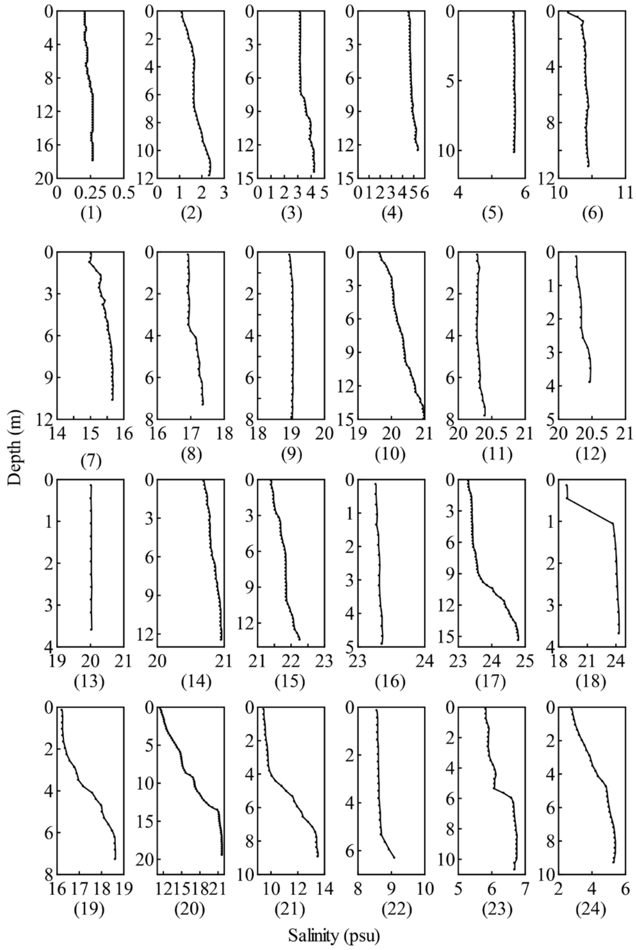

Fig. 16. Vertical profiles of salinity at the 24 observation points along Pathway II recorded with the CastAway CTD data logger (Period I, September 14, 2018). (See also Figs. 5 and 13.)

of the river was around 2 psu from points 6 to 7. Points 1 – 5, located in the upstream of Can Gio area, had only a faint influence by tide. Furthermore, this stretch has smaller river–sections and much less receiving water from upstream flow; thus, the hydrodynamics weakly occurred. Point 8 was located at the intersection of three rivers: Long Tau, Dua, and Dong Tranh rivers, which were greatly impacted by river discharge and tide from the East Sea. Thus, the difference from the surface to bottom was only approximately 1 psu. However, this point had a strong fluctuation in the vertical profile of both periods, as shown in the Figs. 14 and 15. Along the downstream of Long Tau River (below Nga Bay Station), the salinity had a high value. In Period I, it reached more than 24 psu at the bottom and nearly 21 psu at the surface. In Period II, the value of salinity profiles was larger, with a maximum of nearly 29 psu in at bottom and 23 psu at the surface. Salinity was dramatically different between points 13 and 14 on the Long Hoa River, the small river connecting Can Gio and Dong Tranh capes. Salinity in this river was high, around 24 psu in the Period II. However in Period I, salinity was approximately 18.3 psu at point 13, located near Long Tau River Mouth. It then decreased to approximately 16.2 psu at point 14, near Soai Rap River mouth. This phenomenon can be explained by the difference in discharge of the two rivers. The salinity in Soai Rap River was lower than that in Long Tau River. Between the two observed periods, Period I and Period II, the salinity change in points 16, 17, and 18 was particularly high, ranging from 8 to 12 psu from the surface to the bottom. The salinity in Dong Tranh Cape in September 13, 2018 (Period I) was different from that at point 15, located near Long Hoa River, and point 16, located near Soai Rap River mouth. In Period I, salinity was also very low in points 19, 20, and 21 located around Vam Co River, because Vam Co River also discharged a high volume of water to Soai Rap River in this period.

Figure 16 shows the vertical salinity profiles for 24 points along Long Tau, Dong Tranh, and Thi Vai rivers in Period I. According to the tidal level in the period, salinity in the upstream of Long Tau River on September 14 (Period I) was higher than that on September 13 (Period I) because of the different level of the tide. On September 14, the tidal level at starting point was higher than that on September 13. The different salinity value was observed in the salinity profiles at Point 4 on September 13 and Point 3 on September 14. Salinity in Dong Tranh River from points 4 to 10 increased nearer to Thi Vai River. Salinity in Thi Vai River from points 11 to 17 was higher than 20 psu.

CONCLUSIONS

In order to assess the influence of river inflow discharge and tidal motion to the spatial–temporal distribution of salinity along the main rivers in Can Gio mangrove forest located in the south of Vietnam, field observations were conducted to collect salinity time series, spatial salinity distribution, and vertical profiles of salinity during two periods in the wet seasons of 2017 and 2018. Period I in 2018 marked the middle of the rainy season; it had a higher discharge from the upstream rivers and was at middle tide. Period II in 2017 encompassed the end of the rainy season; it had a normal discharge from the upstream rivers and was at spring tide.

The observed data of two periods showed a clear relationship between salinity and the combined effects of tide and river inflow. Salinity in Can Gio area changed depending on spatial locations and the time of year. The salinity in the Period I was consistently lower than that of the Period II.

Upstream flows and tidal regime primarily influenced the salinity change. The salinities in the upstream of Long Tau and Soai Rap rivers were low, increasing when the distance to the sea decreased. Moreover, the salinities along Soai Rap River: at Phu Xuan, Vam Co, and Dong Tranh Cape were significantly affected by the upstream flows at Phu Xuan and Vam Co. However, this trend was not similar to that of Thi Vai River, which had relatively minimal upstream discharge. Thus the area along Thi Vai River had a high salinity, with the salinity almost entirely driven by the tidal regime.

Sudden salinity changes were found along Dong

Tranh River and Thi Vai River during observation in the Period I. No evidential data was collected from these sites of sudden depletion, but rather sudden saline depletion was explained by observations during actual navigation. Heavy rain occurred during the field observation, creating freshwater rainfall–runoff at the drylands, which eventually became wetlands became during the ebb tide period and entered the rivers through small creeks. Thus in the rivers, alternating, unmixed saltwater and freshwater bands could be visually identified due to the sudden freshwater inflow. However, a more detailed survey would be needed to identify further causes of sudden salinity fluctuation in this area.

AUTHOR CONTRIBUTIONS

V. T. H. THU, T. TABATA, and K. HIRAMATSU designed the study and conducted the field observations. T. A. NGOC contributed to the field observations. V. T. H. THU wrote the draft of the manuscript. T. TABATA and K. HIRAMATSU revised the manuscripts. M. HARADA assisted in the preparation of the manuscript. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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