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Research Article
A Spatial Nutrient Distribution Due to Seabass Aquaculture Activities at Setiu, Terengganu, Malaysia

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Abstract
Background: Setiu wetlands is located in the state of Terengganu facing the Southern part of South China Sea, Malaysia. This wetland has a diverse ecosystem that represents a vast array of biological diversity and abundance in utilizing natural resources. However, there is large scale of aquaculture activities within and nearby the wetland which could threaten the ecosystems of this area. The surface water are the most exposed to pollution due to their easy accessibility to the disposal of wastewaters. **Objective:** Thus, the main objectives of the study are to determine the surface water distribution of ammonia and phosphorus due to aquaculture activities with respect to the baseline data of these parameters. **Methodology:** The samples were taken on October, 2014 (dry season) and November, 2014 (wet season) at 18 different areas. It was observed that the impact of human activities such as agriculture and aquaculture were the responsible factors for higher ammonia and phosphorus concentrations recorded in the study area. **Results:** From the observed results, wet season has high concentration of nutrient where the total ammonia nitrogen during the low tide was (1.5311 ± 0.0419 mg L^{-1}) and during high tide was (1.4298 ± 0.0334 mg L^{-1}). Meanwhile the ortho-phosphate level during the low tide and high tide were (0.0280 ± 0.0048 mg L^{-1}) and (0.0340 ± 0.0230 mg L^{-1}), respectively. **Conclusion:** Tidal hydrodynamics influenced the changes of the concentration parameters in the water column. More important, the concentration of ammonia and phosphorus in water can determined to monitor the maximum carrying capacity of the aquaculture activities that would not jeopardize a sustainability of ecosystem according to NWQS standard.

Key words: Nutrient aquaculture, hydrodynamic, carrying capacity, TAN, ortho-phosphorus

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Setiu wetlands is located in the state of Terengganu facing the Southern part of South China Sea, Malaysia. The area of Setiu wetlands is approximately 23,000 ha and mainly consists of riparian forests lining the riverbanks, freshwater *Melaleuca* swamps, peat swamps, mangroves, brackish water lagoon with vegetated sand islands, seagrass beds and sandy beaches[1]. The aquatic system is an important aspect of wetlands and the water quality. It is a critical factor that must be addressed when prioritizing wetlands management activities. If wetlands lose their functional capacity to absorb and transform contaminants, impacts to streams and lakes would be expected shortly thereafter[2]. In addition, surface water are the most exposed to the pollution due to their easy accessibility for contaminations, such as contaminated directly from air, discharge water, overflow during wet weather, eroded soil particles and also ground water. Furthermore, the anthropogenic influences such as urban, industrial and agricultural activities increase the exploitation of water resources as well as natural processes, such as precipitation inputs, erosion, weathering of crustal materials, degrade surface water and damage their use for drinking, industrial, agricultural, reaction or other purposes[3].

Aquaculture is one of the examples of human activities, which contribute to the environmental decline of coastal water and the collapse of fisheries stocks worldwide[4]. Alongi *et al.*[4] also mentioned of the efforts made to minimize environmental impacts by utilizing less damaging commercially viable methods of culturing. Unfortunately, this efforts have resulted in the growth of intensive fish cage farming, especially in the tropical areas where fish and shrimp ponds have caused severe environmental damage. Consequently, increasing attention has been paid to environmental protection of coastal and estuarine water. It is aimed to obtain the full understanding and accurate prediction of the fate of pollutants in such water bodies, which has become the highest priority for water utilities and other stakeholders. Vidal *et al.*[5] reported that among the different types of water pollution, eutrophication has been identified as one of the greatest contemporary threats to the wellbeing of coastal ecosystems. In addition, the rapid expansion of marine aquaculture is a potential solution to the problem of overfishes and fisheries depletion worldwide, but it is still a major threat to ecosystems. In the same way, the impacts from open aquaculture are the nutrients flush in water bodies (Fig. 1) and other wastes to the surrounding environment[6].

Shirodkar *et al.*[7] stated that, estuarine dynamics depend upon tides, currents (hydrodynamic process) and riverine inputs. Additionally, the low and high tide have a large effect on the amount of nutrients and other water characteristics that affect the ecosystem of the estuary. Moreover, majority of

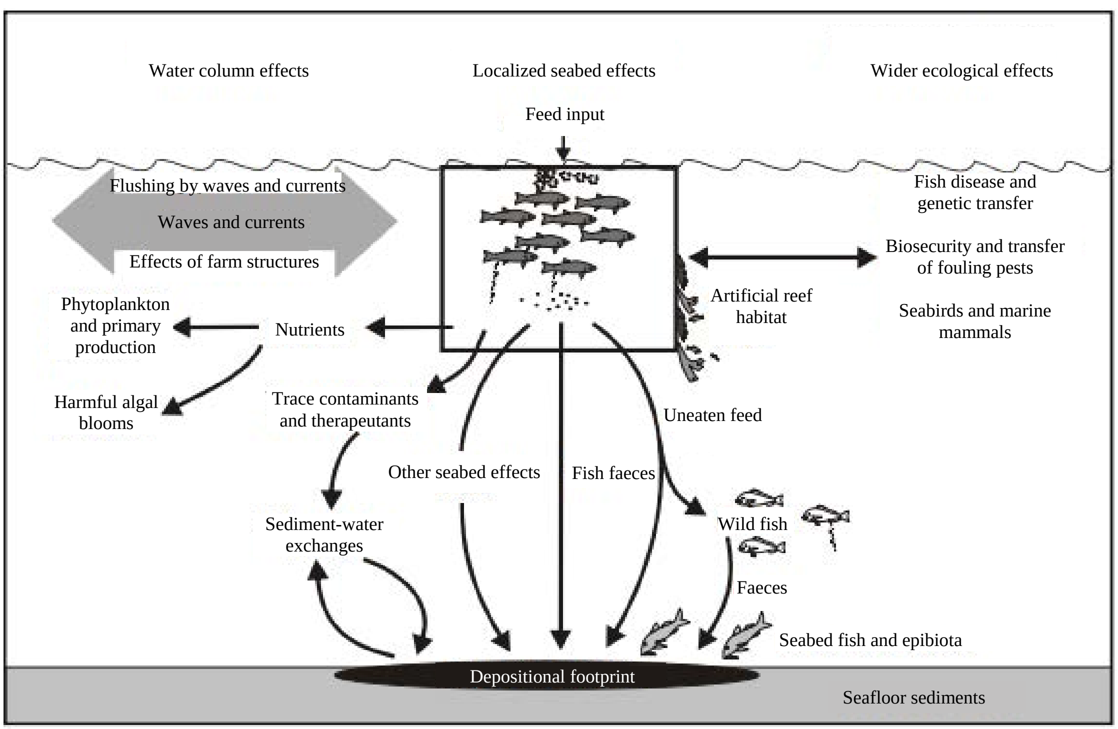

Fig. 1: Process how nutrient can affect the ecosystem[5]

the contaminants entering the estuary along the riverine course are either pushed upwards during the high tide or downwards during the low tide and in the process gives rise to increase in the contaminants. This process had caused the changes in the water quality at various locations along the estuarine region[7].

One of the major concerns of Setiu wetlands is the contamination resulting from anthropogenic activities including the waste discharges from aquaculture activities and human activities due to the inward and outward movement of contaminants with respect to tides in the region of Setiu estuary and their impact on water quality and the productivity. These concerns have not been explored properly. In this study, an attempt has been made to understand how nutrient distribution from aquaculture activities affect water quality, the assimilative capacity and productivity of Setiu river water over different seasons and determine the maximum carrying capacity for the aquaculture activities that would not jeopardise the sustainability of the ecosystem. The role of hydrodynamics in maintaining the water quality of Setiu river water has been studied using the hydrodynamic module (MIKE 21).

MATERIALS AND METHODS

Study area: In order to develop the knowledge and understanding on nutrient distribution by aquaculture activities and its carrying capacity, this study was conducted where aquaculture activities were persistently generating attention to the department of environment, university researchers and the public. Setiu wetlands is a major aquaculture spot that involves brackish water cage culture, pond culture, pen culture and oyster culture. The length of study areas encompasses the estuaries until the upstream of approximately 3.5 km as shown in Fig. 2. The study had considered both dry and wet seasons in 2014. The spatial study was based on activities at 18 sampling stations along the lagoon. The study area consisted mainly the residential areas, aquaculture area and mouth of the river. A 0.5 m depth from the water surface was chosen for water sampling due to the shallowness of water in the study area.

Sampling and experimental set-up: *In situ*, seasonal and tidal monitoring of physiochemical parameters and major nutrients (TAN and ortho-phosphate) were undertaken for the surface water body. For *in situ* monitoring, temperature, salinity, pH and DO were measured using hydrolab quanta. Meanwhile, for laboratory analysis, water samples were collected at 0.5 m depth during dry and wet seasons under both high and low tide condition. Van-Dorn water samplers were deployed to collect samples. Water samples were stored in the bottles and immediately preserved in an ice-box after 1 mL concentrated sulphuric acid added and later carried to laboratory for nutrient analysis (TAN and ortho-phosphate)[8]. During analysis of nutrient concentration, water samples were filtered by using 0.45 μm glass fibre filter paper to minimize the changes of nutrient content due to biological activity[9]. The ascorbic acid and Nesslerization methods were used to determine phosphate and ammonia respectively. A UV/Vis-1601 spectrophotometer was used for estimating the concentration of water nutrients.

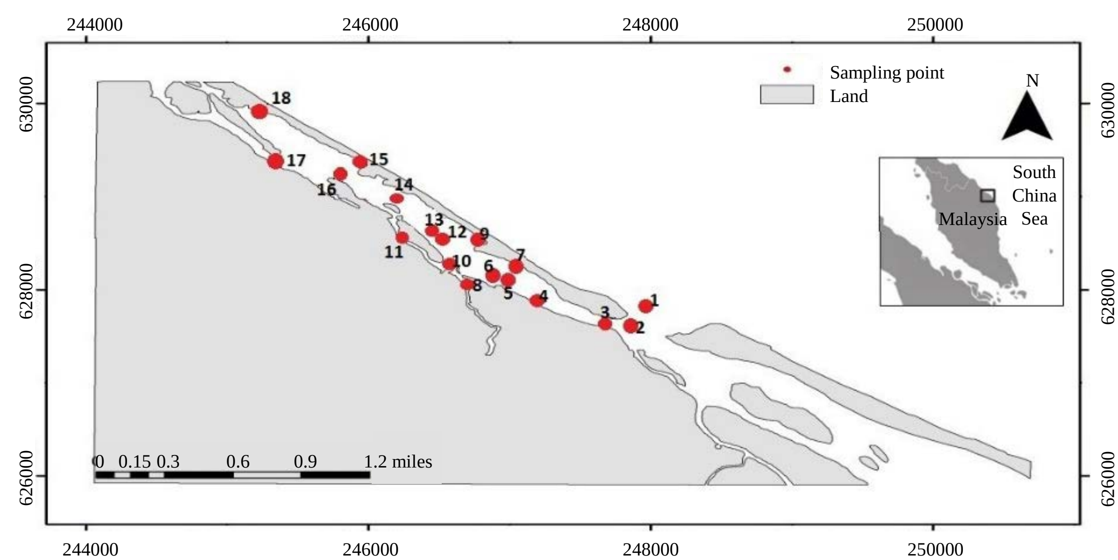

Fig. 2: GPS location of sampling in the Setiu estuary-lagoon, Terengganu, peninsular Malaysia

Hydrodynamic influence: Hydrodynamic factors can also influence the water quality by affecting the distribution of nutrient in surface water layers. Among the hydrodynamic factors which affect the water quality are tidal, rainfall, wind speed and direction, bathymetry and currents. All of these data were collected from European centre for medium-range weather forecast (ECMWF) to be used in the modelling of the water quality. For tidal, diurnal tidal occurred at the study area as Terengganu has mixed tides with dominant diurnal. The low and high tides are among the effecting mechanism of the distribution of nutrient in surface water layers. In addition, wind speed and direction affect the current flows which also influence the distribution of nutrient.

MIKE 21 modelling: For the simulation process, the hydrodynamic and Ecolab modules of MIKE 21 numerical model were used. The MIKE 21 is a two dimensional mathematical models which can be used to simulate water flow, waves, water quality and sediment. Ecolab can be used for water quality simulation, forecast of water quality, water environment impact assessment, restoration of water environment and water environment planning. The hydrodynamic model coupled with water quality software was used to simulate the current situation at study area. This hydrodynamic module calculated the hydrodynamic behaviour of water in response to variety forcing functions, while the Ecolab modules described the chemical, biological and ecological responses and interactions between the stated variables. The local continuity Eq. 1 is written as:

$$\frac{\partial A_x}{\partial t} + \frac{\partial Q}{\partial x} = q \text{ (Conservation of mass)} \tag{1}$$

The St. Venant for momentum and how the simpler forms may be derived by dropping terms are shown in Eq. 2 as follows[10]:

$$\frac{\partial Q}{\partial t} + \partial \frac{\frac{\partial Q^2}{A}}{\partial x} gA \frac{\partial y}{\partial x} - gA(S_0 - S_f) = 0 \tag{2}$$

Equation 2 shows local advective pressure gravity friction acceleration force.

And also in Eq. 3:

$$\frac{\partial Q}{\partial t} = gA(S_0 - S_f) - gA\frac{\partial y}{\partial x} - \frac{\partial(\frac{\partial Q^2}{A})}{\partial x} \text{ (Conservation of momentum)} \tag{3}$$

where, A is the wetted area (or reach volume per unit length), t is the time, Q is the discharge, x is the distance downstream, q is the lateral inflow per unit length, g is the acceleration due to gravity, y is the depth, a is a momentum coefficient, S_0 is the bed slope and S_f is the friction slope.

Carrying capacity: Environmental carrying capacity of aquaculture is defined as the maximum limit of nutrient suspended in water body. There are correlation between nutrient and aquaculture where aquaculture activities contribute the nutrient inputs in water bodies through waste discharge and feeding rate. In addition flushing rates also contribute to the nutrient input in water bodies. In this study, the values of nutrient capacity measured are based on the standard concentration of nutrient in water quality.

RESULTS AND DISCUSSION

Effect of hydrodynamic to water quality and nutrient: Figure 3 and 4 show the pattern of hydrodynamic factors for different seasons affected the DO, TAN and otrho-phosphate concentration. The hydrology cycle had a great influence on the water quality of a river, mainly the rainfall which highly depends on wet and dry seasons specifically in Malaysia[11]. There was no rainfall recorded in dry season during sampling time but in wet season, rainfall was recorded based on tidal data during sampling time which is around 08:00 am until 13:00 pm. These rainfalls affect the water level of the river[12]. Other than that, there were also different temperatures in dry season and wet seasons.

From the data obtained, the dry season exhibited higher temperature compared to the wet season. It was due to the humid environment in wet season whereas hot environment in dry season. It also reported by Akhir[13] that during northeat monsoon, the precipitation and overcast skies are among the factors that contribute to the lower temperature and salinity. Other than that, the rainfall factor also affect the concentration and distribution of DO content and TAN concentration in the river[12]. The increasing input of fresh water in wet season caused increasing DO content in water and increasing TAN concentration. It was due to greater input of nutrient that flowed into the river and

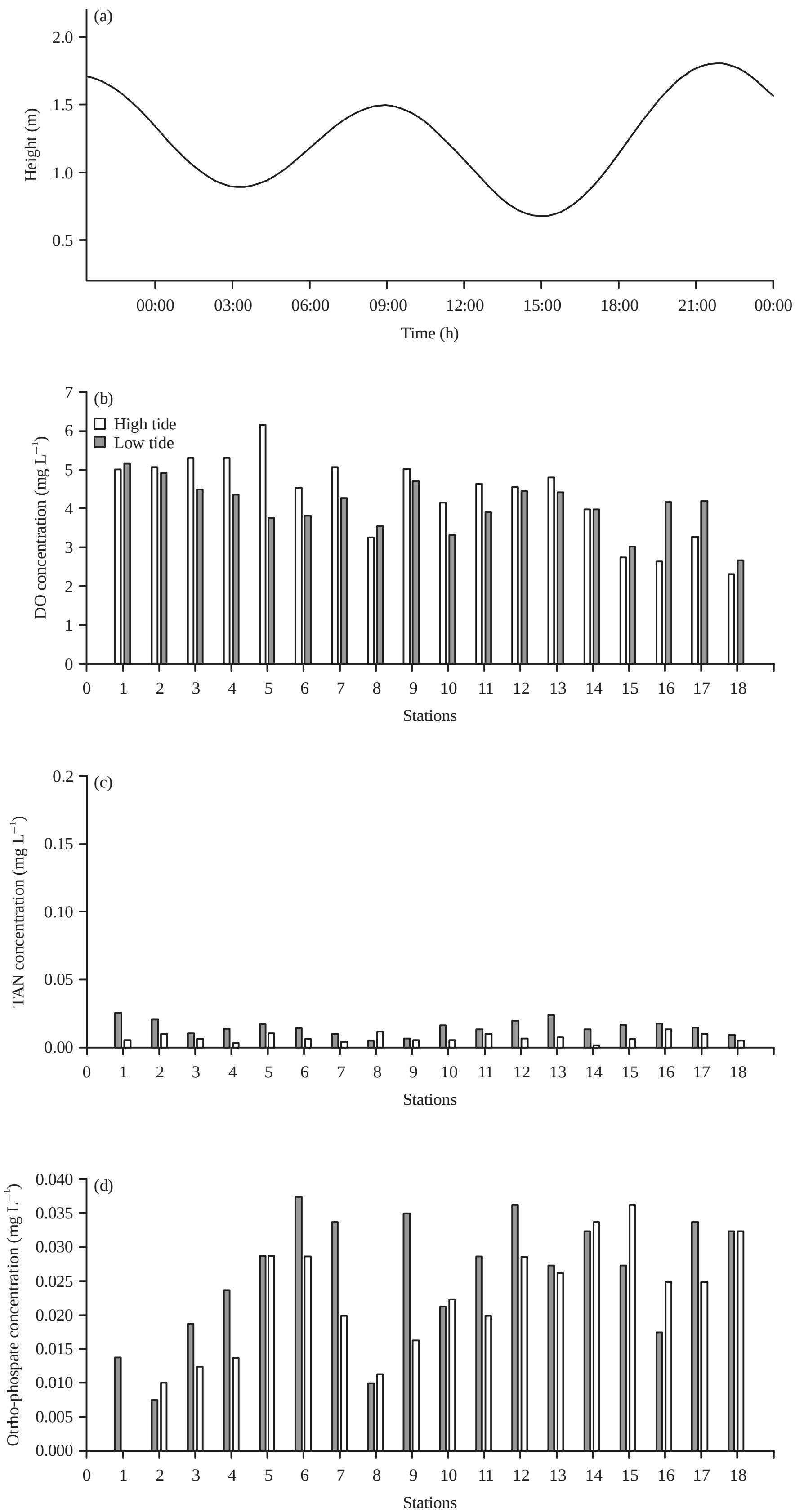

Fig. 3(a-d): Effect of (a) Tidal height, (b) DO concentration, (c) TAN concentration and (d) PO_4^{3-} concentration during dry season

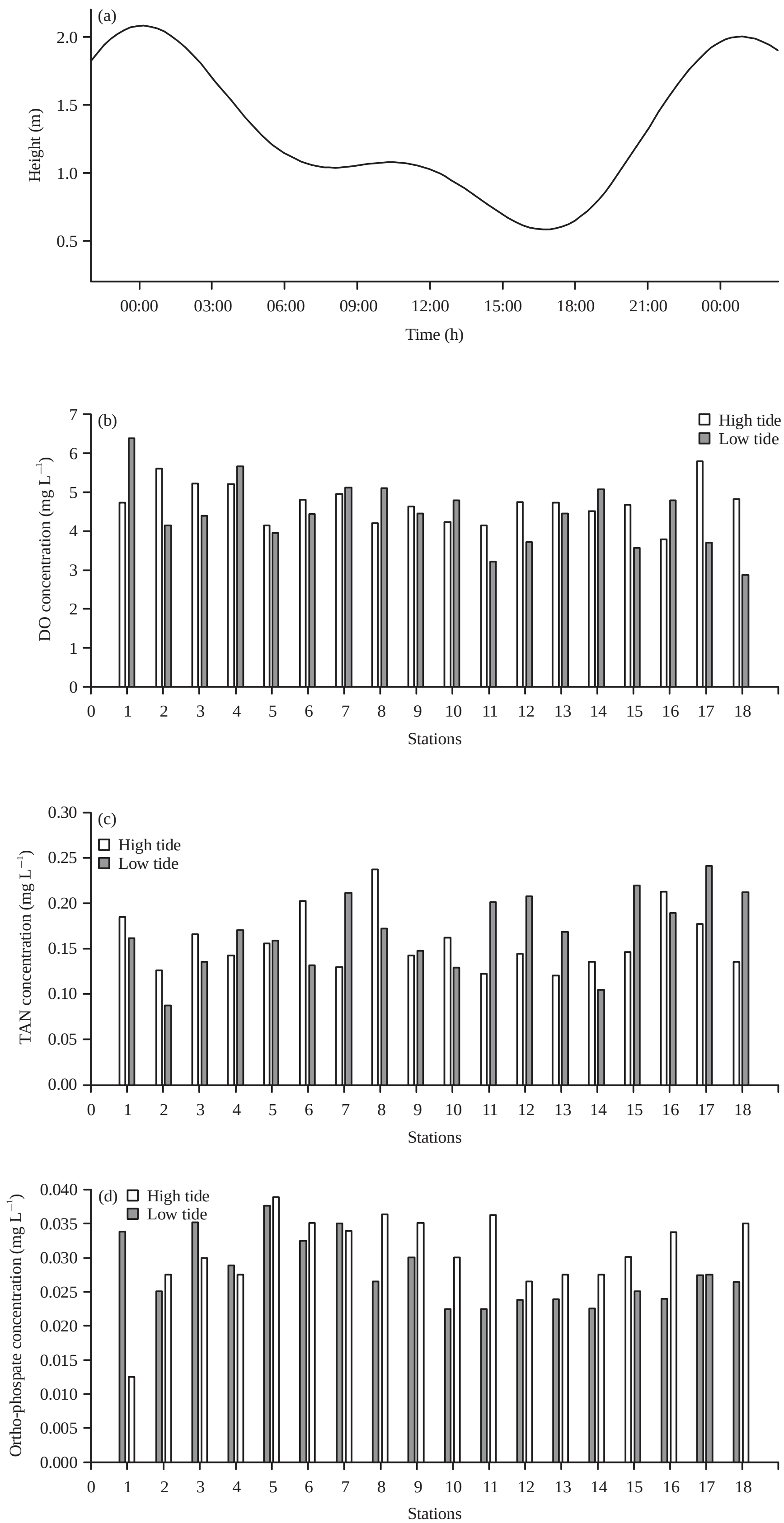

Fig. 4(a-d): Effect of (a) Tidal height, (b) DO concentration, (c) TAN concentration and (d) PO_4^{3-} concentration during wet season increased the concentration of TAN in the water. Addition of fresh water increased the dissolved oxygen in water[14]. Furthermore, dry season and wet seasons gave effect to the hydrological characteristics of the river in terms of flow rate, velocity and volume of river[13]. Other than rainfall, tidal also effects the changes in river water quality. Figure 3 and 4 also show the pattern of 24 h diurnal tide occurred in dry and wet seasons during the sampling time. According to Lee and Seng[14], tidal types for Malaysia are semi-diurnal and mixed tide with dominant semi-diurnal. Furthermore, the study areas were located in the state of Terengganu facing to the Southern part of South China Sea. It has mixed tide with dominant diurnal. The highest elevation of tide recorded was 2.13 m in wet season. It is also influenced by strong wind, which effect the tidal cycle and magnitude[15].

Concentration of NH_4-N and PO_4^{3-}-P: Nutrient analysed in the present study were TAN and PO_4^{3-}-P. Table 1 shows the mean and range of nutrient concentration in dry season and wet season. From the results collected, high value for TAN and PO_4^{3-}-P (1.5311±0.0419 and 0.0280±0.0048) were seen in wet season during low tide. River discharges can be enhanced by rainfall and weathering rates are affected by precipitation and temperature[16], which can lead to higher nutrient values during the wet seasons.

From the results obtained in Table 1 and Fig. 5, the lower concentration of nutrient was recorded at point 1 where this point was located near coastal area, away from the wetlands and acted as a control station. It was due to no major anthropogenic activities around this point. Therefore low concentration of nutrients was observed[17]. Other than that, there were large differences of TAN concentration during dry season and wet season. High concentration of TAN during wet season was observed. In contrast to this, lower amount of TAN were detected during dry season. It is believed due to the river runoff from inland areas which are characterized by diversed agricultural and aquaculture activities[18]. Both activities involve the use of fertilizer and other chemicals. Other than that, wastewater discharged and eroded soils may contribute to the higher concentration of ammonia during wet season. For nutrient PO_4^{3-}-P, during wet season high phosphate level could be related to the high rate of decomposition of organic matter, run-off from surface catchment and interaction between water and sediment[19]. In general, river runoff greatly modifies the N:P ratio in water column[18]. From the observation, upstream station had high concentration of PO_4^{3-}-P, probably due to fertilizer runoff from the large-scale palm oil plantation activities. Suratman and Latif[20] reported that there were several types of phosphorus containing fertilizer used in agriculture. Other than the upstream, there were also high nutrient at the middle area of river where aquaculture activities were carried out[20]. These factor have made significant environmental impact on coastal ecosystem for example coastal eutrophication, frequent harmful algal bloom events and seasonal hypoxia. Moreover, concentrations of PO_4^{3-}-P at downstream were low due to less human activities at that area. In addition, the nutrient concentration at station 6, 8, 12, 13 and 15 were quite high due to close vicinity to the aquaculture area. It was due to the waste from brackish cage culture and oyster production in the surrounding areas. The increasing fish food, manure, animal waste, fish debris and fish skeletons beneath the cages can increase the level of nutrient in water especially the level of ammonia[21]. This effluent may be an environmental hazard if it causes undesirable environmental changes. In the monsoon period, reduced feeds are administered because ammonia levels can be excessive as a result of decrease in temperature that reduced the rate of algal photosynthesis and thus less ammonia is removed by this means[22]. Generally, results obtained around 50 m from the cage during dry season which is 0.0132 mg L^{-1} can be considered as contributed by nutrient discharged from the aquaculture activities. Meanwhile, results during the wet season which is 0.1645 mg L^{-1} can be considered as nutrient without contribution from aquaculture in the study area. Hence from the value of nutrient from the aquaculture activities and without aquaculture activities are considered as nutrient contributed from outside activities[22] which are 0.1513 mg L^{-1} agreed that at lower concentrations, around 0.05 mg L^{-1}, un-ionised ammonia is harmful to fish species and can result in poor growth and feed conversion rates, reduced fecundity and fertility and increase stress and susceptibility to bacterial infections and diseases. Meanwhile, at higher concentrations, exceeding 2.0 mg L^{-1}, ammonia causes gill and tissue damage, extreme lethargy and death. The input of soluble nitrogenous and phosphorous compounds from urban and agricultural runoff have been shown to cause hypernutrification which is increases in nitrogen above ambient levels in the environment.

The hydrodynamic effect also contributed to the changes in level of nutrient surrounding the fish cage. Examples of hydrodynamic factor involved are tidal, wind and flow of water[23]. Figure 6 shows the concentrations of ammonia are

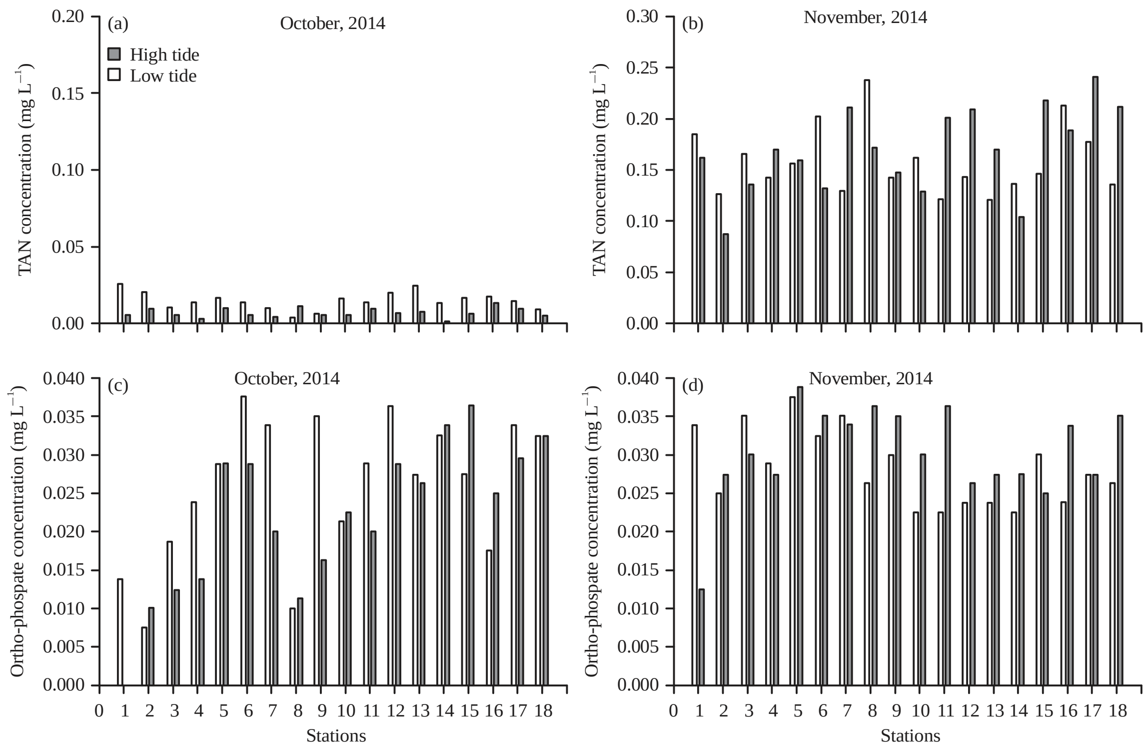

Fig. 5(a-d): Graph pattern of (a) TAN concentration during dry season, (b) TAN concentration during wet season, (c) Ortho-phosphate concentration during dry season and (d) Ortho-phosphate concentration during wet season

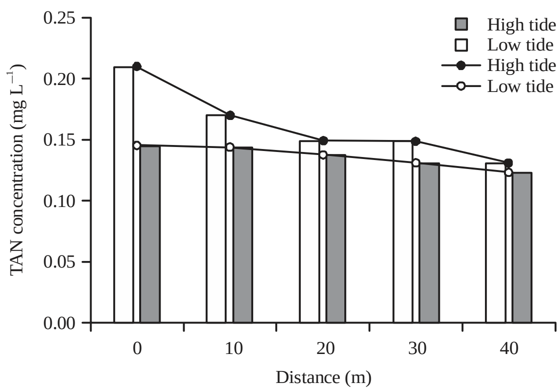

Fig. 6: Distribution of ammonia concentration from fish cage during high tide and low tide

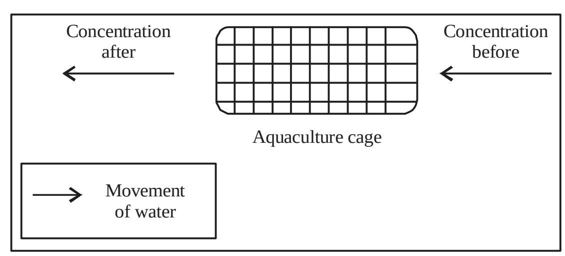

Fig. 7: Illustration movement of nutrient concentration before fish cage and after fish cage

decreasing with increasing of distance. The tidal and flow of water are the main factors in the distribution of nutrient in water. Nutrient from fish cage dispersed throughout the river based on tidal and water flow[19]. The environmental effects of nutrient enrichment are site-specific and largely depend on the prevailing physicochemical and biological features.

Figure 7 illustrates the movement of nutrient concentration. There are differences of ammonia level before and after water flow throughout the fish cage area as shown in Fig. 8 due to movement of water through the fish cage area. The results obtained are similar to those with the factors causing the distribution of nutrient in water columns through hydrodynamic effects such as tidal, wind and also flow of the water[19]. Water exchange can also cause differences in nutrient concentration inside and outside the cage. Wei *et al*.[24] observed that the flow speed declined from the mouth to the upstream of the river and the outflow was slowed by the increased increased aquaculture activities and infrastructure[25]. Thus, movement of nutrients from

Table 1: Mean and range of TAN and PO_4^{3-}-P concentration at the 18 sampling site of Setiu river during dry and wet season

	Dry season		Wet season	
Parameters	High tide	Low tide	High tide	Low tide
Total ammoniacal nitrogen (mg L^{-1})	0.0806±0.0039	0.0175±0.0077	1.4298±0.0334	1.5311±0.0419
Ortho-phosphate (mg L^{-1})	0.0210±0.0093	0.026±0.0090	0.0340±0.0230	0.0280±0.0048

Table 2: Suggested water-quality criteria for water fishery for getting high yield via applying minimum input[26]

Parameters	Acceptable range	Desirable range	Stress
Temperature (°C)	15-35	20-30	<12, >35
Turbidity (cm)		30-80	<12, >80
Water colour	Pale to light green	Light green to light brown	Clear water, dark green and brown
Dissolved oxygen (mg L^{-1})	3-5	5	<5, >8
BOD (mg L^{-1})	3-6	1-2	>10
CO_2 (mg L^{-1})	0-10	<5, 5-8	>12
pH	7-9.5	6.5-6	<4, >11
Alkalinity (mg L^{-1})	50-200	25-100	<20, >300
Hardness (mg L^{-1})	>20	75-150	<20, >300
Calcium (mg L^{-1})	4-160	25-100	<10, >250
Ammonia (mg L^{-1})	0-0.05	0-<0.025	>0.3
Nitrite (mg L^{-1})	0.02-2	<0.02	>0.2
Nitrate (mg L^{-1})	0-100	0.1-4.5	>100, <0.01
Phosphorus (mg L^{-1})	0.03-2	0.01-3	>3
H_2S (mg L^{-1})	0-0.02	0.002	Any detectable level
Primary productivity (CL^{-1} day^{-1})	1-15	1.6-9.14	<1.6, >20.3
Plankton (No. L^{-1})	2000-6000	3000-4500	<3000, 7000

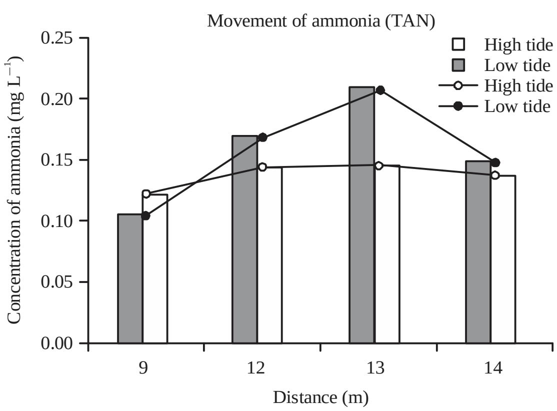

Fig. 8: Pattern of nutrient movement in and out of fish cage

upstream to the open sea may be impeded, which was suggested by the high concentrations of nutrients found at this area.

The optimum range of the nutrient concentration NH_4-N and PO_4^{3-}-P are reported in Table 2. The suggested acceptable range for NH_4-N and PO_4^{3-}-P are <0.05 mg L^{-1} and <2 mg L^{-1} respectively, while for desirable range are <0.025 mg L^{-1} and <3 mg L^{-1}, respectively[26]. These precautions and the following guidelines if taken will not only raise productivity and economic benefits but will also help the farmers in maintaining eco-friendly river. The NH_4-N at the study area during the high tide is 1.4298±0.0334 and the low tide is 1.5311±0.0419. Meanwhile, the mean PO_4^{3-}-P at study area during high tide and low tide were 0.0125±0.023 and 0.028±0.0048. Both NH_4-N and PO_4^{3-}-P concentration were in acceptable range for NH_4-N and desirable range for PO_4^{3-}-P. Increasing of nutrient concentrations may result in increased phytoplankton biomass, that may lead to algal blooms.

Figure 9-14 show the series of nutrient and selected physicochemical distribution during low tide and high tides by seasons. The different colours show the level of concentration whether high or low. The output of this 2D simulation shows that the hydrodynamic factors such as tidal, wind and water flow affect the distribution of concentration of nutrients and physicochemical parameters. Other than that, it also shows that the inputs of high concentrations are by the anthropogenic activities in the river such as aquaculture activities[17]. The concentration of nutrient at fish cage area are a little higher than the others area. The DO and BOD parameters have been affected where the concentration of DO was higher and concentration of BOD was decreasing. The results of simulation has been supported the findings by Akhir and Yong[27] where during the wet season and high tide condition concentration of DO was increasing due to

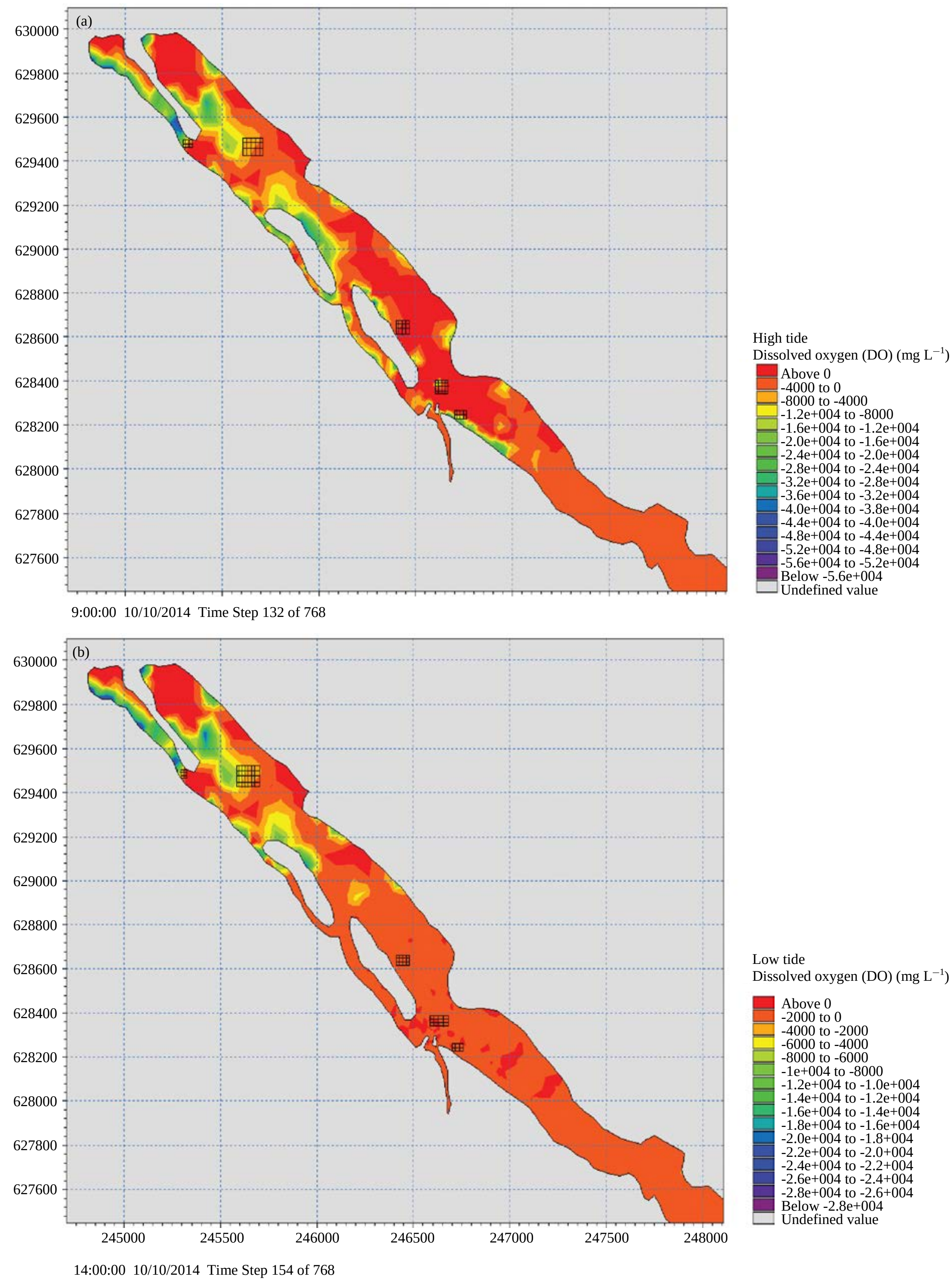

Fig. 9(a-b): 2D mapping and simulation of DO distribution at (a) High tide and (b) Low tide during dry season

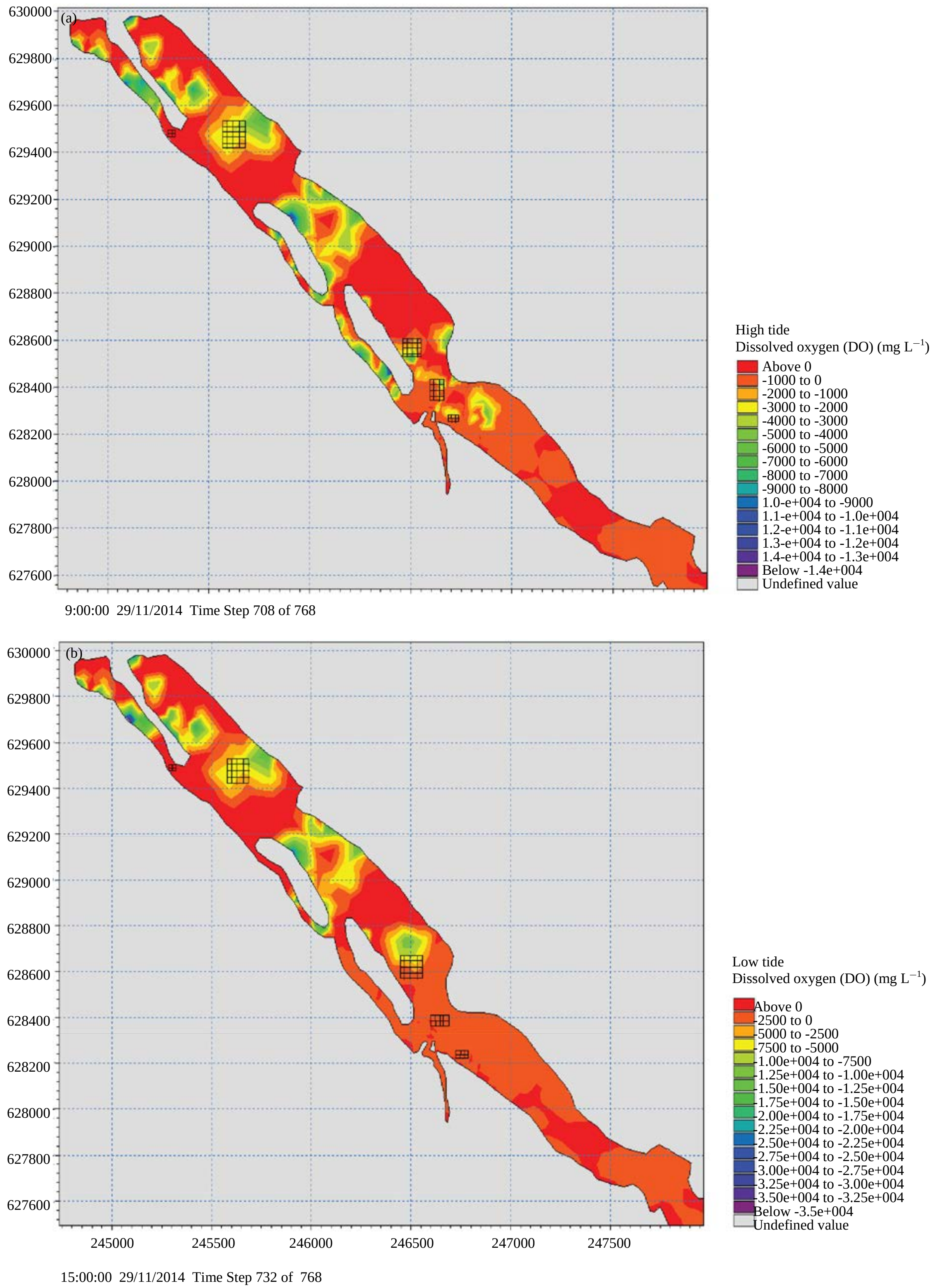

Fig. 10(a-b): 2D mapping and simulation of DO distribution at (a) High tide and (b) Low tide during wet season

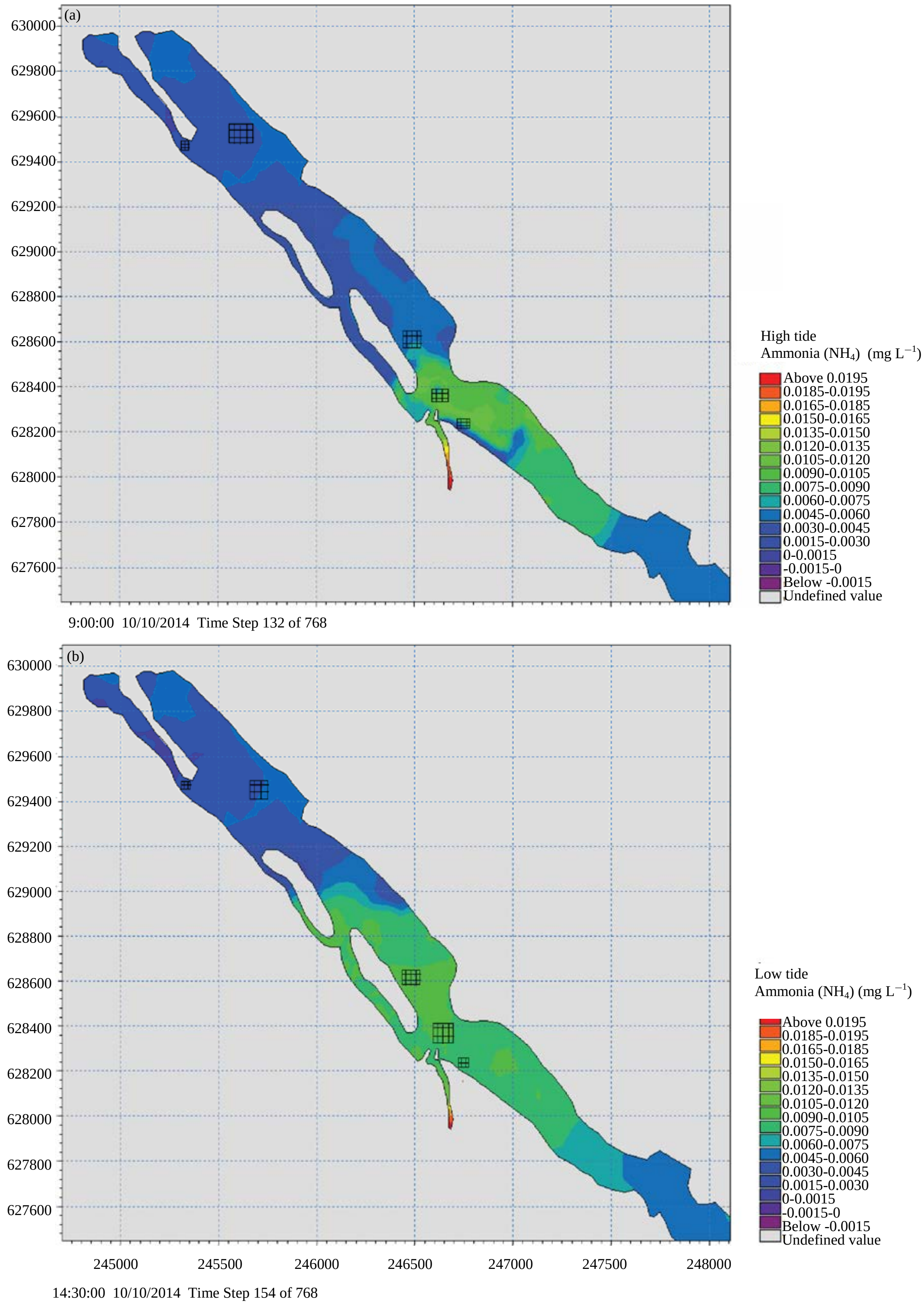

Fig. 11(a-b): 2D mapping and simulation of total ammonia nitrogen distribution at (a) High tide and (b) Low tide during dry season

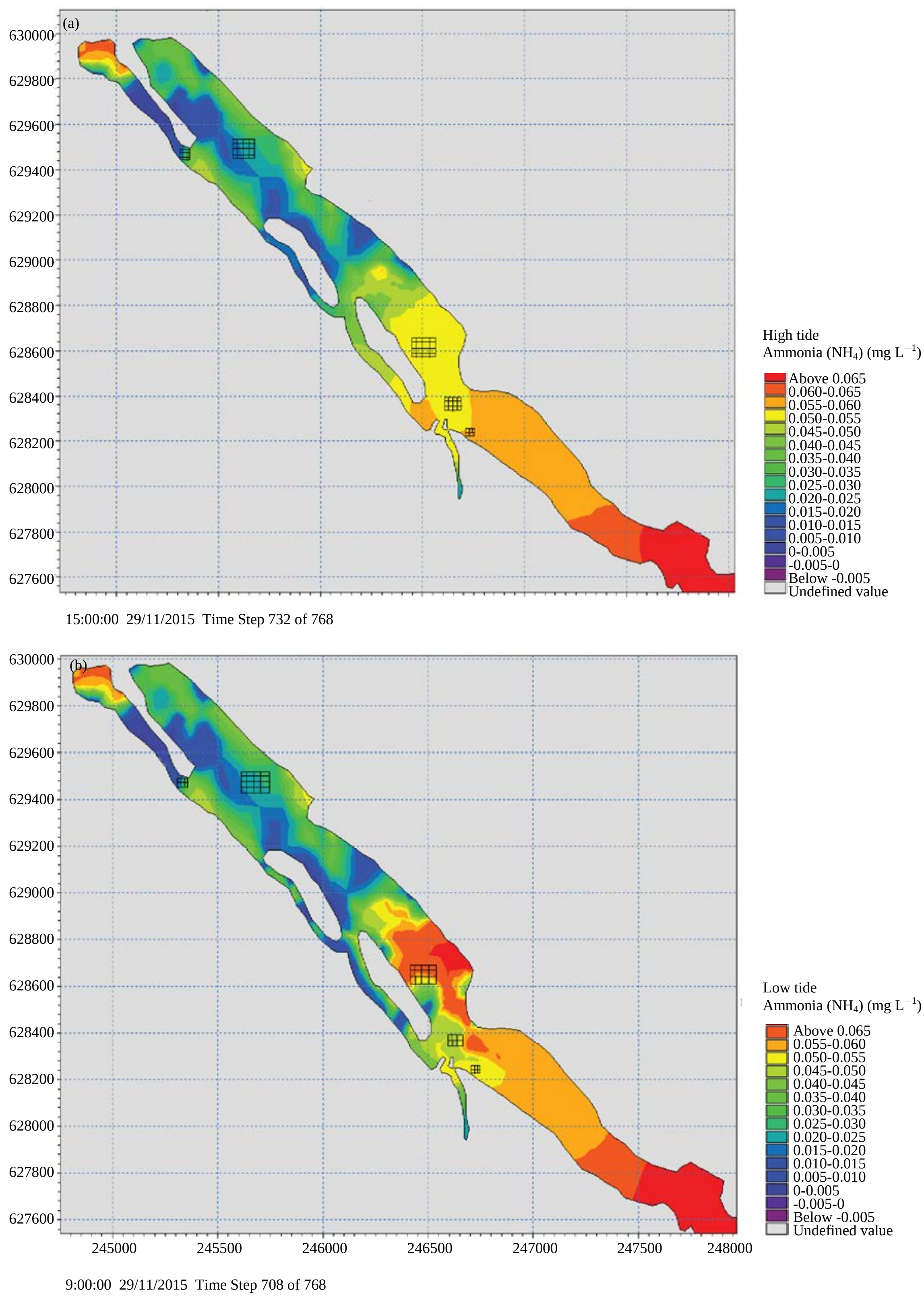

Fig. 12(a-b): 2D mapping and simulation of total ammonia nitrogen distribution at (a) High tide and (b) Low tide during wet season

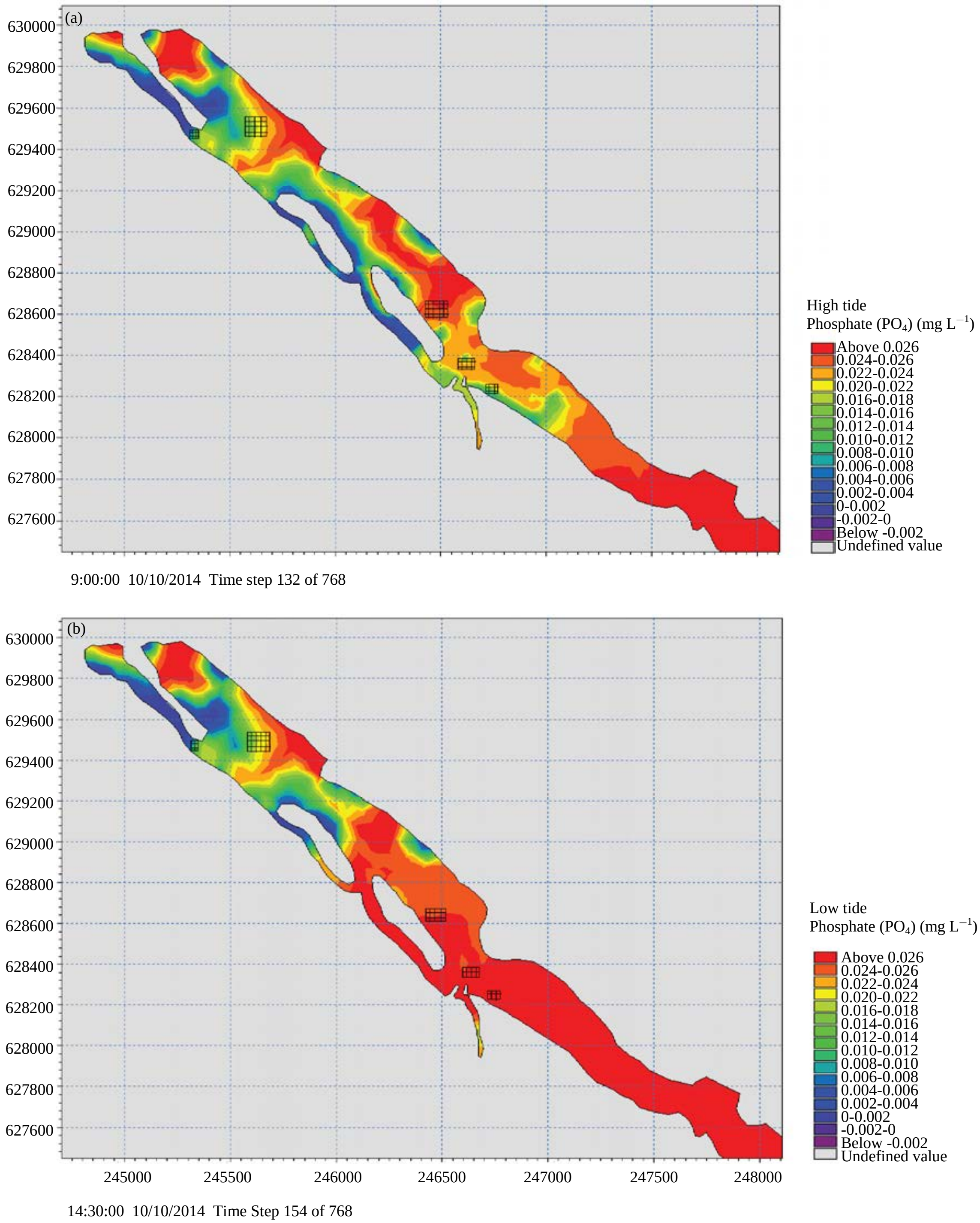

Fig. 13(a-b): 2D mapping and simulation of ortho-phosphate distribution at (a) High tide and (b) Low tide during dry season

addition of dissolved oxygen into the water and more dilution occurs. Other than that the concentration of nutrient also increased during wet season due to overflowing of nutrient from the surrounding activities. This numerical water quality model are useful for understanding of biological process and also the influence of climate change on water quality condition in aquatic system.

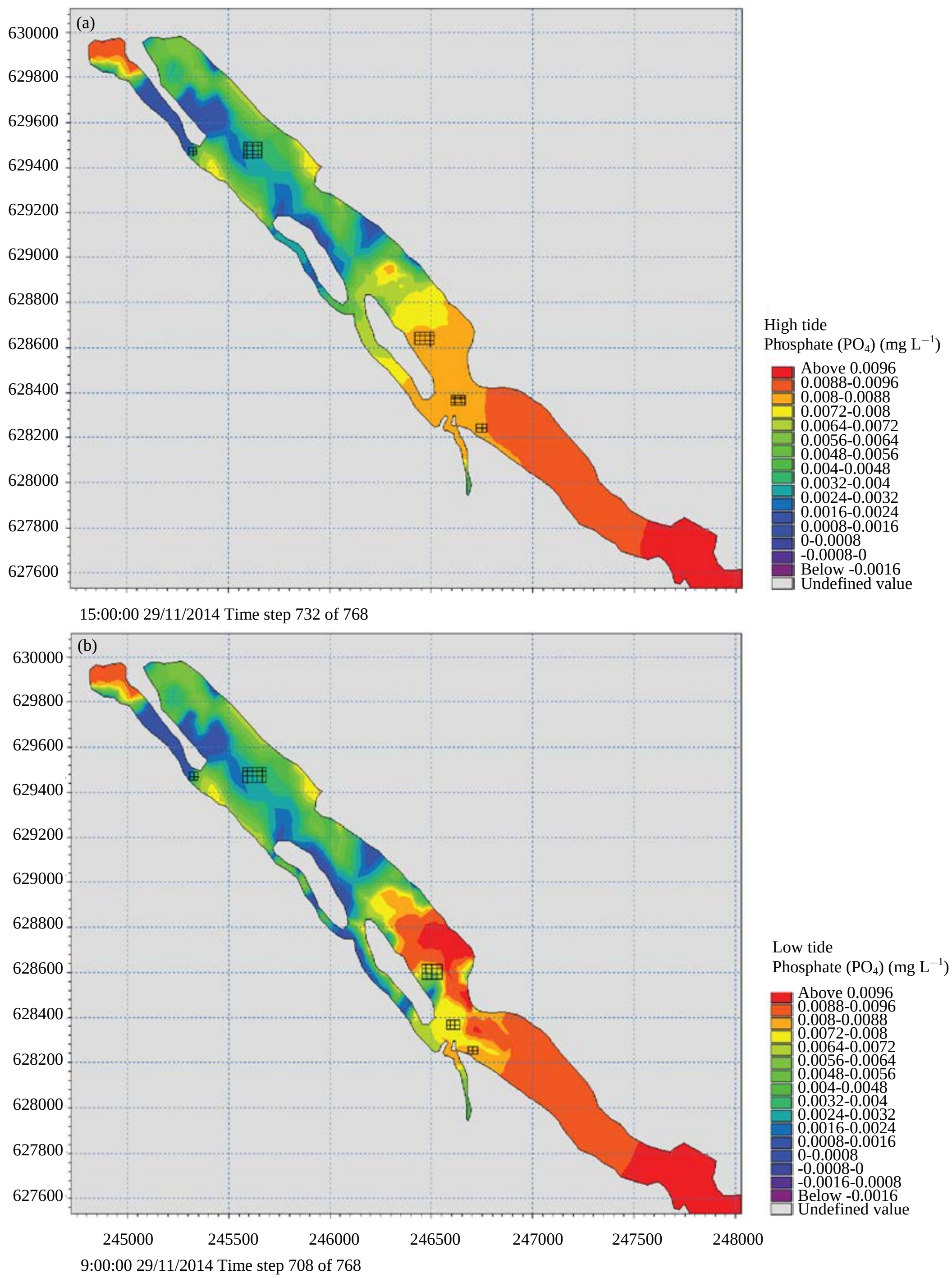

Fig. 14(a-b): 2D mapping and simulation of ortho-phosphate distribution at (a) High tide and (b) Low tide during wet season

CONCLUSION

This present study summarizes the seasonal and tidal fluctuation in nutrient distribution affected by aquaculture activities in Setiu river. The results indicate that there are differences of nutrient concentration affected by seasonal changes, tidal and also by human activities. High concentration of TAN and PO_4^{3-} were observed during wet season whereas during dry season elevated concentrations were also observed at some sampling points which are near the fish cage. It can be seen in simulated results of MIKE 21-EcoLab module which indicate that the distribution of nutrient concentration are affected by the tidal hydrodynamic. However, increasing of uncontrollable aquacultures activities still pose threats to the water quality of the river as well as the ecosystem there. It is hoped the findings of the study will be useful in developing policies for management of aquacultures activities in Setiu wetlands.

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