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Effects of different types of nutrient effluent from shrimp ponds on the seedling growth of *Kandelia obovata*

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Abstract

Extensive shrimp ponds are located next to the landward edges of most of mangrove forests in China. A shrimp pond may influence mangroves by (1) routine effluent between pond and tide, and (2) dredging effluent from pond-dredging at least once a year. Our study consisted of two experiments to study the effects of these two effluents on the seedling growth of *Kandelia obovata*. One experiment simulated the effects of routine effluents. The other simulated four sedimentation thicknesses (0 cm, 2 cm, 4 cm, 8 cm) over mangrove soils by dredging effluent from pond-dredging, and revealed the cumulative effects of dredging effluents on *K. obovata*. At each of the three fixed salinities, i.e., 5, 15 and 25, routine effluent did not result in significant differences in each of the measured growth parameters of *K. obovata* seedlings. However, effects of dredging effluent on seedling growth of *K. obovata* were related with sedimentation thickness. Most growth parameters showed maximum values at sedimentation thickness 4 cm. The data indicated that *K. obovata* accelerated its growth under moderate sedimentation thicknesses and it was tolerant and adaptable to shrimp pond-cleaning effluent sediments up to about 8 cm in our experiment.

Key words: routine effluent, dredging effluent, shrimp pond, excessive nutrients, biomass allocation, mangroves

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1 Introduction

Mangrove wetlands have been known as a low-cost and high-efficiency system for the treatment of municipal wastewater (Tam and Wong, 1997). Most mangrove wetlands are located in developing countries where anthropogenic activities are frequent and usually cause irreversible environmental degradation (Serrano-Grijalva et al., 2011). In recent years, aquaculture activities have grown fast. Food and Agriculture Organization (FAO, 2012) forecasted that by the year of 2022, world fisheries and mainly aquaculture production would provide additional 22 billion kg fish. Aquaculture especially shrimp production has rapidly developed near mangrove forests.

Since intensive shrimp culture requires high input of pelleted feed, it generate large amount of organic wastes and unassimilated food. Shrimps only make use of approximately 20% of nitrogen added to ponds as shrimp food (Briggs and Fvnge-Smith, 1994) and most part is reserved in routine effluent as exchanged water between ponds and tide, as well as dredging effluent as sludge water from ponds during dredging periods. Related study also showed that phosphorus is considered to be one of the main limitations for plant production in tropical areas (Sanchez, 2002). Mangroves could absorb nutrients from wastewater and the wetlands are effective in removing organic matter, nitrogen, phosphorus and heavy metals (Moroyoqui-Rojo et al., 2012). Moreover, most mangrove species are highly sensitive to soil nutrient availability (Boto et al., 1985; Naidoo, 2009). Nutrient addition could promote stem elongation of dwarfed mangrove (Lovelock et al., 2006), increase branch number of *Avicennia germinans* (Whigham et al., 2009) and enhance leaf production (Feller et al., 2003a). After the sixth month, NPK addition resulted in an increasing growth of mangroves (Ribeiro et al., 2015). So we made hypotheses as follows: (1) The addition of routine effluent could promote growth of *K. obovata*; (2) Increasing discharge extent of dredging effluent (increasing sedimentation thickness above mangrove soil) could also promote growth of *K. obovata*.

During shrimp pond cleaning periods, the surface sediments in pond bottom soil are flushed by using high-pressure hydraulic giants, then the sludge water is usually discharged into coastal waters through mangrove floors. Therefore, some suspended solids from shrimp pond-dredging discharges cover over mangrove soil. These processes may also cause environmental problems including disease, environmental degradation and accumulation of black and glutinous sediments in pond bottom soil (Rosenberry, 1993; Shang et al., 1998). Numerous publications reported the adverse effects of shrimp aquaculture on water quality and biodiversity in both coastal lagoons and near-shore

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marine habitats as well as effects of urban sewage, livestock wastewater, chemical industry wastewater and oily wastewater on mangrove forests (Boaventura et al., 1997; Duke et al., 1997; Naylor et al., 2000; Karakassis et al., 2002; Ye and Tam, 2002; Burford et al., 2003; Trott et al., 2004; Bartolini et al., 2011; Ke et al., 2011; Donato et al., 2012). However, little attention was paid to the effects of effluents of shrimp ponds including both routine and dredging effluents on mangroves. Biochemical responses of mangrove plants to inorganic pollutants and environmental conditions have been extensively reported (Takemura et al., 2000; Ye and Tam, 2002; Ye et al., 2005; Caregnato et al., 2008). Ecological responses of mangrove plants to exogenous nitrogen include the increased or decreased abundance, changes in reproduction parameters or ecosystem functions (Bartolini et al., 2009).

As for shrimp ponds, researches were confined to the quality of wastewater purification without going into details of mangrove plants. Effects of routine and dredging effluents from shrimp ponds on growth of mangrove plants were rarely reported. In case of high nutrient concentrations in sediments of shrimp ponds containing uneaten feed, dead plankton, mineral soil, airborne debris, shrimp feces, etc. (Le et al., 2005; Vaiphasa et al., 2007; Zhang et al., 2011), discharges of pond-dredging effluent would inevitably affect mangrove ecosystems. Thus, questions need to be addressed were: Did the two types of nutrient effluent make different effects on the growth of mangrove plants? Can the dredging effluent be constantly discharge through mangroves?

In China, extensive aquaculture ponds especially shrimp ponds are located next to landward edges of most mangrove forests, and *Kandelia obovata* (i.e., *Kandelia candel* in previous publications) is a predominant mangrove species which has some pioneer properties and is considered as a main reforestation species (Chen et al., 2005). This species is found in all mangrove-distributed provinces in China. In our research, shrimp farms nearby mangrove areas discharge routine and dredging effluents into coastal waters through mangrove forests. Routine effluent is frequently produced during the exchange of water between ponds and tides, while dredging effluent only appears once in a year for one pond when aquaculture section finishes. Therefore, the former is essentially shrimp pond water with nutrient levels similar to tide water but frequently disturbs mangroves, while the latter is sludge water after cleaning the pond bottom with high contents of suspended solids (SS) rich in nutrients and might have cumulative effects on mangroves due to its sedimentation on mangrove soil.

The aim of the present study was to simulate the routine exchanged water and sedimentation condition of shrimp pond-dredging discharges into mangrove forests to quantify their effects on the early development of this species. Specifically, the objectives of this study were: (1) to explore effects of these two types of effluents from shrimp aquaculture on growth of mangrove plants; (2) to explore the extent of dredging effluent discharged through mangrove floor, i.e., sedimentation thickness of shrimp pond-dredging effluent above mangrove soil.

2 Materials and methods

2.1 *Materials*

Mature and healthy propagules of *K. obovata*, which had uniform size in similar length ((23.33±0.36) cm) and fresh weight ((18.08±0.59) g) were collected from mangrove forest (24°24′N, 117°55′E) along the Jiulong River Estuary in Fugong Town, Longhai County, Fujian Province of China (Fig. 1). This site has tropical coastal climate of South Asia, with regular semidiurnal tide. Mangrove forests were in the high tide zone and cannot be flooded during the neap tide each month. Annual average temperature was 21°C, with lowest monthly average temperature at 13°C in January. Annual precipitation was 1 365 mm; relative humidity was 81%; and mean annual sunshine duration was 2 040.5 h. Salinity in soil was 15–21 and pH was about 7.0. Vegetation community was artificial restoration of *K. obovata* pure forest in banding distribution, which was about 30 m width. Intensive shrimp ponds were widely distributed in landward side. Sampling area had poor drainage facilities and effluent from shrimp ponds was always directly discharged into the surrounding mangrove areas without treatment.

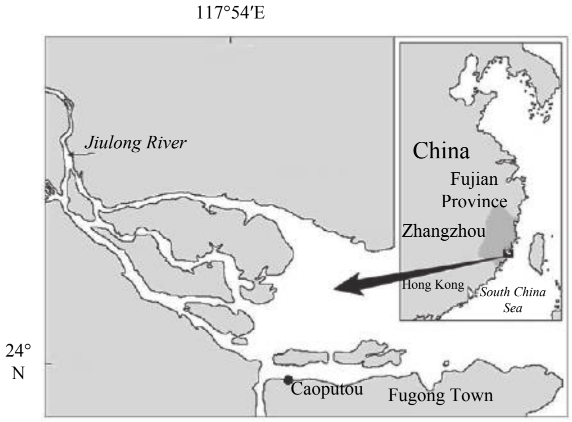

Fig. 1. Map of sampling area.

At the same area, mangrove soil was collected as greenhouse pot-cultivation substrates. In August 2008, routine effluent was collected from the outlet of one shrimp pond near the mangrove forest and stored at 4°C in laboratory as treating liquids used in experiment one. In May 2009, dredging effluent (sludge water), as sedimentation materials for experiment two, was collected from the same shrimp pond through the discharge pipe for dredging effluent after flushing the pond bottom with high-pressure hydraulic giants. In addition, artificial seawater was with different salinity levels of 5, 15 and 25 for experiment one, only one salinity level of 15 for experiment two. The salt used to prepare the artificial seawater was sun-dried with natural seawater at a sea salt field in Xiamen.

Some physico-chemical characteristics such as salinity, pH, SS, TN (total-nitrogen) and TP (total-phosphorus) of routine and dredging effluents from shrimp ponds, as well as those of artificial seawater were determined (Table 1). Compared with routine effluent, dredging effluent was nutrient rich in surface sediments of shrimp pond, which contained plenty of nutrients such as nitrogen and phosphorus. The collected mangrove soil was loamy with 24.04% of particles larger than 0.02 mm, pH 7.05, water content of 42.88%, organic matter content of 2.67%, TN content of 1.32 g/kg, and TP content of 0.81 g/kg. While the shrimp pond sedimentation was clay soil, 8.88% of which had particle size larger than 0.02 mm, pH of 7.34, the ratio of water content of 49.90%, organic matter of 1.94%, TN of 1.88 g/kg, and TP of 1.48 g/kg. Polyethylene pots used for plant cultivation had 21 cm diameter and 17 cm height, and each of them had three 1 cm diameter holes at the bottom to allow rapid drainage after being irrigated.

Table 1. Physio-chemical characteristics of routine and dredging effluent from shrimp ponds and artificial seawater used in this study

Water for treatments	Salinity	pH	SS/mg·L^{-1}	TN/mg·L^{-1}	TP/mg·L^{-1}
Routine effluent	5–15	7.66–7.83	143–152	4.72–5.92	1.33–1.72
Artificial seawater	5	7.70	0.00	2.02	0.03
Artificial seawater	15	7.84	0.00	2.38	0.05
Artificial seawater	25	7.96	0.00	2.53	0.10
Dredging effluent	15	8.20	192.93	377.24	286.44

Note: SS represents suspended solids, TN total nitrogen and TP total phosphorus.

2.2 *Routine effluent*

To test growth responses of *K. obovata* seedlings to routine effluent at different salinity levels, 18 pots were divided into six treatments, each of which had three replicates (pots). Four *K. obovata* propagules were planted in each pot with 5 kg mangrove soil (1/3 propagule length inserted into soil). At the beginning of this experiment, propagules were allowed to germinate and grow for three months, and there were no significant differences in stem height ((30.80±0.86) cm, F=0.634, P=0.678 from One Way ANOVA) and leaf number (9.03±0.15, F=1.288, P=0.331 from One Way ANOVA) of seedlings among the six treatments. The experimental design was a completely randomized block, with two fixed factors, salinity (three levels, 5, 15 and 25) and water quality (two levels, i.e., routine effluent, and artificial seawater as control). During the experimental period, for each routine effluent treated pot, 300 mL routine effluent was irrigated every two days according to the frequency of water exchange between most shrimp ponds and tide, and 300 mL artificial seawater was irrigated every day. For each control pot, we only irrigated 300 mL artificial seawater every day.

2.3 *Dredging effluent*

To examine growth responses of *K. obovata* seedlings to dredging effluent, another experiment was designed, with one fixed factor (sedimentation thickness due to dredging effluent) with four levels (treatments) of 0, 2, 4 and 8 cm due to different intensity of discharge of dredging effluent, and each treatment had three replicates (pots). Before planting propagules, substrates in pots of the four treatments were set up by (1) irrigating 800 mL artificial seawater of salinity 15 for 12 times to each of three pots with 5 kg mangrove soil as control pots (Treatment ST0); (2) irrigating 200 mL dredging effluent and 600 mL artificial seawater of salinity 15 for 12 times to each of three pots with 4.735 kg mangrove soil, and forming a final steady sedimentation thickness of 2 cm above mangrove soil by dredging effluent (Treatment ST2); (3) irrigating 400 mL dredging effluent and 400 mL artificial seawater of salinity 15 for 12 times to each of three pots with 3.75 kg mangrove soil, and forming a final steady sedimentation thickness of 4 cm above mangrove soil by dredging effluent (Treatment ST4); and (4) irrigating 800 mL dredging effluent for 12 times to each of three pots with 2.5 kg mangrove soil, and forming a final steady sedimentation thickness of 8 cm above mangrove soil by dredging effluent (Treatment ST8). Then *K. obovata* propagules were planted in each pot with 1/3 propagule length inserted into substrates. Before the start of this experiment, there were no significant differences in stem height ((15.05±0.33) cm, F=1.793, P=0.226 from One Way ANOVA) and leaf number (6.06±0.07, F=3.000, P=0.095 from One Way ANOVA) of seedlings among the four treatments. Since propagule plantation, this experiment lasted for 224 d during which each pot was irrigated with 300 mL artificial seawater of salinity 15 every day. All planted propagules successfully germinated and all seedlings survived the whole experimental period. Stem height, stem basal diameter, branch number, leaf number, leaf water content and succulence of seedlings were determined every month but only the final data are shown in results. At the end of this experiment, all seedlings were harvested, rinsed thoroughly with deionized water, dried at 70°C to constant weight for the measurements of biomass and its partition (ratio of leaf biomass, LMR; ratio of stem biomass, SMR; ratio of root biomass, RMR; and ratio of root biomass to shoot biomass, R/S). Besides, TN and TP were analyzed for different organ of *K. obovata* seedlings and different matrix treatments. All of the chemical analyses were followed by the standard methods as described by Allen et al. (1974).

2.4 *Statistical analysis*

Mean and standard error (SE) of each parameter were calculated for each treatment. For experiment one, differences in stem height, stem basal diameter, leaf number and leaf fall biomass between water quality levels and among salinity levels were tested by using a parametric two-way analysis of variance (ANOVA). For experiment two, one-way ANOVA followed by Duncan's New Multiple Range Test was used to isolate any significant difference among the four treatments. All the parameters were considered significant at P<0.05. Statistical analyses were performed by using IBM SPSS Statistics 22.

3 Results

3.1 *Effects of routine effluent on seedling growth of K. obovata*

At each of the three salinity levels 5, 15 and 25, shrimp pond wastewater (routine effluent) did not result in significant differences from the control in measured parameters of *K. obovata* seedlings (Fig. 2). Wastewater did not have a significant impact on stem diameter while salinity effect reached significant level. Treatment under salinity 25 can suppress growth of diameter. As for leaf number, no significant differences were found at salinity of 5 and 25 between two water levels. While leaf number under wastewater treatment increased 21.88% compared with the control at salinity of 15. Salinity level affected leaf number in which it was significantly lower in salinity of 25 than value in salinity of 15 under wastewater treatment.

3.2 *Effects of dredging effluent on seedling growth of K. obovata*

3.2.1 *Growth status*

Similar performance due to sedimentation of dredging effluent from shrimp ponds was found for the morphological parameters including stem height, stem diameter, branch number and leaf number of *K. obovata* seedlings after 224 d of experiment (Fig. 3). Compared with the control (ST0), the three treatments with 2 cm, 4 cm and 8 cm sedimentation thicknesses (ST2, ST4 and ST8) had higher or similar values of all of these parameters. Sedimentation thickness of dredging effluent had significant

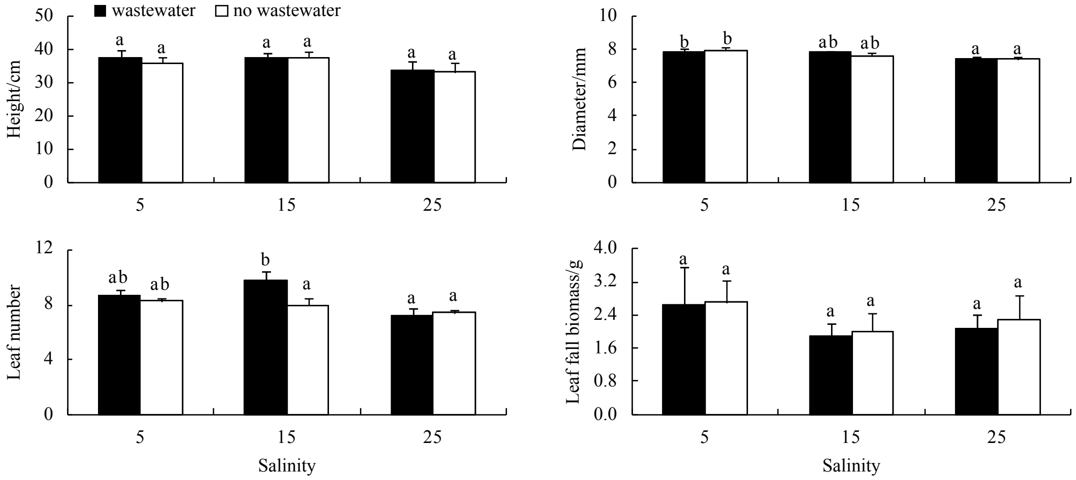

Fig. 2. Effects of shrimp pond routine effluent on stem height, stem diameter, leaf number and leaf fall biomass of *K. obovata*. Mean and SE (standard error) of three replicates and six treatments are shown. Different letters in each treatment indicate there were significantly different at $P<0.05$.

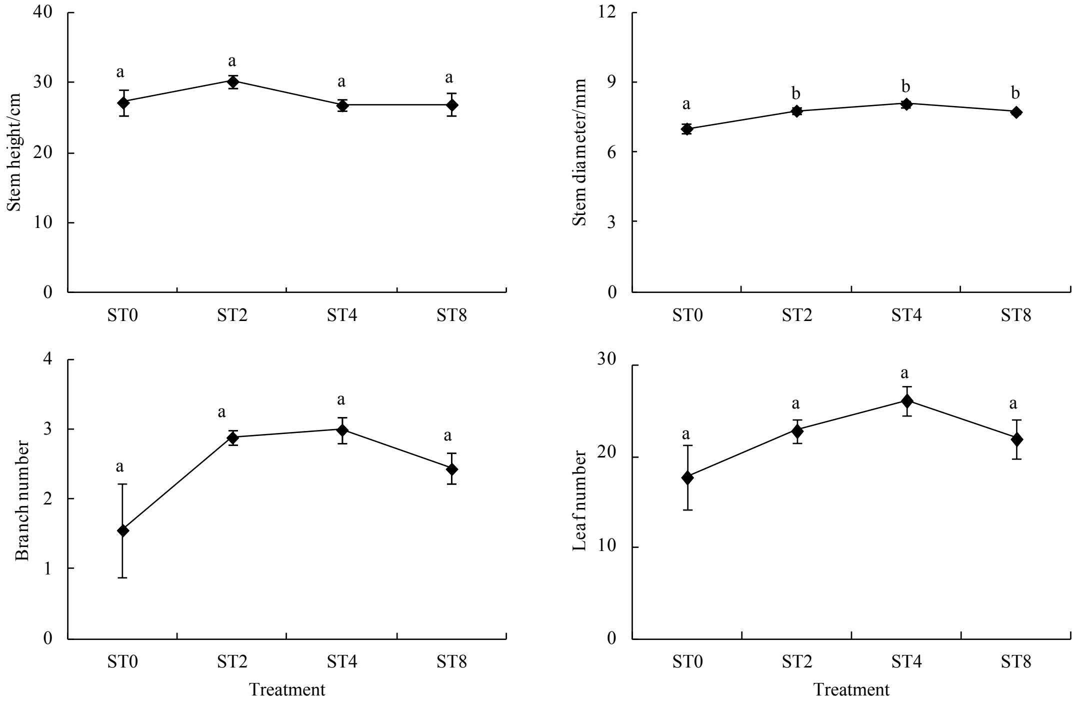

Fig. 3. Effects of simulated cumulative sedimentation thicknesses on stem height, stem diameter, branch number and leaf number of *K. obovata*. Mean and SE (standard error) of three replicates are shown, straight line with different letters in each treatment indicates significant difference at $P<0.05$ according to one-way ANOVA test. ST0, ST2, ST4 and ST8 represent cumulative sedimentation thicknesses of 0 cm (the control), 2 cm, 4 cm and 8 cm, respectively.

impacts on stem diameter ($F=9.762$, $P=0.005$).

The tendency of biomass parameters under sedimentation thickness of dredging effluent was similar to that of morphological parameters (Fig. 4). Maximum values were detected in ST2 or ST4. Significantly higher values of leaf biomass were occurred in treatments ST2 and ST4 than those in ST0 ($F=5.052$, $P=0.030$). However, this enhancement was weakened when dredging effluent further sedimented to 8 cm (ST8).

Accordingly, we calculated parameters of biomass partition (Table 2). LMR and SMR were favorable under ST2 or ST4 and their lowest values were found in ST0 or ST8. On the contrary, RMR and R/S were lowest under ST4 and highest under ST0.

Sedimentation of dredging effluent had significant effects on leaf water content ($F=4.325$, $P=0.043$) (Fig. 5). For all of the four treatments, the mean leaf water content varied within 72.88%–75.95%, and the mean values of leaf succulence were 3.42–3.91 g/dm^2. Both parameters had similar change patterns with sedimentation thickness, and increased when the sedimentation thickness increased from 0 to 4 cm, except for the values of ST8 which were lower than ST4. Besides, we measured soil conductivity at the end of our experiment. They were 4.52, 4.73, 5.67 and 6.57 mS/cm under treatment ST0, ST2, ST4 and ST8, respect-

Table 2. Effect of simulated sedimentation thickness on biomass allocation of *K. obovata*

Treatment	LMR	SMR	RMR	R/S
ST0	0.32±0.01^{a}	0.33±0.01^{a}	0.35±0.00^{a}	0.54±0.03^{a}
ST2	0.35±0.01^{a}	0.34±0.02^{a}	0.31±0.03^{a}	0.45±0.07^{a}
ST4	0.38±0.01^{a}	0.33±0.01^{a}	0.29±0.00^{a}	0.41±0.01^{a}
ST8	0.36±0.01^{a}	0.32±0.02^{a}	0.31±0.03^{a}	0.46±0.05^{a}

Note: Means and SE (standard error) are shown. SEs with different letters in each treatment indicates significant difference at $P<0.05$ according to one-way ANOVA test. LMR, SMR, RMR and R/S represent ratios of leaf biomass, stem biomass, root biomass and root/shoot, respectively. ST0, ST2, ST4 and ST8 represent simulated sedimentation thicknesses of 0 cm (the control), 2 cm, 4 cm and 8 cm, respectively.

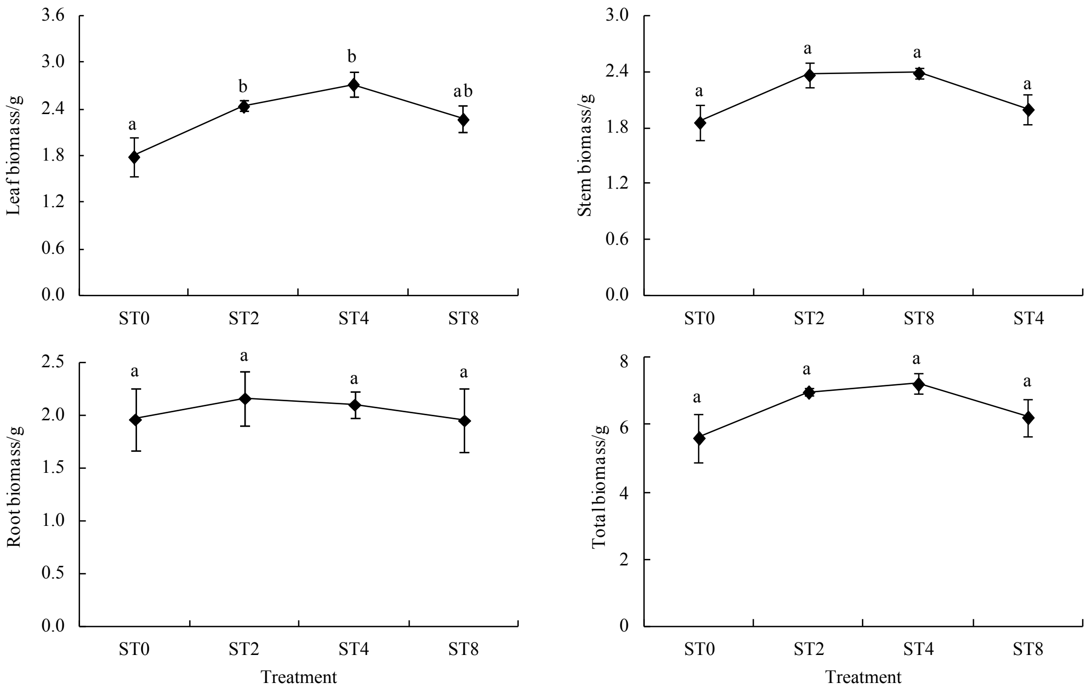

Fig. 4. Effects of simulated cumulative sedimentation thicknesses on biomass of *K. obovata*. Mean and SE (standard error) of three replicates are shown, straight line with different letters in each treatment indicates significant difference at $P<0.05$ according to one-way ANOVA test. ST0, ST2, ST4 and ST8 represent cumulative sedimentation thicknesses of 0 cm (the control), 2 cm, 4 cm and 8 cm, respectively.

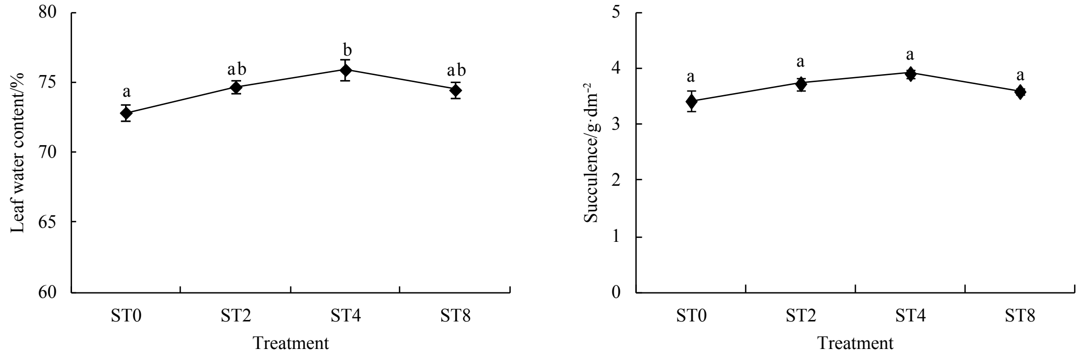

Fig. 5. Effects of simulated cumulative sedimentation thicknesses on leaf water content and succulence of *K. obovata*. Mean and SE (standard error) of three replicates are shown, straight line with different letters in each treatment indicates significant difference at $P<0.05$ according to one-way ANOVA test. ST0, ST2, ST4 and ST8 represent cumulative sedimentation thicknesses of 0 cm (the control), 2 cm, 4 cm and 8 cm, respectively.

ively.

3.2.2 *Nutrition status*

Table 3 showed nutrient content of different matrix treatments and changes of nitrogen and phosphorus content in different organs of *K. obovata* at the end. Dredging effluent significantly affected MN (nitrogen content in matrix) and MP (phosphorus content in matrix) under our four treatments (MN: $F=12.693$, $P=0.002$; MP: $F=7.828$, $P=0.009$). Both two indexes increased with adding of sludge. Nitrogen content in different or-

Table 3. Nitrogen and phosphorus content in different matrix treatments and *K. obovata* organs at the end

Item/g·kg^{-1}	ST0	ST2	ST4	ST8
MN	1.36 ± 0.03^{a}	1.39 ± 0.04^{a}	1.41 ± 0.04^{a}	1.61 ± 0.02^{b}
MP	0.77 ± 0.02^{a}	0.83 ± 0.02^{a}	0.87 ± 0.04^{ab}	0.96 ± 0.04^{bc}
LN	13.71 ± 0.06^{a}	13.73 ± 1.82^{a}	14.04 ± 1.61^{a}	13.17 ± 0.86^{a}
SN	5.47 ± 0.95^{a}	6.19 ± 0.50^{a}	9.55 ± 1.96^{a}	7.01 ± 0.19^{a}
RN	5.15 ± 0.55^{a}	5.97 ± 0.14^{a}	5.91 ± 0.78^{a}	5.78 ± 0.68^{a}
LP	2.47 ± 0.25^{a}	2.56 ± 0.22^{a}	2.49 ± 0.17^{a}	2.61 ± 0.13^{a}
SP	1.92 ± 0.03^{a}	2.09 ± 0.14^{a}	2.49 ± 0.18^{a}	2.36 ± 0.15^{a}
RP	4.43 ± 0.03^{a}	4.54 ± 0.30^{a}	5.71 ± 0.39^{b}	5.85 ± 0.20^{b}

Note: Means and SE (standard error) are shown. SEs with different letters in each treatment indicate significant difference at $P<0.05$ according to one-way ANOVA test. MN and MP represent nitrogen and phosphorus content in matrix; LN, SN and RN represent nitrogen content in leaf, stem and root of *K. obovata*; LP, SP and RP represent phosphorus content in leaf, stem and root of *K. obovata*. ST0, ST2, ST4 and ST8 represent simulated sedimentation thicknesses of 0 cm (the control), 2 cm, 4 cm and 8 cm, respectively.

gans reached top in ST4 or ST2. Phosphorus content of root in ST4 was significantly higher than ST0 (F=7.736, P=0.009).

4 Discussion

In natural conditions, mangrove habitat is lacking of nutrients (Tomlinson, 1986; Wang et al., 2003). Many studies showed that most mangrove plants were sensitive to changes of nutrients (Boto et al., 1985; Feller, 1995; Yates et al., 2002; Feller et al., 2003b; Naidoo, 2006). Besides, adaptation to salinity levels vary by mangrove species (Downton, 1982; Clough, 1984; Kao et al., 2001) and it was reported that an increase in NaCl from 85 to 430 mmol/L significantly reduced the growth of seedlings of *K. candel* (Kao et al., 2001). However, routine effluent from shrimp ponds in our study did not result in predicted significant differences in seedling growth of *K. obovata* at each of the designed salinities (5, 15 and 25), even though the experiment lasted for 14 months, longer than most of other experiments on mangrove seedlings. It is different from discharge of livestock wastewater with NH_4^+-N and PO_4^{3-}-P contents of 36.1 and 53.7 mg/L which significantly enhanced seedling growth of *K. candel* (i.e., *K. obovata*) collected from Wong Chuk Wan mangrove swamp of Hong Kong after 144 d of treatment in greenhouse pot-cultivation systems (Ye and Tam, 2002). The reason might be that nutrient levels of routine effluent in our present study were not sufficient enough to significantly affect mangroves. For example, TN contents of routine effluent were 4.72–5.92 mg/L, at the same magnitude order as DIN contents (1.553–1.904 mg/L) of tide water at the Jiulong River Estuary during tide flooding periods in July 2012 (Qiu and Ye, 2013), indicating that routine effluent had nutrient levels similar to waters adjacent to mangrove forests. Since influence of shrimp pond routine effluent is a long-term process and mangrove nature reserve in the Jiulong River Estuary has appeared to degrade in varying degree, we recommend strengthening the management to avoid discharging of routine effluent without any effective purification.

For mangrove species, because of low concentration of nitrogen and phosphorus in matrix (Boto and Wellington, 1983), nutrient content in habitat had the most direct impact on nutrient elements in mangroves. Sediments were rich in nitrogen and phosphorus when clearing shrimp ponds (Burford and Lorenzen, 2004; Hossain et al., 2009). At the end of our experiment, the maximum values of TN and TP content were mostly detected in ST4 and ST8, and discharge of moderate amount of dredging effluent can promote growth of mangrove plants theoretically. Several studies have shown mangrove wetlands were good for TN and TP removal efficiency (Sansanayuth et al., 1996). Boto and Wellington (1983) reported that adding nitrogen and phosphorus in mangrove communities would promote plant growth and lead to addition of nutrient content in plants. However, there was no significant difference in leaf nitrogen content among our four groups, it followed an order of ST4 > ST2 > ST0 > ST8. Probably like previous studies, excessive phosphorus fertilization may cause plant lodging, undesirable delayed senescence at later stages of growth and deterioration of grain quality (Drinkwater and Snapp, 2007; Subedi et al., 2007). Excessive phosphorus fertilizers caused environmental pollution and increased production cost (Li et al., 2016). In our study, maximum values of nitrogen and phosphorus content in leaf, stem and root were mostly detected under small amount of dredging effluent (2 cm and 4 cm), which indicated suitable amount of sludge under 8 cm in our study was beneficial to nutrition absorption. This means utilization of dredging effluent from shrimp pond has a threshold. Accumulating sedimentation above or below the threshold in environment is not conducive to absorption of mangroves.

Unlike routine effluent, dredging effluent had high loads of nutrients such as nitrogen and phosphorus which chronically cumulated into shrimp pond sediments mainly as shrimp feces, unassimilated food, and residues (Páez-Osuna, 2001; Trott et al., 2004; Anh et al., 2010). Nutrient and particulate matter exported from shrimp ponds have been determined in some experiments (Xie et al., 2004). Study in South China reported that shrimp pond sediment wash-out resulted in TN loading of 71.284 g/(m^3·a), and TP loading of 35.386 g/(m^3·a), respectively, 100–1 000 times higher than the loading from tidal water exchange (Wu et al., 2014). In our experiment, dredging effluent had TN of 377.24 mg/L and TP of 286.44 mg/L, which were 79.92–63.72 times and 215.37–166.53 times of those in routine effluent. Among four sedimentation thickness treatments (0 cm, 2 cm, 4 cm and 8 cm), ST4 had the highest values for almost all measured morphological parameters. That is, enhancement of dredging effluent to seedling growth of *K. obovata* was more obvious under moderate retention quantity of dredging effluent into mangrove forests and this impact would decrease with the further sedimentation of dredging effluent. Our result was consistent with a study of effects of residential sludge on growth parameters of *Acacia auriculiformis*: study recorded that the concentrations of nitrogen and phosphorus were highest in T4 (soil + residential sludge = 1:1) but the growth and biomass of seedlings were the maximum in T5 (soil + residential sludge = 2:1) (Hossain et al., 2009). During our experiment, each dredging effluent irrigation treatment especially ST4 group was leafy and had stout branches. It is different from the control group which branched less and had leaves in light green. This phenomenon also indicated that addition of dredging effluent with nutrition could promote the growth of *K. obovata* in a certain extent, in contrast to lacking of nutrition in control group.

It is an ecological adaptation when plants faced mineral element variation. Changing of nutrient supply in environment would change plants biomass and could lead to changing of nutrient allocation proportion in different organs (Ibrahim et al., 1998). After 224 d of culturing in our experiment, leaf biomass under treatment was significantly higher than the control and the maximal leaf, stem and total biomass was observed under ST4. This result was consistent with previous report that plant biomass in wetlands would increase with applying of nitrogen (Mitsch et al., 1994). However, our further sedimentation over ST4 of dredging effluent resulted in low biomass and biomass of ST8 was closest to ST0. It showed biomass of *K. obovata* increased following addition of shrimp pond dredging effluent rich in nitrogen and phosphorus, but slowed down after reaching a certain amount of irrigation. It is similar to the results from Chen et al. (1995) that *K. obovata* seedlings treated with natural municipal wastewater had higher biomass than those in concentrated wastewater which contained five and ten times of the nutrients.

Increases in biomass and shifts of biomass from roots to shoots are well-documented responses of mangroves to soil nitrogen and phosphorus enrichment (Linder and Rook, 1984; Naidoo, 2009). Similarly, nitrogen enrichment increased the biomass of all aboveground plant parts of *Cyperus iria* (Awan et al., 2015). In terms of biomass partition, *K. obovata* seedlings in our study had the highest LMR and lowest RMR at ST4, which means *K. obovata* allocated more biomass to the ground part especially to leaves. For ST0 lacking of nutrition, plants allocated more biomass to roots, which may be beneficial to absorption of mineral elements. Our study validated the optimal allocation theory that plants would allocate more biomass in order to increase the restrictive function of organ or part of the resource utilization (Bloom et al., 1985). Study also showed that in order to assimilate adequate nutrients, roots prolifically grew into substrates with low nutrient levels, and plants take advantage of nutrient patches by increasing total root length and fine root production (Blair and Perfecto, 2001; Hodge, 2004).

Leaf water content is an indirect parameter reflecting plant growth, and high values were related with rapid metabolic and growth rates of *K. obovata* seedlings treated with wastewater (Chen et al., 1995; Ye et al., 2003). Severe water stress reduced leaf area and, consequently, reduced photosynthesis and affected metabolism, resulting in stunted growth (Lisar et al., 2012). Our study also reflected that addition of dredging effluent promoted metabolism of *K. obovata* seedlings in some degree. Leaf water content of *K. obovata* seedlings significantly increased due to sedimentation of dredging effluent at ST4 from shrimp ponds, which enhanced their growth. Soil conductivity was 4.52, 4.73, 5.67 and 6.57 mS/cm, increasing with sedimentation thicknesses, which had positive correlation to salinity at the end of our experiment. Previous studies showed that succulent leaves can store large amounts of water to reduce salt concentration and increases in leaf succulence are one of the indicators of halophytes to high salinity stress (Jennings, 1968; Short and Colmer, 1999). In the present study, sedimentation of dredging effluent increased leaf succulence of *K. obovata* seedlings and level of leaf succulence followed the order of ST4 > ST2 > ST8 > ST0. This maybe because increasing ion concentration in the matrix of dredging effluent influenced water absorption and caused osmotic stress. From this index, increasing succulent degree under our treatment enhanced adaptability to salt stress from dredging effluent. However, the adaptability reduced when filling thickness reaches 8 cm, indicating high sedimentation (ST8) resulted in negative effect on seedling growth compared with the moderate sedimentation (ST4) and it was not conducive to long-term growth of *K. obovata* under environment of this substrate.

Comprehensively, discharge of shrimp pond effluent especially dredging effluent is not suitable for the growth of *K. obovata* in the long run. The mangrove soil we collected was loamy with 24.04% of particles larger than 0.02 mm while shrimp pond sedimentation was clay soil, 8.88% of which particle size larger than 0.02 mm. This particle size factor may influence growth of plants since research showed that growth of mangrove had positive correlation with percentage of sediment particle size greater than 0.02 mm (De Lange and De Lange, 1994). Moreover, physical and chemical properties of mangrove soil will change after sewage irrigation of shrimp ponds, such as low permeability (Yap, 2000), which may make it difficult for reforestation. Study in Pak Phanang, Thailand, confirmed that the excess sediments discharged from nearby shrimp ponds reduced mangrove growth rates and increased mortality rates. Besides, comparison between four dominant mangrove species revealed that different mangrove species could tolerate different sedimentation depth: *Avicennia marina* could tolerate sedimentation rates of >6 cm/a (Vaiphas et al., 2007). Since shrimp pond sediment is clay soil and soil particle composition is an important ecological factor affecting other physic-chemical and biological characteristics of soil, further cumulative effect may be not suitable for growth and evolution of mangrove plants. In our experiment, addition of routine effluent hardly promotes growth of *K. obovata* and increasing discharge extent of dredging effluent (increasing sedimentation thickness above mangrove soil) could not always promote growth of *K. obovata*, with growth conditions in ST8 slightly higher or close to ST0. We infer that *K. obovata* could tolerate sedimentation rates of <8 cm/a. Thus, we advise controlling discharge of shrimp pond effluent, otherwise, it will eventually affect the function of the mangrove ecosystem.

5 Conclusions

Comprehensively, there was no expected promotion effect to growth of *K. obovata* from the two types of nutrient effluents. Although discharge of dredging effluent at a moderate strength (sedimentation thickness under 8 cm over mangrove soil) would enhance *K. obovata* growth, further dredging effluent should be prohibited in the study site because of the possible harmful substances in dredging effluent in addition of nutrients. Besides, shrimp pond sediment was clay, and changes in matrix characteristics may influence growth of mangroves. Since mangrove ecosystems are endangered in China, enrichment of shrimp pond sediments into mangrove system must be controlled. Management should be enforced in order to protect both mangroves and aquaculture development. Moreover, our study was based on laboratory culture while other effects may have in field condition. Further studies are needed to investigate the long-term and harmful substances in shrimp farm effluent.

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