Executive Summary

This study was conducted in line with the project Revitalization of Tsui Ping River carried out by Drainage Service Department (DSD). This study consists of two parts: (1) laboratory scale tests on selected plant species; (2) on-site planting trial of in-stream and floating plantation at an urban engineered channel. The objectives of this R&D Study are:

- To compare the ability of different plant species of different river zones in accumulation and removal of pollutants in synthetic river water;
- To compare the performance of batch and continuous flow experiments in the removal of the pollutants for each plant species;
- To investigate the removal rates of different pollutants in the tested plant-soil combination and clarify its relationship with changes of biomass;
- To identify the most tolerant species in water logging condition.
- To identify aquatic plant species that will survive in the channel and adaptability of the species for the given environment
- To identify plant fixing systems that will allow the plants to survive under both dry and wet seasons in particular during flooding of the channel; and
- To provide design recommendations and operational experience for selecting the appropriate planting works for adoption in urban engineered channels.

Part 1: Laboratory Study on Planting Trial

Methodology

A total of 21 plant species, including mangroves, shrubs, and herbs were tested in lab-tanks and fed with controlled carbonaceous pollutants and nutrients. The growing conditions were designed to simulate the field conditions, including tidal differences, salinities, and water flow. The concentrations of the pollutants were monitored over time to understand the dynamic changes of pollutants degradation; and the biomass were weighted by sections after the experiments. The targeted water channel receives high organic pollutants from domestic outfalls. The restoration project has divided the watershed into 3 zones, *i.e*., from upstream to downstream, including a freshwater zone (Zone A), a brackish water zone (Zone B) and a seawater zone (Zone C). The average flow rate is approximately 57,508 m^3/d and the chemical oxygen demand (COD), ammonia (NH_4^+), and dissolved oxygen (DO) of the river water were 28.4, 1.0, and 7.2 mg/L, respectively.

The plant species investigated in this project include *Colocasia tonoimo* (CT), *Panicum maximum* (PM), *Saururus chinensis* (SC), *Acorus calamus* (AC_a), *Thalia dealbata* (TD), *Alocasia macrorrhizos* (AM), *Alisma plantago-aquatica* (APA) for Zone A; *Typha orientalis* (TO), *Juncus effuses* (JE), *Crinum asiaticum* (CrA), *Commelina diffusa* (CD), *Cyperus alternifolius* (CyA), *Phragmites australis* (PA) for Zone B; and high saline species, *Aegiceras corniculatum* (AC_c), *Kandelia obovate* (KO), *Bruguiera gymnorrhiza* (BG), *Acanthus ilicifolius* (AI), *Acrostichum aureum* (F) and *Clerodendrum inerme* (CI) for Zone C, where most of the plants were true mangroves. Before experiments, the plant species employed in Zone A, B, and C were cultivated in 0 ppt, 5 ppt and 15 ppt saline water with pollutant-free condition for 15 days. After 15-days of acclimation, experiments started and synthetic stormwater was added into each tank. Water samples in each tank would be taken at day 0, 1, 3, 7, 15, and 30 for analysis.

Lab-scale water tanks were constructed with dimensions of 150 cm length, 30 or 40 cm width, and 50 cm height. The differences of 40 cm and 30 cm in width were applied for comparatively the bigger tree/shrub species and smaller herbal species, respectively. A total of nine plant (same species) were evenly placed in a tank. The water depth from the soil surface was approximately 10 cm. Synthetic water with 16.4 mg/L ammonia, 164 mg/L peptone and 44 mg/L glucose was employed in the experiments. In order to match the changed salinities in different zones, 0 ppt, 5 ppt and 15 ppt concentrations of coral salts were employed in Zones A, B and C, respectively. To simulate the tidal effects, the tested plants were kept in water (high tide) for 16 hours and taken out from the water for 8 hours (low tide). The batch experiments (with static flow) and continuous flow experiments (with flow rate of 3-8 L/s) were conducted simultaneously, where pump originated power to support continuous flow experiments.

Plant height and leaf number of each species were recorded. Fresh biomass of each part (leaf, stem, and root) of the plant was weighted after segregation, then each part of the plant was taken for dry weights. The samples were oven-dried at 80 °C until constant weights. The total dry biomass weight of each plant was calculated by summation of the weight of all the samples.

Results

Biomass tests

The changes of physical properties of the tested plant species are presented in **Figure 1**. For plant species in Zone A, the heights of plants showed a wide variation from 39.3 cm to 127.4 cm (day 30), and the height in batch and continuous flow experiments were similar. All the plant heights at day 30 were slightly lower than that at day 0. Leaf number of all plant species were nearly same except for SC. The average leaf number of SC by day 30 in batch experiment were 47.4 and accounted for roughly half of that in continuous flow experiment of 73.9. In general, almost dry biomass weight of plants in continuous flow was more than that in batch. In Zone B, the heights of plant were ranged from 13.8 cm (CrA) to 71.4 cm (JE) at day 30. Among the heights of all plant species, CrA gained the maximum increase of 186% and 47% in batch (from 9.3 cm to 26.72 cm) and continuous flow experiments (from 9.3 cm to 13.8 cm), respectively. EH showed the highest reduction rate of 38% in height in both batch and continuous flow experiments, respectively, which was decreasing from initial 56.4 cm and 55.7 cm to 34.8 cm and 34.7 cm by day 30. Leaf number at day 30 showed a wide variation from 6.3 to 116.3. The maximum falling of leaves was observed in CD, whose average leaf number in batch and continuous flow experiments reduced from 191.4 and 227.5 to 96.3 and 116.3, respectively. CD showed up to 32% height reduction compared to initial value. CD was observed to be intolerant to 5 ppt saline water early in the acclimation period (*i.e.*, no pollutants), which was confirmed by control experiments. There was a litter difference between the results in batch and continuous flow experiments. Initial biomass of CyA, TO and EH decreased from 51.4 g, 32.6 g and 67.8 g to approximately 32 g, 20 g, and 33 g in both batch and continuous flow experiments, while PA, SS and CrA showed a significantly increase rate of 290%, 113% and 265%, respectively. For Zone C, the highest value was obtained from A whose height was more than 70 cm throughout whole experimental period. All height of plant species kept relatively stable throughout 30-day growing, except the height of F, which dropped from 53.8 cm to 42.9 cm in batch experiment and decreased from 34 cm to 29.95 cm in continuous flow experiment. In both batch and continuous flow experiments, the leaf number varied from 8.6 to 66. Compared to the initial values, average leaf number reduced 9.5% and 1.9% in batch and continuous flow experiments.

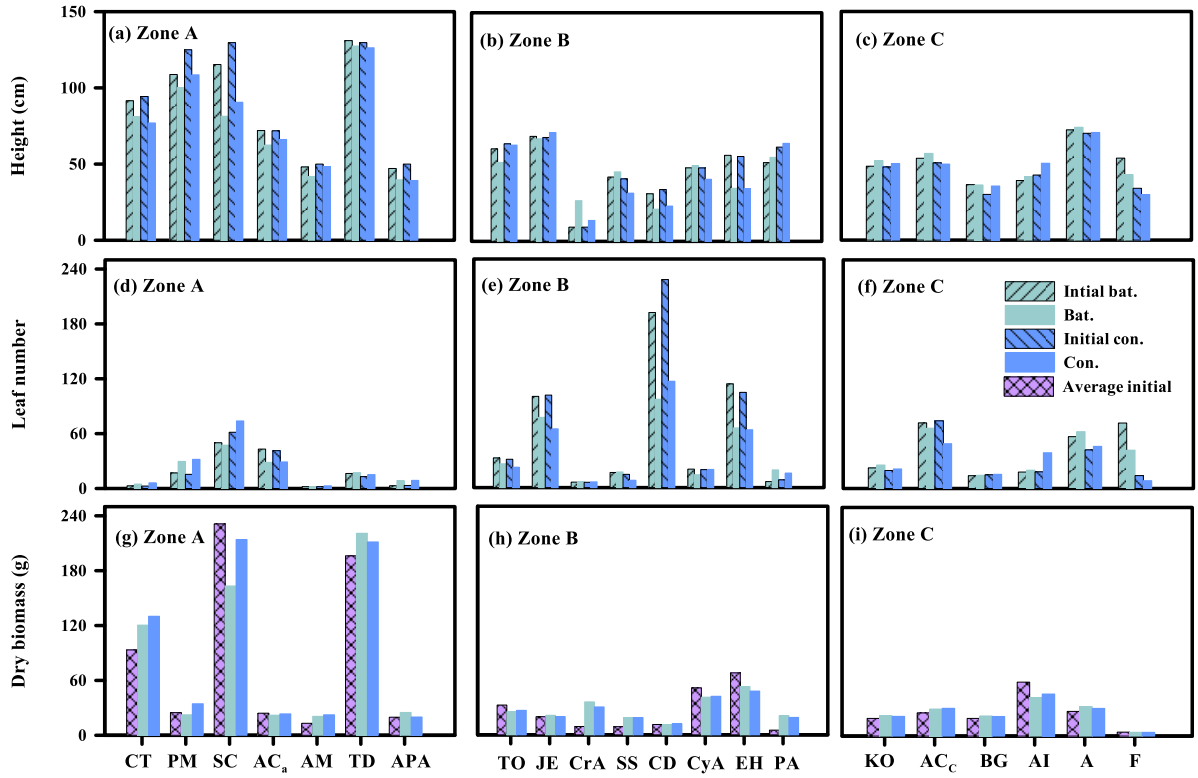


Figure 1 Physical properties of plant species

Water quality improvement

The results of three water quality parameters (TOC, COD, and NH_4^+) per unit mass biomass was shown in **Figure 2**. Pollutants per unit biomass fitting curves were constructed based on calculated data, represented by dash lines. Second order kinetics were found to be applicable to simulate the COD and TOC degradation, while exponential fits were applicable to NH_4^+. The curves showed reliable fitting with almost all R^2 of equation ranged from 0.85 to 0.98. TOC in continuous flow and COD in both flow patterns treated by AI; TOC and COD in both flow patterns treated by F performed poor fitting by all models. It was observed that leaves of F were shrinkage from day 7 to the end, and leave of AI fell and yellowed stared from day 7. These poor growth condition of F and AI may cause irregular pollutants per unit dry biomass and invalid fitting.

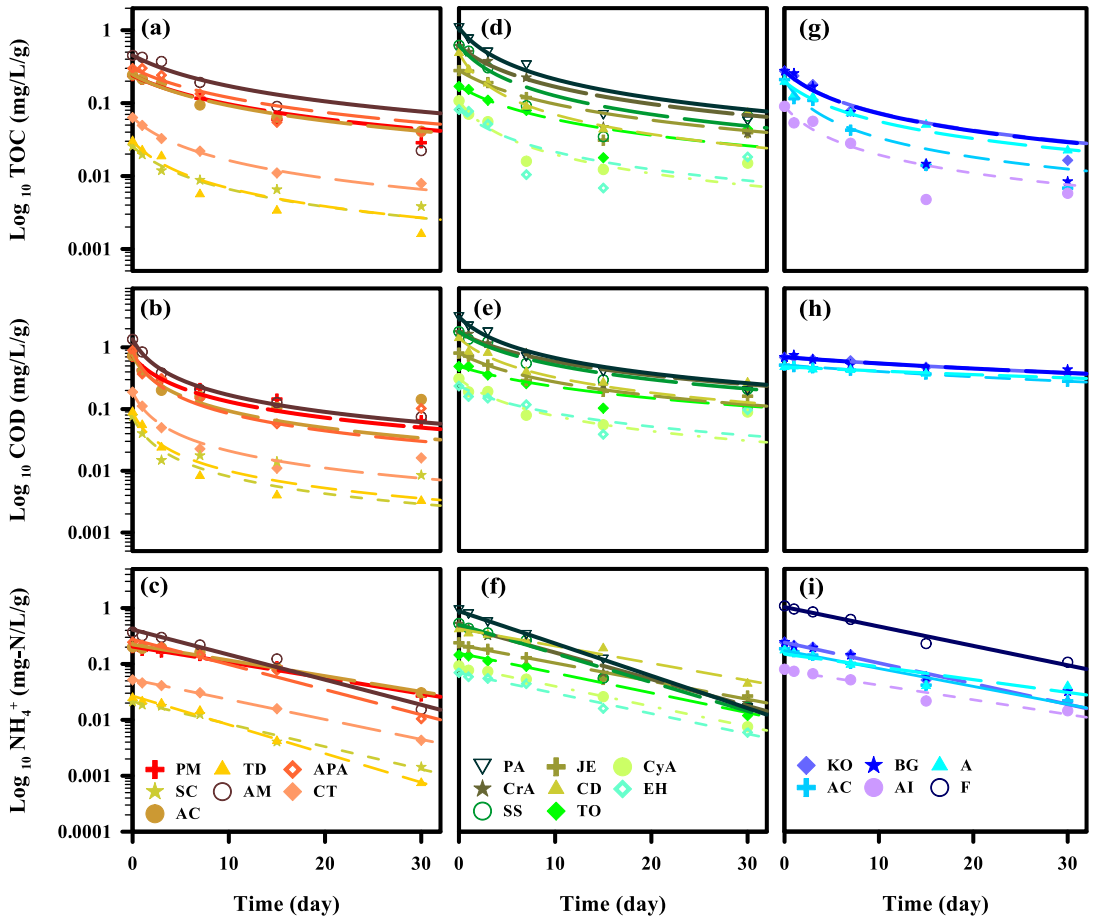


Figure 2 Pollutants per unit biomass in batch experiments in Zone A, B and C (a, b, and c for Zone A; d, e, and f for Zone B; g, h, and I for Zone C)

According to the curve fitting equations and their parameters, half-life coefficients ($t_{1/2}$) of each species were calculated for the degradation of three pollutants by 21 plant species in synthetic stormwater were revealed in **Figure 3**, of which **Figure 3** (a) and (d) described $t_{1/2}$ of TOC, COD and NH_4^+ treated by seven species in Zone A, including CT, PM, SC, AC[a], TD, AM and APA. In both of batch and continuous flow experiments, $t_{1/2}$ by all species followed the order of NH_4^+ > TOC > COD. The results indicated COD were the easiest to remove ($t_{1/2}$ of COD ranged from 0.81 to 2.26 days), and NH_4^+ require longer time to be degraded ($t_{1/2}$ of NH_4^+ ranged from 6.4 to 12.2 days). Compared to $t_{1/2}$ of NH_4^+ and TOC in batch experiments, $t_{1/2}$ in the continuous flow experiments were obviously shorter. There was no large difference between $t_{1/2}$ of COD in batch and continuous flow experiments. The $t_{1/2}$ of COD in Zone B and C in continuous flow experiments were shorter than that in batch experiment. The continuous flow can promote pollutants degradation due to more rapid gas transfer and higher DO in the processes. In Zone A, $t_{1/2}$ of TOC in both flow patterns varied from 2.0 to 6.7 days, that of TD and CT were shorter than other species. TD also can remove NH_4^+ with the fastest rate among all species in Zone A, whose $t_{1/2}$ was both 6.5 days in batch and continuous flow experiments. All the average DO was higher in continuous flow experiments than the batch systems. The $t_{1/2}$ of pollutants treated in Zone B were shown in **Figure**

3 (b) and (f). Eight species were cultivated with 5 ppt salinity, including TO, JE, CrA, SS, CD, CyA, EH and PA. The $t_{1/2}$ of TOC varied from 1.7 to 5.7 days. CD, CyA and PA had higher removal efficiency of TOC, whose $t_{1/2}$ varied from 1.7 to 2.9 days. The COD curves presented a considerable variation in $t_{1/2}$ (2.3-8.8 days). The shorter $t_{1/2}$ were from PA (2.8 days and 2.7 days for batch and continuous flow, respectively). NH_4^+ was more difficult to remove than TOC and COD, whose $t_{1/2}$ ranged from 3.8 to 9.9 days. CrA and PA can remove NH_4^+ with the fastest rate than other species in Zone B, and TO and EH had lower pollutants removal efficiency with longer $t_{1/2}$. For Zone C, six plant species, *i.e.*, KO, AC_c, BG, AI, A and F, were tested, and the results of $t_{1/2}$ were demonstrated in **Figure 3** (c) and (g). The $t_{1/2}$ of TOC ranged from 0.50 and 3.95 days, and the $t_{1/2}$ of NH_4^+ varied from 5.6 to 10.6 days. AI have poor capability in COD removal, even possibly deteriorate aquatic quality due to poor growing conditions. F were noted that leaves shrinkage from day 7 to the end of experiments. This health condition may lead to disorder TOC and COD degradation and hence not considered in our discussion.

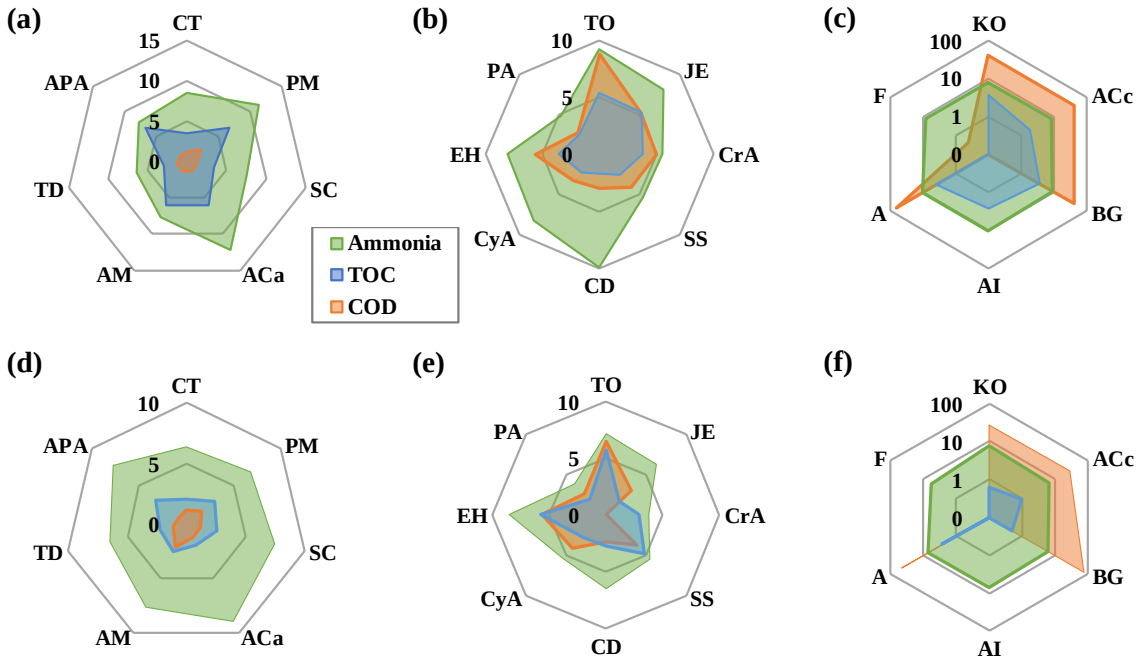


Figure 3 Half-life ($t_{1/2}$) of pollutants treated by 21 plant species

Conclusion

The half-life coefficients ($t_{1/2}$) of pollutants demonstrated that five particular plant species (*i.e.*, CT, TD, CrA, PA, KO and AC_c) have more significant capabilities for water purification. The gradual decreases of COD half-life in freshwater (1.04-2.26 days), brackish water (2.33-8.80 days), and sea water (27.19-75.08 days) plants indicated that increased salinity or plant species with high tolerances to sea water showed less tendency absorbing the COD. EH and SS were regarded to be improper species in the testing environment, as they suffered from frequent defoliation or stand fall during experiments. Based on the experiment results, the recommended plant species with proper performance on water purification were provided in **Table 1**. However, pollutant removal shall serve only an extra function of greening and cannot be treated as the main water purification approach in watershed restoration.

Table 1. Recommended species

Locations	Zone A	Zone B	Zone C
Recommended species	*Colocasia tonoimo*	*Crinum asiaticum*	*Kandelia obovate*
	紫芋 (CT)	文殊蘭 (CrA)	秋茄 (KO)
	Thalia dealbata	*Phragmites australis*	*Aegiceras corniculatum*
	再力花 (TD)	蘆葦 (PA)	蠟燭果 (AC^c)
	Saururus chinensisv	*Scaevola sericea*	*Acanthus ilicifolius*
	三白草 (SC)	海草桐 (SS)	老鼠簕 (AI)

Part 2: On-site Planting Trial

Methodology

Four types of trial submerged planting systems, named soil berm with boulders, palm rock, ecological bags and grasscrete were used in the trial. Two types of trial floating island planting systems named biodegradable coir filled mat and plastic pot were used in the trial. All the trial submerged planting systems were installed in Zone A, B and C while the trial floating island planting systems were only installed in Zone C. 33 plant species were tested in this planting trial. For each species, 5 plants were planted on each planting system. A 20-month establishment and monitoring period started in May 2018.

Results

The planting systems were damaged with different extent during the heavy rainstorms in 6-8 June 2018. To provide better flood resistance to the submerged planting systems, an enclosure system was developed to provide better resistance to the flow and strengthen the submerged planting systems. The enclosure system consisted of a steel plate enclosure and a reinforcement mat structure. The strengthening works were completed in May 2019. In general, all submerged planting systems were well retained after the strengthening works, although loss of soil was identified. The Biodegradable Coir Filled Mat retained very well after the strengthen works.

Conclusion

High strength turf reinforcement mat should be used and the planting openings on the mat should be stitched well after planting works as to minimize soil lost from the top of the plating system. The submerged planting systems should be recessed type and with steel plate enclosure. Ecological bag planting system was recommended to be used in Zone A because it contained higher amount of soil which facilitated the growth of plant. Palm rock planting system was recommended to be used in Zone B and Zone C because the soil and plant were elevated by the plam rock, continuous submergence of plant root could be avoided. The biodegradable coir filled mat floating island system with further reinforcement using steel wire was recommended.15 planting species were recommended to be planted on site. Pre-planting of plants on the precast planting systems in a nursery was recommended to allow enough time for root anchoring into the planting system.