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Xiao-Ling Tong
Ocean College, Zhejiang University, Hangzhou, China. The Second Institute of Oceanography, Hangzhou, China.

Tsung-Yi Lin
Department of Geography, National Taiwan Normal University, Taipei, Taiwan, R.O.C, aeolin@ntnu.edu.tw

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DUNE RESTORATION EXPERIMENTS DURING A TYPHOON SEASON ON TAIWAN'S SI-CAO COAST

Xiao-Ling Tong[1, 2] and Tsung-Yi Lin[3]

Key words: dune restoration, typhoons, sand fence, vegetation coverage.

ABSTRACT

The restoration of coastal dunes, a common form of soft protection, can not only save considerable construction and maintenance costs but also facilitate the maintenance of coastal ecological environments and natural landscapes. Taiwan sustains frequent typhoons and its Si-Cao coast has been seriously affected by previous storms. Restoration of the sand dunes of the Si-Cao coast is necessary and urgent, and the influence of typhoons should be fully considered in dune restoration. Therefore, four test sets were created to perform dune restoration experiments in the northern section of the Si-Cao coast by using different methods, materials, and layouts. We compared topographical and vegetation survey results preceding and following four typhoons, and used this information to identify suitable construction methods for typhoon-affected dunes. These results indicated that artificial vegetation did not perform ideally because the growth of vegetation was slow under the influence of typhoons. Oyster bamboo racks were found to have a positive effect on sand trapping, and provided a shelter that enabled plants to grow naturally. Sand accumulation between two fences was substantial, but moderately dispersed. After consecutive typhoons, vegetation coverage showed a downward trend in all four test sets; however, the sand fence set had the highest protective effect on vegetation. Spinifex littoreus exhibited a strong ability to resist typhoons; after a slight decrease, its coverage improved markedly. According to these results, we provide recommendations for dune restoration on the Si-Cao coast.

I. INTRODUCTION

Soft protection (Mitsch, 1998; Capobianco and Stive, 2000) is a method of coastal management that combines the self-regulation of natural ecological systems with a limited amount of human activity to achieve self-protection of coastal systems. In recent 30 years, with the practice of coast protection engineering and further scientific research, the focus of coast protection has gradually shifted from hard protection (Van der Meer, 1987; Pilkey and Wright III, 1988; Mahalingaiaha et al., 2015) to soft protection (Carmo et al., 2010; De Vriend and Van Koningsveld, 2012; Korbee et al., 2014), which more greatly emphasizes respecting and protecting nature.

The restoration of coastal dunes, a common form of soft protection, can not only save considerable construction and maintenance costs but also facilitate the maintenance of the coastal ecological environments and natural landscapes (Bochev-Van der Burgh et al., 2009, 2011). The shape of coastal dunes often changes because of coastal forces, and with this topographic change, coastal dunes absorb the energy of natural forces, resist tides and waves, and protect coasts. Therefore, coastal dunes form a natural coastal protection barrier (Doody, 2012) and can effectively buffer the attacks of typhoon waves (Carter, 1988; Hesp, 2000). Artificial dunes are the most frequently employed coastal protection measures because of their cost effectiveness and wide applicability (Gómez-Pina et al., 2002). Artificial dunes are formed by using fences to trap and accumulate sand (Warren and French, 2001; Anthony et al., 2007). The stability of these dunes can then be increased through artificial planting (Troeh, 1983; Nordstrom, 2008). Such plants accumulate additional sand and increase the dunes' volume, thus improving coastal protection. This coastal defense is ideal for coasts with abundant sand and wind energy (Rozynski and Pruszak, 2005).

Taiwan's steep terrain and abundant rainfall result in substantial transport of sediment by river, leading to a large supply of beach sediment. This and frequent monsoons in Taiwan cause coastal dunes to develop considerably. However, because of rapid exploitation combined with lack of public awareness of the importance of preserving the coastal ecological environment, coastal dunes in Taiwan are being destroyed, leading to

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[1] *Ocean College, Zhejiang University, Hangzhou, China.*
[2] *The Second Institute of Oceanography, Hangzhou, China.*
[3] *Department of Geography, National Taiwan Normal University, Taipei, Taiwan, R.O.C.*

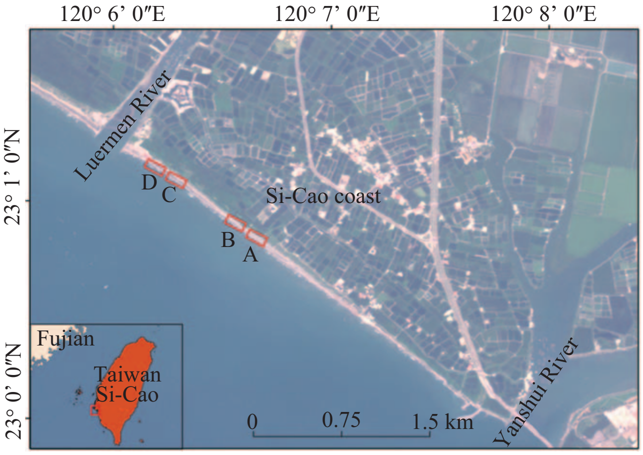


Fig. 1. Location of the four test sets.

environmental disasters that endanger coastal residents’ lives and property. Therefore, these dunes require urgent protection and restoration (Hsu et al., 2006; Hsu et al., 2007).

Taiwan sustains frequent typhoons, meaning that every year, between three and seven typhoons strike the island. Because the considerable destructiveness of typhoons plays a crucial role in the evolution of coastal dunes (Van de Graff, 1977; Vellinga, 1982; Claudino-Sales et al., 2010; Karunarathna, 2014), the influence of such weather events should be fully considered in dune restoration in Taiwan; therefore, coastal dunes and their vegetation should be promoted in the interest of typhoon resistance. However, the influence of typhoons has not been fully considered in previous dune restoration projects in Taiwan (Huang and Yim, 2014).

The Si-Cao coast, which is located in the southwest of Taiwan, is seriously impacted by typhoons, forcing the coastline back. Because of the current lack of coastal protection in Taiwan, restoring its sand dunes is necessary and urgent. Therefore, four test sets were constructed to perform dune restoration experiments in the northern section of the Si-Cao coast by using different methods, materials, and layouts. By comparing the survey results preceding and following four typhoons during 2010, we identified suitable construction methods for dunes under the influence of typhoons. Furthermore, dune restoration could not only protect and beautify the Si-Cao coast but also strengthen its ability to resist tides and waves, preparing it for resistance to following typhoons.

1. Study Area

The Si-Cao coast, which is 4 km long, lies between the Luermen River and the Yanshui River (Fig. 1). Fishponds are located inland from the coast; between these fishponds and the coast are coastal windbreaks. The northern section of the Si-Cao coast is generally composed of natural sand beaches, with no artificial structures and relatively broad coastal windbreaks. However, when typhoons make contact, because of the low heights of the dunes, seawater floods the mixed forest areas through the lower parts of the dunes. These mixed forest areas are currently polluted with driftwood and expandable polystyrene from this flooding.

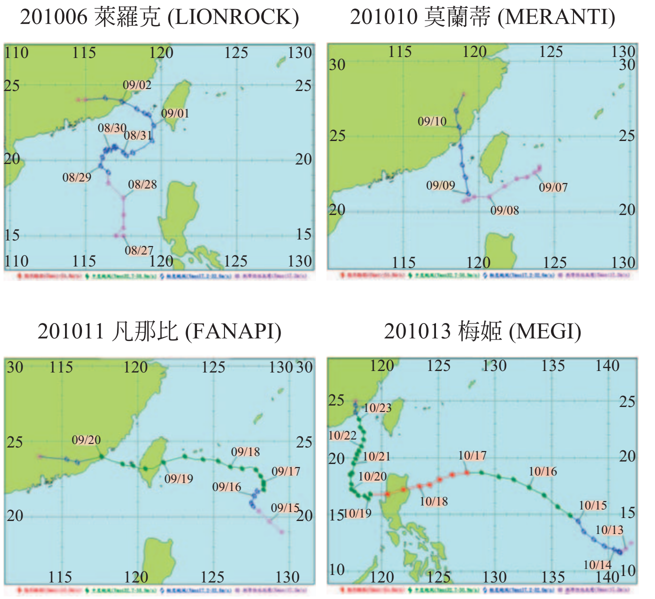
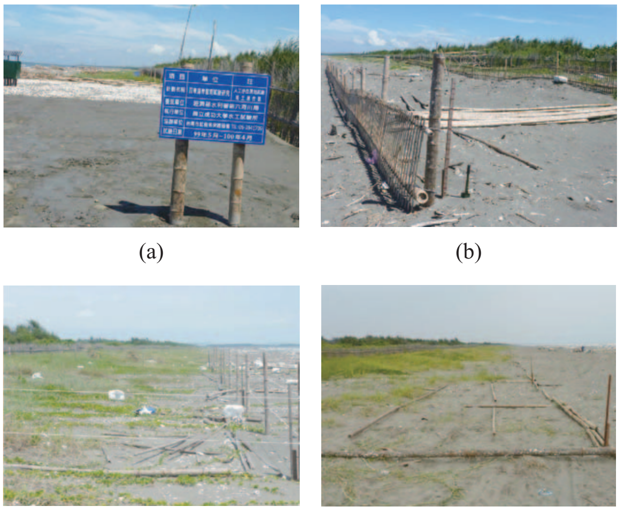


Fig. 2. Sketch of typhoon routes (pink line-tropical depression; blue line-mild typhoon; green line-moderate typhoon; red line-severe typhoon).

2. Meteorological Conditions and Typhoons in 2010

According to the data recorded by the Tainan meteorological station from 1981-2010, the monthly average temperature of Tainan is between 17.6 and 29.2°C, with the minimum temperature occurring in February, and the maximum in July. The monthly average rainfall is between 14.4 and 395.1 mm, with the minimum occurring in December and the maximum in August; rainfall is mainly concentrated in the spring and summer. The monthly average wind speed is between 2.8 and 3.8 m/s, with the minimum occurring in May and the maximum in January; moderately high wind speeds occur throughout the winter. From September to February, the prevailing wind directions are north-northeast, northeast, and north, and in March, influenced by the North Pacific High, the prevailing wind direction turns southwest.

Four typhoons (Fig. 2) influenced Tainan in 2010, namely Lionrock, Meranti, Fanapi, and Megi. Lionrock, which was a mild typhoon, moved to the northwest after its wind circle contacted the southern coast of Taiwan on September 1, and progressed into Fujian at 7 AM on September 2. Meranti, which was also a mild typhoon, moved north after its wind circle contacted the southern coast of Taiwan on September 9, and progressed into Fujian at 4 AM on September 10. Fanapi, which was a moderate typhoon, landed at Hualien at 8 AM on September 19, and progressed into Fujian at 7 AM on September 10. Megi, which was also a moderate typhoon, moved north after it progressed into the Taiwan strait on October 22, and further progressed into Fujian at 1 PM on October 23.



(a) (b)

(c) (d)

Fig. 3. Four test sets on the Si-Cao coast.

II. EXPERIMENTS

The following four test sets (Fig. 1) were constructed in the backshore above the mean high tide: an artificial dune set (Set (a)), a sand fence set (Set (b)), a natural plant set (Set (c)), and an artificial plant set (Set (d)). Each test set was constructed with an area of 50 m along the shore by 20 m inland (Fig. 4).

1. Test Set Setup

Set (a), the artificial dune set, is shown in Fig. 3(a). An artificial dune with a 50 m × 20 m area was piled to a 2.5 m height and then divided into three parts paved with muddy sand, oyster shells, and randomly packed oyster bamboo racks, respectively, from south to north. The purpose of this set was to compare the differences among the three pavements in their ability to support plant growth and fix sand under the influence of typhoons. The three pavements were constructed from local materials. This set was completed in June 2010.

Set (b), the sand fence set, is shown in Fig. 3(b). Two rows of fences were constructed on the front edge and the central line of the set, respectively. Each fence was 50 m long and 0.9 m high with a porosity of approximately 66%, and the two fences were 10 m apart. The purpose of this set was to test the ability of fences to trap sand and to test their protective effect during typhoons. The fences were constructed from driftwood and oyster bamboo racks. This set was completed in June 2010.

Set (c), the natural plant set, is shown in Fig. 3(c). Only dunes of natural composition were fixed in this set. The set was placed near the seaside, with an area of 50 m × 10 m, and was used as the control group. This set was completed in May 2010.

Set (d), the artificial plant set, is shown in Fig. 3(d). Seeds of *Ipomoea pes-caprae*, *Spinifex littoreus*, *Canavalia rosea*, *Bidens alba*, and *Chenopodium virgatum* were sown in the set near the seaside over a 50 m × 10 m area at the beginning of May 2010. At the end of May 2010, 100 *I. pes-caprae* and 100 *S. littoreus* individuals were planted with 1 m spacing. During the period from May to September, this set was watered every 3 days. The purpose of this set was to test the ability of plants to resist typhoons.

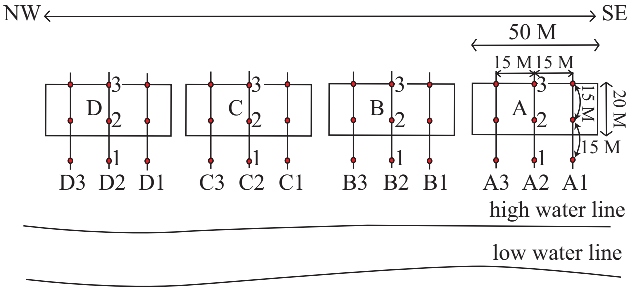


Fig. 4. Survey profile setup.

2. Test Set Measurement

Three profile points were established in each set for conducting topography and vegetation surveys (Fig. 4); the spacing between these survey profiles was 15 m. Surveys were conducted monthly, on August 11, September 13, October 18, and November 19. The topography surveys used Trimble RTK GPS, whose horizontal and vertical accuracy is 1 cm. In addition, all field measurements were conducted by professionals.

III. RESULTS AND DISCUSSION

1. Wind Action

We applied the formula recommended by Bagnold to calculate the threshold wind velocity of sand in the test sets: for Eq. (1), ρ_s and ρ are the mass densities of sand and air, A is set as 0.1, d is the sediment diameter, z is the measuring height of wind, and z_0 is the reference height at which the wind velocity is zero. According to the mean sediment diameter in the test sets (0.24 mm), the threshold velocity was 3.93 m/s. However, the average wind velocity of Tainan in summer is 3 m/s. In addition, northerly winds, which prevail after September, are blocked by coastal windbreaks. Therefore, the sand dunes are less affected by the prevailing wind. This section examines the strong winds that prevail during typhoons.

$$u_t = 5.75A\sqrt{\frac{\rho_s - \rho}{\rho} gd} \bullet \lg \frac{z}{z_0} \tag{1}$$

$$z_0 = 0.035 \ln \frac{d}{0.18} \tag{2}$$

$$Q = \frac{1.0 \times 10^{-4}}{\lg(100z)^3} \mathrm{t}(u_x - 16)^3 \tag{3}$$

Because the Si-Cao coast faces southwest, the strong southwest winds have a considerable influence on its sand dunes.

Table 1. Hourly wind velocity and direction of Tainan during typhoons.

Typhoon	Wind speed (m/s)	Wind direction	Observation time	Total sediment discharge (kg/m)	Transverse discharge (kg/m)
LIONROCK	9.3	190	2010/9/2 11:00	59.3	48.1
LIONROCK	9.9	190	2010/9/2 12:00	84.2	68.2
LIONROCK	9.3	190	2010/9/2 13:00	59.3	48.1
LIONROCK	9.1	190	2010/9/2 14:00	52.3	42.4
MERANTI	8.4	180	2010/9/10 2:00	32.1	22.8
MERANTI	8.3	190	2010/9/10 3:00	29.7	24.1
MERANTI	7.5	180	2010/9/10 4:00	14.8	10.5
MERANTI	7.1	190	2010/9/10 9:00	9.7	7.9
MERANTI	7.4	180	2010/9/10 10:00	13.4	9.5
MERANTI	7.7	180	2010/9/10 11:00	17.9	12.7
FANAPI	13.8	200	2010/9/19 21:00	424.5	386.3
FANAPI	17.1	180	2010/9/19 22:00	1050.8	746.0
FANAPI	9.8	190	2010/9/20 11:00	79.6	64.5
FANAPI	8.6	190	2010/9/20 12:00	37.2	30.1
FANAPI	8.7	190	2010/9/20 13:00	40.0	32.4
MEGI	8.7	190	2010/10/23 13:00	40.0	32.4
MEGI	6.6	180	2010/10/23 22:00	5.2	3.7
MEGI	6.7	180	2010/10/23 23:00	5.9	4.2

Therefore, we selected a wind date during a typhoon (wind velocity greater than 3.93 m/s, and wind direction of 225° ± 45°) and used the sediment transport formula recommend by Bagnold to calculate the sediment discharge. In Eq. (3), u_x is the actual wind velocity at height z, and t is the duration of the wind event. The sediment discharge values calculated using the mean sediment diameter in the test sets (0.24 mm) are shown in Table 1. The transverse sediment discharges caused by Lionrock, Meranti, Fanapi, and Megi are 206.7 kg/m, 87.4 kg/m, 1259.3 kg/m, and 40.3 kg/m, respectively. Furthermore, the resulting average accumulation heights in the test sets are 0.39 cm, 0.16 cm, 2.38 cm, and 0.08 cm, respectively. Overall, the wind had moderate influence on the test sets, but the influence was not substantial.

2. Natural and Artificial Plant Sets

The natural plant set, which did not entail any protection or restoration measures, was used for comparison with the other three test sets. Its comparison graph of topographic profiles (Fig. 5, top) displays little change from August to October, but the inland side exhibited erosion and the side near the ocean showed accumulation from October to November. This indicates that the first three typhoons had little influence on the set, whereas Megi had comparatively more influence. The first two typhoons, Lionrock and Meranti, were mild, small-scale typhoons without high wave run-up. Fanapi was stronger than the previous two, but its route was from the east coast through the central mountains to the Taiwan strait, and thus its influence was limited to the Tainan coast. Moreover, its highest wave coincided with low tide levels, leading to a lower wave run-up. Megi was moderately far from the coast, but its intensity was the strongest; in addition, the maximum height of the typhoon waves coincided with high tide, which caused typhoon waves to submerge the test sets. When the waves receded, the sediments at the back of the test sets were carried forward.

The artificial plant set had similar dunes to those of the natural plant set. Its comparison graph of topographic profiles (Fig. 5, bottom) illustrates that the three profiles changed little from August to October, but exhibited slight accumulation from October to November. Compared with the natural plant set, the performance of the artificial plant set was not ideal, because under the influence of typhoons, vegetation grew slowly, and the artificial plant set had less vegetation coverage compared with that of the natural plant set.

3. Different Surface Pavements

Set A was the artificial dune set; its three profiles (Fig. 6, top) represented three surface pavements.

A1 was paved with muddy sand. Overall, the side farthest from the ocean changed little, whereas the side nearest to the ocean eroded considerably from August to November. After drying, the muddy sand surface formed a layer of hard cover, which had a protective effect on the sand under it. During the early monitoring stages, no wind erosion was detected. However, the muddy sand surface had poor permeability, and during typhoons, the rainfall was substantial. Thus, little rainwater infiltration occurred, and the rainwater scoured two shallow erosion ditches in front of the slope, which led to loss of sand in the artificial dune body. Because the rainwater did not con-

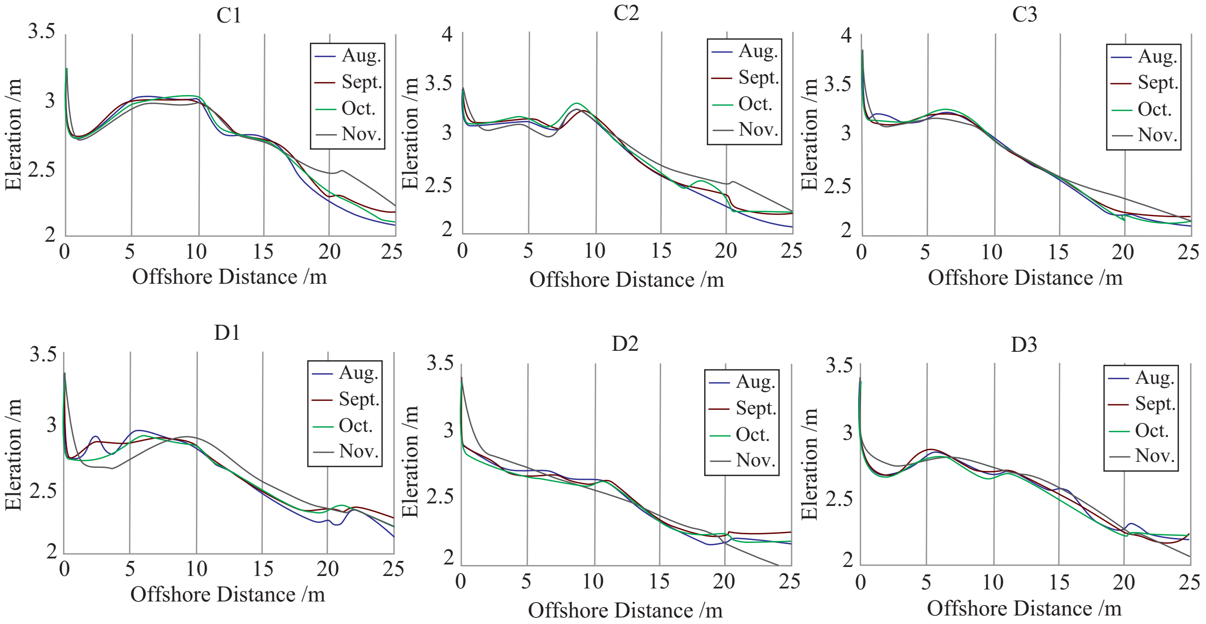


Fig. 5. **Changes in topographic profiles in the artificial and natural plant sets (0-20 m is the range of the test sets. Changes in set C focused on the inland side, whereas changes in set D focused on the side near the ocean; both sets had substantial changes from October to November).**

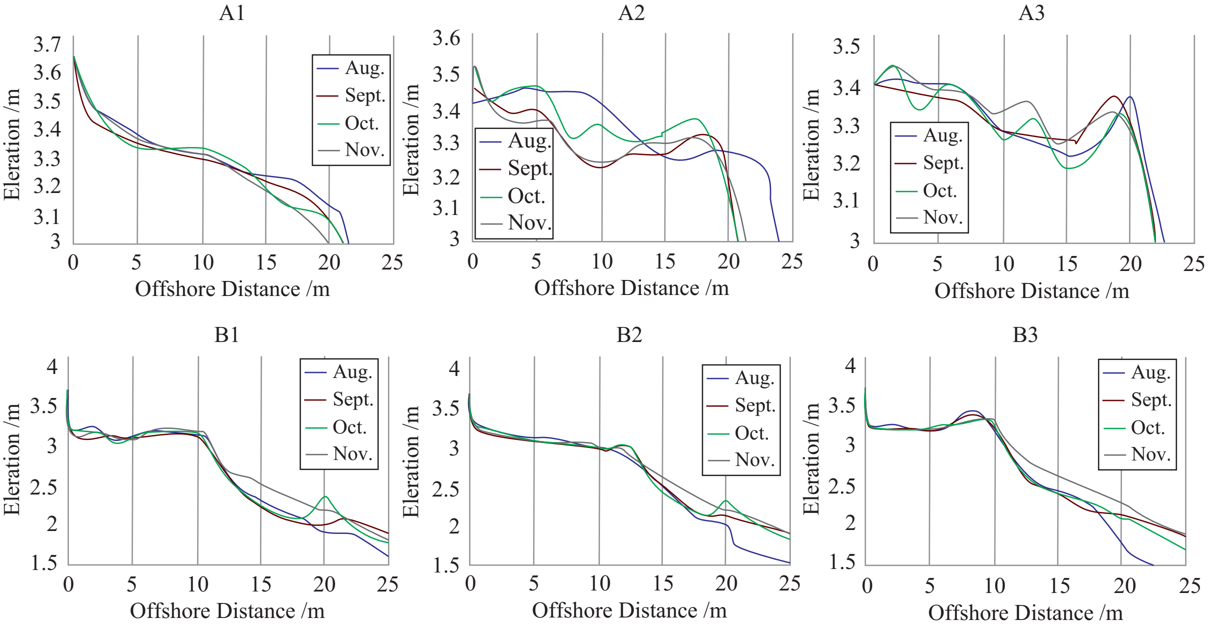


Fig. 6. **Changes in topographic profiles in the artificial dune and sand fence sets (0-20 m is the range of the test sets; A1 and A2 eroded, A3 accumulated sand, and set B accumulated sand between the two fences).**

verge into streams on the inland side, this side was less affected by erosion. After the rainwater converged into streams on the ocean side, flow velocity accelerated, which led to erosion on the ocean side. Each typhoon led to erosion on the side nearest the ocean; after four typhoons, the cumulative erosion was substantial.

A2 was paved with oyster shells. Overall, A2 exhibited erosion from August to November. A2 was constructed to reduce wind erosion, but it possibly promoted sand accumulation because of its increased surface roughness. However, the accumulation effect would disappear after the oyster shells were covered by sand. Without supporting vegetation, erosion would occur again, leaving the oyster shells exposed again; ultimately, the effect of wind erosion was hindered by the oyster shells. Onshore wind, which typhoons Lionrock and Meranti as well as the northwest monsoon in August delivered to the test sets,

Fig. 7. Driftwood in front of the artificial sand dunes after Fanapi.

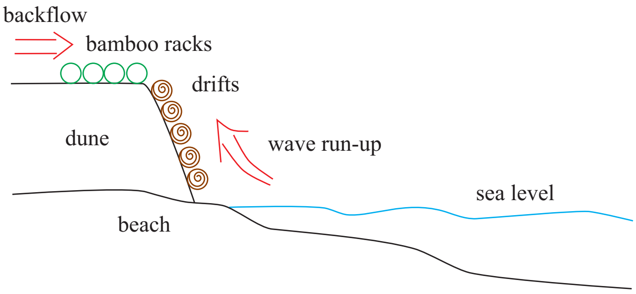


Fig. 8. Typhoon wave action.

caused the sand to recede, and A2 to erode. In September, the wind began to turn to the northeast, and Fanapi delivered offshore wind to the test sets. This caused the sand in the back to progress forward, leading to accumulation in A2. In October, typhoon waves caused by Megi progressed over the sand dunes, and the sand between the oyster shells was washed away, leading to erosion of the sand dune.

A3 was paved with randomly packed oyster bamboo racks. Overall, the inland side of A3 changed little, whereas the side near the ocean accumulated sand from August to November. This pavement not only trapped sand but also provided a favorable environment for plant seeds in the sand dunes to sprout and grow. When sand accretion rose higher than the bamboo racks, this vegetation continued to trap sand; therefore, A3 was the most effective regarding sand accretion of the three surface pavements. After each typhoon made contact, A3 changed little, and even exhibited some accumulation. For example, when Fanapi's waves crossed the border of Tainan, a large amount of debris (including oyster bamboo racks and polystyrene) was blocked in front of the artificial sand dunes (Fig. 7), and the dune body was still in a favorable condition, indicating the ability to resist tides and waves. When the typhoon waves ran up the beach, driftwood and debris were blocked in front of the artificial sand dunes (Fig. 8), thus dissipating wave energy and reducing wave destruction to the dune. When the run-up flowed back, bamboo racks slowed the backflow and blocked sand movement, reducing the sand losses of the dune.

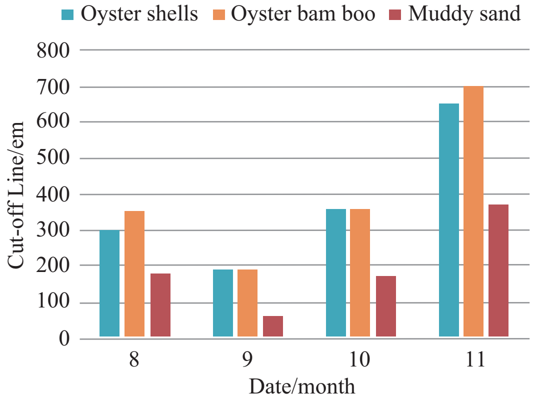


Fig. 9. Vegetation coverage survey in artificial dune set.

The vegetation coverage survey was performed in three parts. The results (Fig. 9) indicated that vegetation grew the most effectively in Set A3, second most effectively in set A2, and most poorly in Set A1. This was because the hard cover of muddy sand and oyster shells made it difficult for plant seeds in the sand dunes to sprout.

4. Two Rows of Fences

The comparison graph of topographic profiles in the sand fence set (Fig. 6, bottom) indicates that the test set behind the back fence changed little from August to November; however, the accumulation between the two fences was substantial. Previously, the fence porosity set for the Ching-Tsao-Lun coast was too low, causing a recirculating bubble to form at the back of the fence, which led to the foot of the fence being eroded. Therefore, in this setup, the fence porosity was set to be 66%, enabling the flow to pass across the fence, thus eliminating the recirculating bubble. The topographic survey shows that the end point of sand accumulation was 8 m at the back of the front fence, and the accumulation was relatively dispersed. Reducing the fence porosity to reduce the wind speed and concentrate the sand accumulation is necessary for future experiments.

Fig. 10 shows that when the fence height was 0.9 m and fence porosity was moderately high, the wind speed at 8 m (9 times the fence height) at the back of the front fence increased rapidly and returned to more than 70% of the original wind speed. Only 2 m of space was available for incipient sediment motion in the front of the back fence; thus, the sand source was limited. The accumulation was low at the back of the back fence, and the back fence was not effective at gathering sand. Therefore, in situations where the sand dunes are not very wide, setting up the back fence is unnecessary.

Typhoons Lionrock and Meranti delivered onshore wind to the test sets. In the situation of strong wind, the wind speed behind the fence would rapidly return to its threshold speed (Fig. 10), and cause the sand in the test set to move. Thus, little accumulation occurred during the first two typhoons, and the

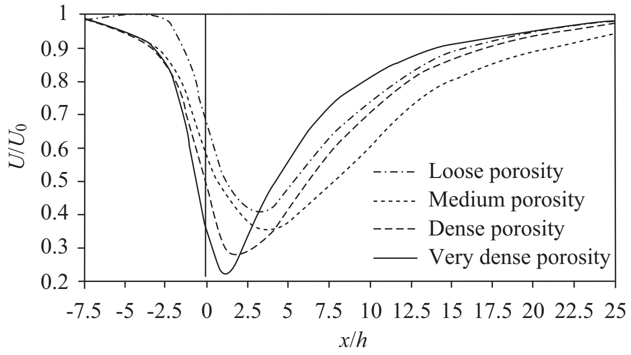


Fig. 10. **Relative wind speed around fences with different porosities. The normalized distance from the fence is *x*/*h* (positive: leeward; negative: windward) and U/U_0 is the relative wind speed, where *U* is the local, time-averaged speed and U_0 is the unobstructed, reference wind speed (Naegëli, 1946; Li and Sherman, 2015).**

accumulation tapered off within 2 m at the back of the front fence. Fanapi delivered offshore wind to the test sets, but under the protection of windbreaks, the test set changed little, except it exhibited slight accumulation by the front fence. The first three typhoons affected the test sets mainly by wind, but the typhoon waves caused by Megi submerged the test sets and pushed sediment from the beach inland. Although parts of the fence were pulled down, 20-30 cm of sand accumulation occurred between the two fences. As described in the first section, the sediment discharge caused by winds during Megi was limited; thus, the accumulation was caused by waves. The sand dunes blocked wave invasion.

5. Changes in Vegetation Coverage

After consecutive typhoons, the vegetation coverage showed a downward trend in all four test sets, especially in the natural plant set. Both Lionrock and Meranti caused moderate withering of plant leaves and a few plants were covered by sand in each set. Fanapi delivered offshore wind to the test sets, but under the protection of windbreaks, its influence on vegetation was limited. Except in the natural plant set, plants returned to growth, and vegetation coverage began to increase. The typhoon wave caused by Megi then passed over the sand dunes, submerged plants, and transported sand; thus, it affected vegetation growth and reduced vegetation coverage.

Fig. 11 (top) illustrates that the sand fence and artificial dune sets were also influenced by typhoons, but the effect was not as serious as that on the natural plants and artificial plant sets. The plants grew considerably in the sand fence set because the fence interfered with airflow, weakened wind force, protected the plants at the back of the fence, and reduced the influence of the typhoons. In addition, the pavements in the artificial plant set reduced wind erosion and the influence of the typhoons. However, the muddy sand and oyster shell pavements created adverse conditions for the plants' growth; thus, vegetation coverage of the artificial dune set remained at a moderately low level.

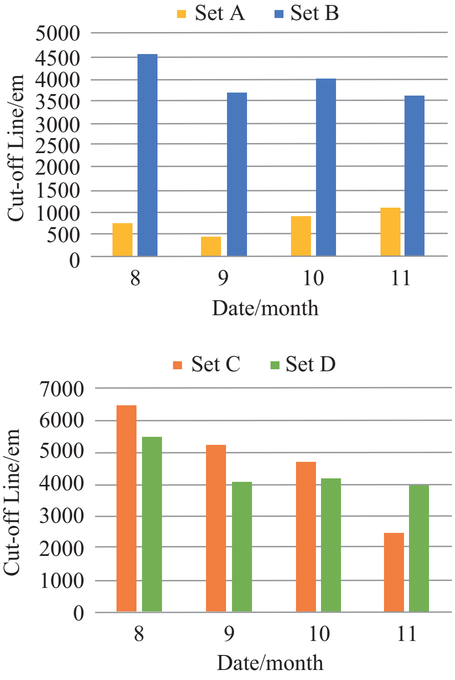


Fig. 11. **Vegetation coverage of the four test sets from August to November.**

Fig. 11 (bottom) illustrates that plant growth in the artificial plant set was not improved compared with that in the natural plant set. This was because the growth duration of the artificial plants was short, and although most artificial plants survived, they grew only in a small set and did not proliferate in a wide range. The natural plants and artificial plants sets had no protective measures against typhoons; therefore, their vegetation coverage declined dramatically, and their ability to resist the typhoons was poor. However, vegetation coverage of the natural plant set decreased during the entire observation period and its decline in each month was evident; it was more affected by the typhoons, whereas that of the artificial plants set was relatively stable.

6. Plant Resistance to Typhoons

Because the viability of plants varies under different circumstances, choosing plants suitable for growth in the Si-Cao coastal dunes under the influence of typhoons is crucial to the success of dune restoration. Fig. 12 displays a comparison of plant coverage: the coverage of *I. pes-caprae* was the highest, that of *S. littoreus* and *C. rosea* was the second highest, and the coverage of *B. alba* was low. In addition, *C. virgatum* withered after July; therefore, after July, its coverage was nonexistent.

I. pes-caprae thrived in the high-temperature, dry, sunny conditions; its expansion ability was very strong, and its coverage was very high. However, because of its large leaves, it was severely affected by the typhoons. From August to September, onshore winds delivered by typhoons caused *I. pes-caprae* to be covered by sand, drastically reducing its quantity. From September to October, offshore winds delivered by typhoons were blocked by windbreaks, and *I. pes-caprae* recovered ra-

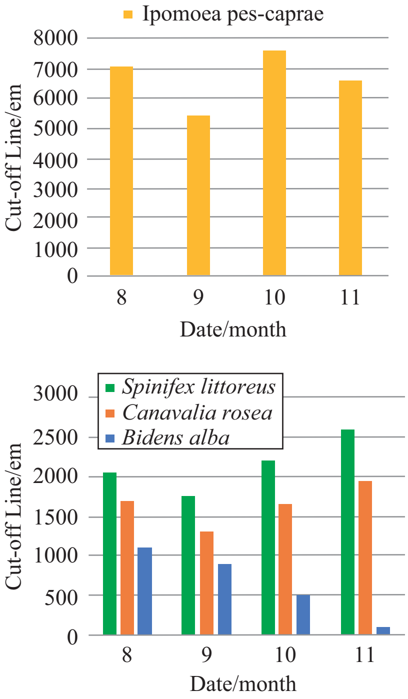


Fig. 12. Plant coverage from August to November.

pidly. From October to November, onshore winds delivered by typhoons reduced it markedly again. Furthermore, *S. littoreus* exhibited a strong ability to resist the effects of typhoons. After a slight decrease from August to September, its coverage improved markedly. Although its expansion ability was not as strong as that of *I. pes-caprae*, its leaves were small, and it had strong drought resistance and salt tolerance. Therefore, it has a strong ability to resist sand burial caused by typhoons. The coverage change of *C. rosea* was similar to that of *S. littoreus*, but its decline from August to September was more considerable than that of *S. littoreus*, and its increase after September was much smaller. Therefore, its ability to resist the typhoons was weaker than that of *S. littoreus*. *B. alba* thrives in the backshore far from the coast; its competitiveness was weaker than that of the other plants, and because of its large flowers, it was severely affected by the typhoons. Its coverage was low and showed a continual downward trend; *B. alba* nearly disappeared in November.

IV. CONCLUSIONS

On the basis of these experiments, we drew the following conclusions:

(1) The performance of the artificial plant set under the influence of typhoons is not ideal because the growth of the vegetation was slow. If artificial plants are the only plants used in dune restoration, the task may not be satisfactorily completed.

(2) Oyster bamboo racks randomly packed had a positive effect on sand trapping and created an environment that enabled plants to grow naturally. Oyster bamboo and sand fences both prevented drifts during the typhoon and facilitated sand accumulation, which could protect sand dunes. The surfaces covered by oyster shells or paved with muddy sand prevented wind erosion, but exhibited little effect on sand accumulation, and created an unsuitable environment for plants to grow.

(3) The accumulation of sand between the two fences was substantial, but moderately dispersed. Reducing the fence porosity to slow wind speed and concentrate the sand accumulation is necessary for future experiments. The back fence did not gather much sand, and in situations where the sand dunes are not wide, constructing the back fence is not necessary.

(4) Because of the recurring effects of typhoons, the vegetation coverage showed a downward trend in all four test sets, especially the natural plant set. Furthermore, the sand fence set exhibited the most effective protection for vegetation because its vegetation coverage remained at a moderately high level.

(5) *S. littoreus* has a strong ability to resist typhoons. After a slight decrease from August to September, its coverage improved markedly; therefore, it should be the first plant selected for dune restoration. *I. pes-caprae* was clearly affected by the typhoons, but its expansion ability was very strong, and its coverage was very high; therefore, it should be the second plant selected for dune restoration.

Based on these conclusions, the following advice is provided for dune restoration in the Si-Cao coast:

Use single row fences with a porosity between 50% and 60% to trap sand; place oyster bamboo racks randomly behind the sand fence; and plant *S. littoreus* as primary and *I. pes-caprae* as secondary coverage. This will improve the ability of sand dunes to resist the effects of typhoons. Creating artificial dunes where the height of existing dunes is too low is necessary; additional restoration measures can be performed subsequently.

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