PERFORMANCE OF A NOURISHED SAND BEACH

IN UPPER GULF OF THAILAND

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Wide sand beaches in Thailand are renowned for attracting many tourists. Pattaya, located near Bangkok in the upper Gulf of Thailand, was ranked the 15th in the Global Destination Cities Index 2019, but its beach almost disappeared. The Pattaya beach is microtidal with an average tidal range of 1.5 m. The average significant wave height is 0.2 m, and the wave energy is low. The beach was widened by placing 130 m^3/m of medium sand along the shoreline length of 2.8 km between two terminal groins constructed in 2018. The bathymetry and topography were measured in 2019, 2020, and 2021. The placed sand in the water depth less than 2 m was reduced by 14% after one year, but the reduction rate was halved after two years. The beach next to the updrift groin may have reached equilibrium, whereas erosion continued for the rest of the nourished beach. The bathymetry in the water depth of 2-4 m may have become stable seaward of the equilibrium beach but was accreting seaward of the eroding beach. Profile changes seaward of a closure depth based on wave breaking were noticeable on this nourishment beach during 2019-2021.

Chapter 1

Introduction

Beach erosion is a chronic problem in Thailand. Coastal structures were built to reduce beach erosion but did not restore wide beaches desired for seaside resorts. Ritphring et al. (2018) compiled a database of beach characteristics, including sediment diameter and beach slope. Seawalls and revetments were reported to protect 10% of Thailand's sandy coastlines. Most sediment diameters range between 0.2-0.5 mm. The average beach slope is 0.1, and the average beach width above the mean sea level is 35 m. The first major beach nourishment in Thailand was carried out at Pattaya (Figure 1.1), the famous resort near Bangkok located on the coast of the Gulf of Thailand. The length of the upper (northern) square area is about 100 km, and the average water depth is 15 m (Sojisuporn et al. 2013). In the following, the beach nourishment project in 2018 is explained concisely. The analysis on the bathymetry and topography is conducted to understand the evolution process of the nourished beach and the sand volume changes. The ultimate goal is to prolong the retention of the placed sand.

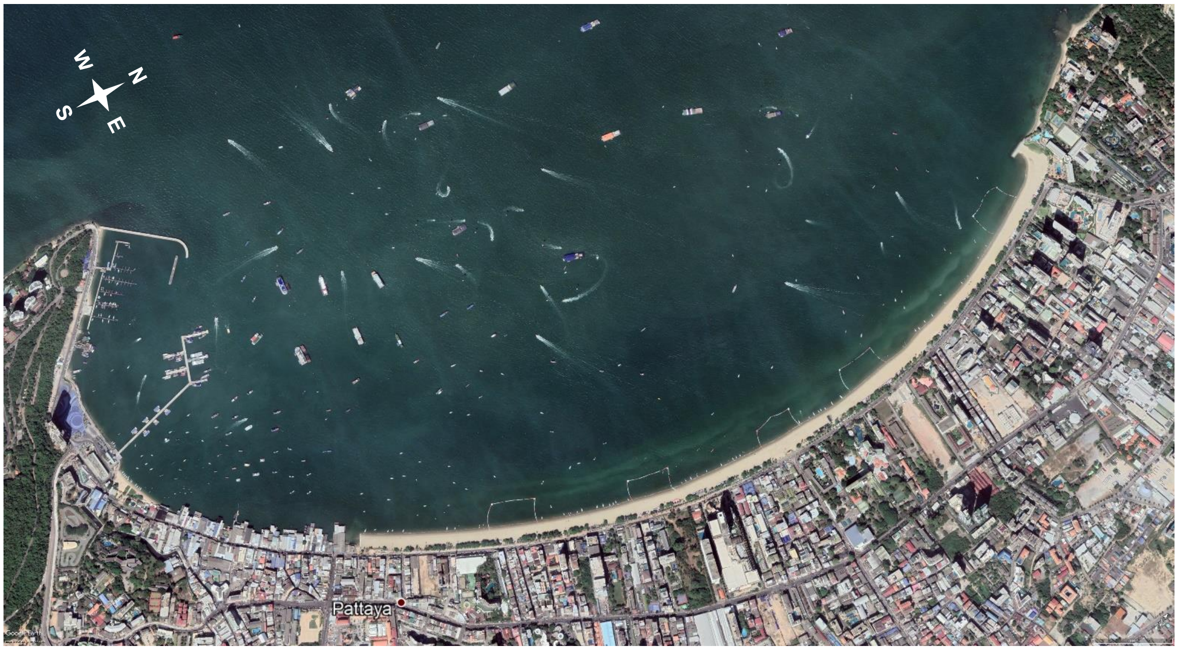
Figure 1.1 Pattaya beach location in Thailand (ArcGIS Pro).

Chapter 2

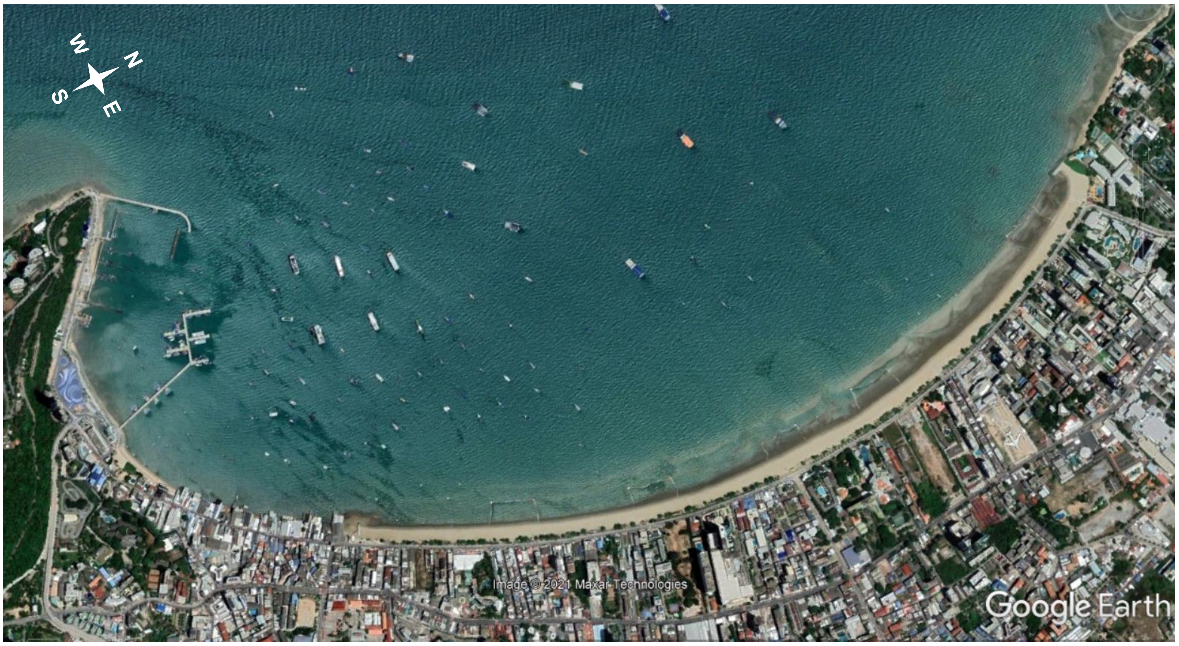
Pattaya Beach

Satellite images of Pattaya beach are available since 2005 (Google Earth Pro, TerraMetrics and Maxar Technologies). The dry beach width in the satellite images was very narrow even in 2005. This study deals with the interval of 2019-2021. Figure 2.1 shows satellite images starting from January 4, 2005 (well before the 2018 beach nourishment) up to August 9, 2021 (more than two years after the beach nourishment.)

2005/01/04 (pre-nourishment)



2019/11/25 (post-nourishment)



2021/08/09 (post-nourishment after more than two years)

Figure 2.1 Pattaya beach (Google Earth Pro, TerraMetrics and Maxar Technologies) starting from January 4, 2005 up to August 9, 2021.

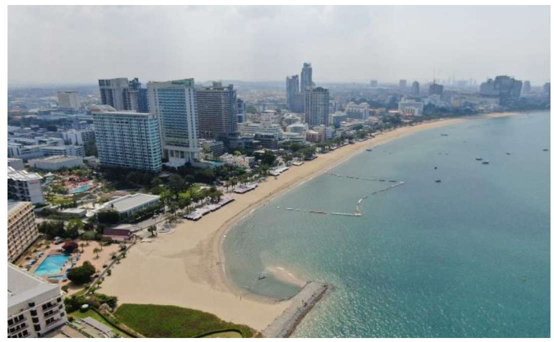
After dredged sand placement, the bathymetry and topography were surveyed in February 2019, February 2020, and January 2021. The borrow site with medium sand of 0.3-0.4 mm median diameter was 20 km from Pattaya beach. Terminal groins were constructed in 2018. The sand was dredged and transported to a booster pump station ship. The transferred sand was pumped through pipelines on Pattaya beach along the curved shoreline of 2.8 km length between the terminal groins (60 m long) at the south and north (left and right in Figure 2.1) ends. The placed sand volume was 363,000 m^3, corresponding to the cross-sectional area increase of 130 m^2. The beach width above the mean sea level was 57 m. The foreshore slope was 0.1. Six photos in Figure 2.2 (a)-(f) show the transformation of Pattaya beach during 2019-2021 after the sand placement.

Intermittent tide gauge data at Ao Udom (Marine Department, 2018), located 20 km north of Pattaya, were used to estimate water level variations relative to the mean sea level. The mean high and low water levels were 0.67 m and -0.83 m, respectively. The mean higher high-water level was 1.07 m, and the highest high-water level, including storm surge, was 1.79 m. Waves at Pattaya were estimated using the empirical formula in Coastal Engineering Manual (USACE 2003) and wind data at Pattaya Meteorological Station located 2.4 km south of Pattaya during 1981-2009. The formula was calibrated using wave buoy data during February-November, 1997. The average significant wave height and peak period were 0.2 m and 1.3 s, respectively. The maximum wave height and period were 2.1 m and 7.1 s, respectively. The predominant wave direction was from the south-southwest.

a. After sand placement (Feb 2019)

b. After one year (Feb 2020)

c. North terminal groin (Feb 2020)



d. North terminal groin (Jan 2021)

e. After two years (Jan 2021)

f. South terminal groin (Jan 2021)

Figure 2.2 Pattaya beach during 2019-2021 after sand placement.

Figure 2.3 shows the depth contours of 0-7 m at Pattaya beach in February 2019, February 2020, and January 2021, after the nourishment where the north is rightward in this figure. The beach profiles were examined along 30 cross-shore lines (L1-L30), where five lines are shown for simplicity.

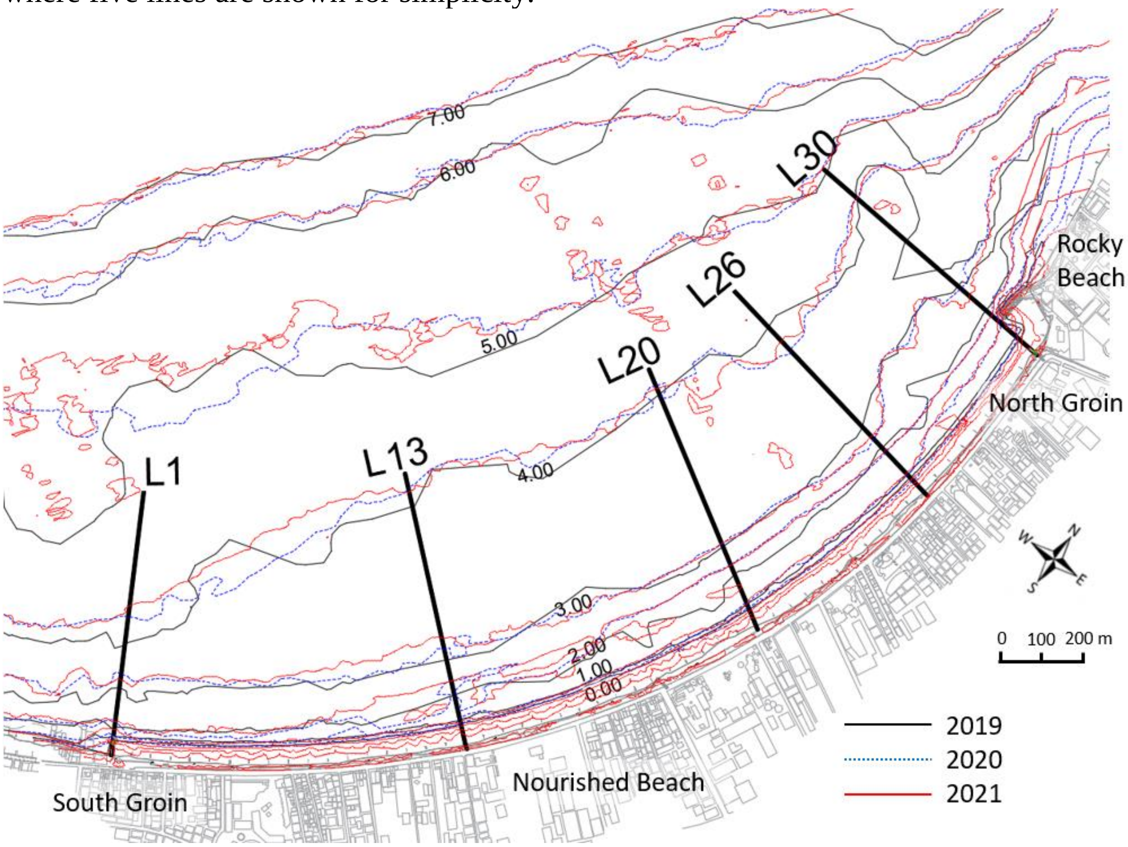


Figure 2.3 Depth contours in meters surveyed in February 2019, February 2020, and January 2021.

In Figure 2.3, L1 is immediately north of the south groin constructed to reduce local southward longshore sand transport observed at L1. Waves from the south are diffracted around the cape south of Pattaya (see Figure 2.1). The diffracted waves cause southward sand transport in the sheltered zone where a harbor was constructed. L30 is immediately south of the north groin constructed to reduce northward longshore sand transport. The sand placement affected the depth contours of 0-2 m between L1-L30 before the 2019 survey. The depth contours of 2-4 m were relatively stationary during

2019-2021. L20 separates the north and south zones with different bathymetric changes. L13 and L26 are located in the middle of L1-L20 and L21-L30, respectively.

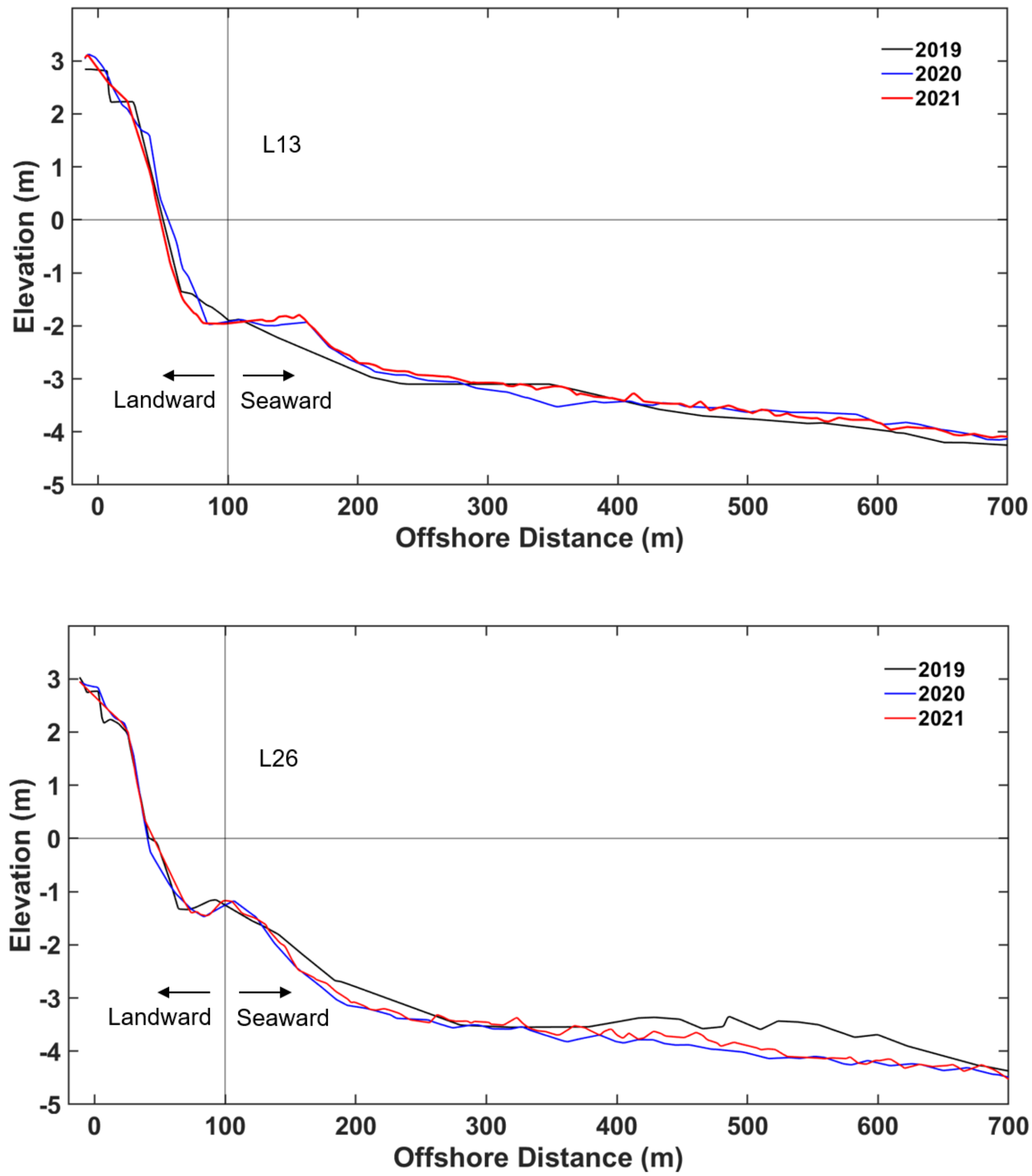


Figure 2.4 Beach profiles in 2019, 2020, and 2021 along Line L13 with offshore accretion and Line L26 with offshore erosion during 2019-2020.

Figure 2.4 shows the beach profiles along with L13 and L26 in 2019, 2020, and 2021. The elevation is relative to the mean sea level. The offshore distance is from the survey reference point located 10 m seaward of the vertical wall with its crest elevation of 3 m. The nourished berm elevation was increased from 2.2 m to 2.8 m in front of the wall. The beach profile evolution diverged at the offshore distance of approximately 100 m for L1-L30. The seaward limit was set at the offshore distance of 700 m of limited bottom elevation changes. The offshore distance of 100 m is used to separate the landward and seaward zones of different profile evolution patterns. The placed sand was eroded during 2019-2021. The water depth at this separation point decreased from about 2 m at L1 to 1 m at L30 because of the northward decrease of the beach slope in Figure 2.3. The seaward zone is accretional for L13 and erosional for L26. The pronounced erosion in the seaward zone of L26 was not expected for the microtidal beach of medium sand in an environment of low wave energy.

Chapter 3

Data Analysis

The beach profile data for L1-L30 are analyzed to explain the bathymetric changes during 2019-2021 in Figures 2.3 and 2.4. The bottom elevation Z_b (x, t) relative to the mean sea level is presented as a function of the offshore distance x at a given time t. The beach profile area change ΔA is calculated separately for the landward and seaward zones from February 2019 to February 2020 (1.0 year) and February 2020 to January 2021 (nearly 1.0 year).

3.1 Beach profile area change

To interpret the beach profile area change ΔA for the 30 lines (L1 – L30), the area change ΔA is separated into ΔA_L = area change in the landward zone of sand placement, ΔA_S = area change in the seaward zone (offshore of sand placement). As mentioned previously, the offshore distance of 100 m is used to separate the landward and seaward zones of different profile evolution patterns. Thus, the beach profile area change calculated separately for the landward and seaward zones is examined using x = 100 m as the boundary of the two zones for the profiles Zb (x, t) with t = 2019, 2020, and 2021.

For the landward zone area change ΔA_L, the difference between $Z_b(x)$ in 2020 and $Z_b(x)$ in 2019 is integrated from x = -10 m to x = 100 m to obtain ΔA_L during 2019-2020. $Z_b(x)$ in 2021 and $Z_b(x)$ in 2020 are used to calculate ΔA_L during 2020-2021. For the seaward zone area change ΔA_S, the calculation procedure is the same except that the integration with respect to x is in the range of x = 100-700 m.

In Table 3.1, the bottom elevation Z_b at x = 100 m and the beach profile area change ΔA_L and ΔA_S for L1 – L30 are summarized. The value of ($-Z_b$) in Table 3.1 is the water depth at x = 100 m.

Table 3.1 Bottom elevation Z_b at x = 100 m and area changes ΔA_L and ΔA_S for L1 - L30

Line	**Z_b (m) at x = 100 m**			**Area (m^2) changes (2019 - 2020)**		**Area (m^2) changes (2020 - 2021)**	
	2019	**2020**	**2021**	**ΔA_L**	**ΔA_S**	**ΔA_L**	**ΔA_S**
L1	-2.89	-2.33	-2.35	146.08	261.61	8.74	24.48
L2	-2.10	-2.35	-2.14	-26.22	30.79	-15.12	68.43
L3	-2.25	-2.19	-2.14	-31.33	-17.94	-8.01	77.38
L4	-1.95	-2.22	-2.09	-30.52	-19.21	-27.50	66.80
L5	-1.98	-2.21	-2.10	-20.08	-29.00	-19.36	85.29
L6	-1.75	-2.25	-2.05	-45.65	-57.07	-21.09	95.75
L7	-2.04	-2.18	-2.03	-25.95	-11.72	1.66	82.86
L8	-1.97	-2.14	-1.96	-41.17	34.33	-9.09	98.58
L9	-1.95	-2.20	-1.96	-45.32	60.25	-25.76	99.25
L10	-2.08	-2.04	-1.89	40.02	64.95	-29.47	79.72
L11	-2.13	-2.02	-1.91	-11.60	50.06	-18.13	62.84
L12	-2.08	-1.89	-1.97	-9.10	57.90	-0.79	63.65
L13	-1.88	-2.10	-1.96	-57.41	26.14	-27.14	27.19
L14	-1.82	-2.19	-2.02	8.35	6.32	-21.19	-31.65
L15	-1.77	-1.99	-1.78	-49.99	41.22	-34.37	-11.82
L16	-1.87	-1.98	-2.05	-60.02	57.13	-19.17	-7.38
L17	-1.84	-1.95	-1.64	-44.14	16.40	-7.83	13.78
L18	-1.83	-1.81	-1.81	24.53	79.06	31.83	-12.57
L19	-1.95	-1.63	-1.90	35.09	94.73	-29.50	-17.58
L20	-2.02	-1.75	-1.95	12.64	-6.10	-25.59	10.79
L21	-1.61	-1.87	-1.54	-20.83	-62.88	-9.17	10.84
L22	-1.29	-1.53	-1.36	-40.75	-174.01	10.86	-73.66
L23	-1.50	-1.46	-1.58	-15.24	-135.90	-7.75	-5.53
L24	-1.41	-1.28	-1.29	-10.60	-121.97	-2.43	10.15
L25	-1.44	-1.22	-1.22	15.04	-187.79	2.89	45.51
L26	-1.25	-1.30	-1.17	-23.55	-214.94	4.90	46.13
L27	-1.31	-1.15	-1.07	-25.28	-207.70	-1.08	60.28
L28	-1.19	-1.13	-0.97	-29.17	-201.07	-4.21	30.03
L29	-1.20	-1.19	-1.07	-31.05	-68.50	-20.03	-13.31
L30	-0.99	-1.08	-0.27	-35.60	-77.60	-0.13	-29.39

3.2 Alongshore length along Pattaya beach

The alongshore distance from L1 is calculated for each of the 30 cross-shore lines whose alongshore spacing decreases offshore as shown in Figure 3.1. The area between L1-L30 is separated into 29 segments in the landward and seaward zones. The alongshore segment length in the landward (seaward) zone is calculated as the segment area divided by the cross-shore distance of 110 m (600 m) in the landward (seaward) zone. The alongshore distance from L1 is the cumulative segment length from the first segment between L1 and L2. The alongshore distance from L1 to L30 is 2660 m and 2280 m in the landward and seaward zones, respectively.

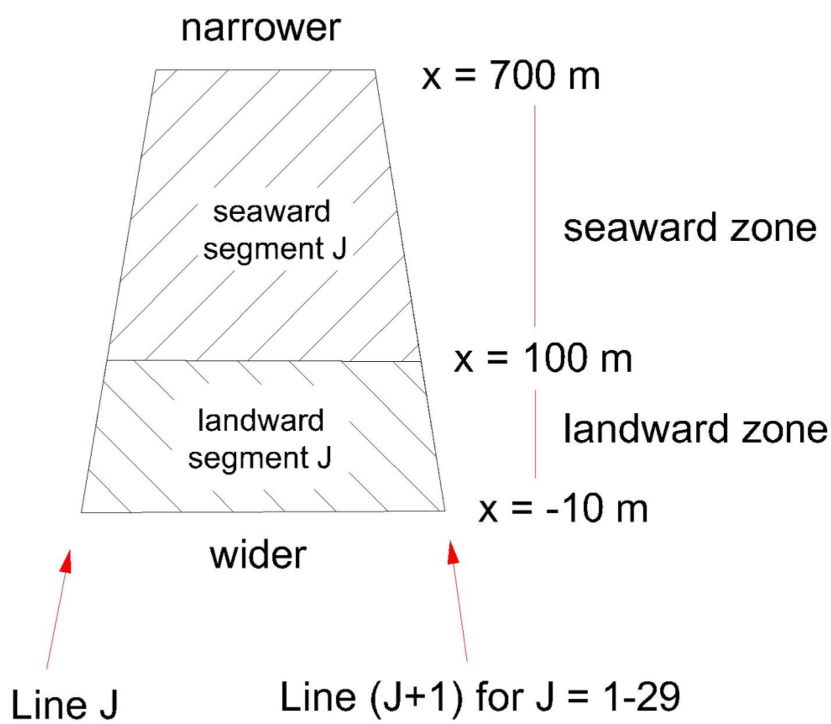


Figure 3.1 Horizontal areas between cross-shore lines and along x = 100 m separating landward and seaward zones.

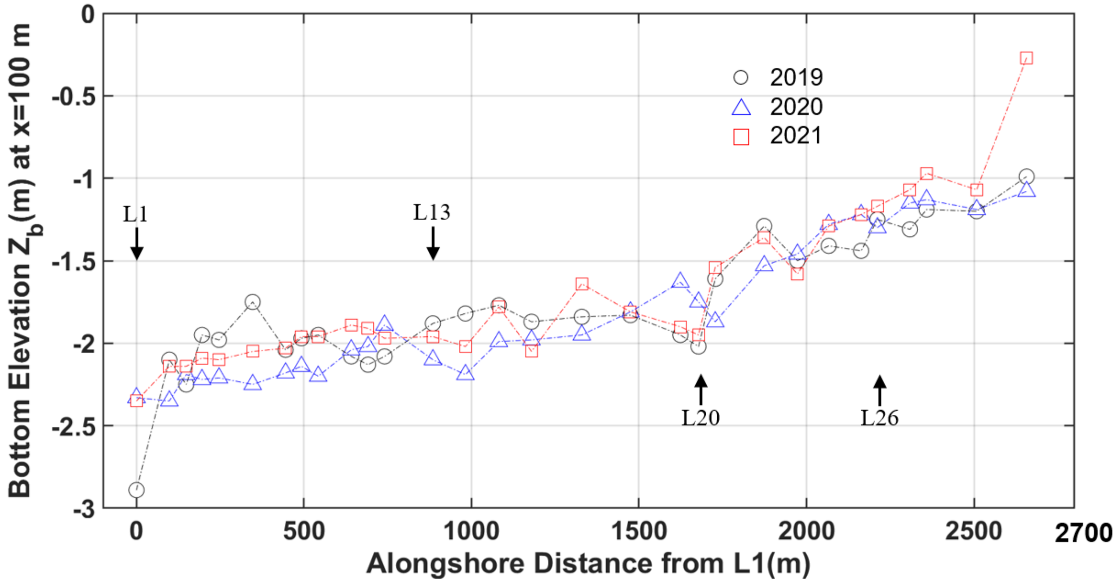


Figure 3.2 Bottom elevation Z_b at x = 100 m along L1–L30 during 2019–2021.

Figure 3.2 shows the alongshore increase of the bottom elevation Z_b at x = 100 m from the south to the north in 2019, 2020, and 2021. The temporal change of Z_b at x = 100 m was relatively small except at L1 and L30 next to the south and north groins in Figure 2.3. The separation of the landward and seaward zones at x = 100 m may be reasonable in view of Figure 3.2.

3.3 Alongshore variation of erosion and accretion

Cross-sectional area changes ΔA in the landward and seaward zones (sand volume change per unit alongshore length) at Line J (J=1-30) are used to examine the alongshore variation of sand loss or gain per unit length (m^3/m). The area change ΔA is plotted as a function of the alongshore distance of Line J, which is the sum of the "landward" segment alongshore length for Segments 1 to (J-1). The following symbols are used for plotting.

	2019-2020	2020-2021
Landward	△	□
Seaward	▲	■

The four different values of ΔA in the two zones and during the two intervals are plotted for each of the 30 cross-shore lines in Figure 3.3 as a function of the landward alongshore distance from L1. For clarity, the area changes in the landward and seaward zones are plotted separately in Figure 3.4 and 3.5, respectively. It is noted that the beach profile area changes from 2015 (before nourishment) to 2019 were presented by Laksanalamai and Kobayashi (2021). The area increase in the landward zone during 2015-2019 was approximately 130 m^2.

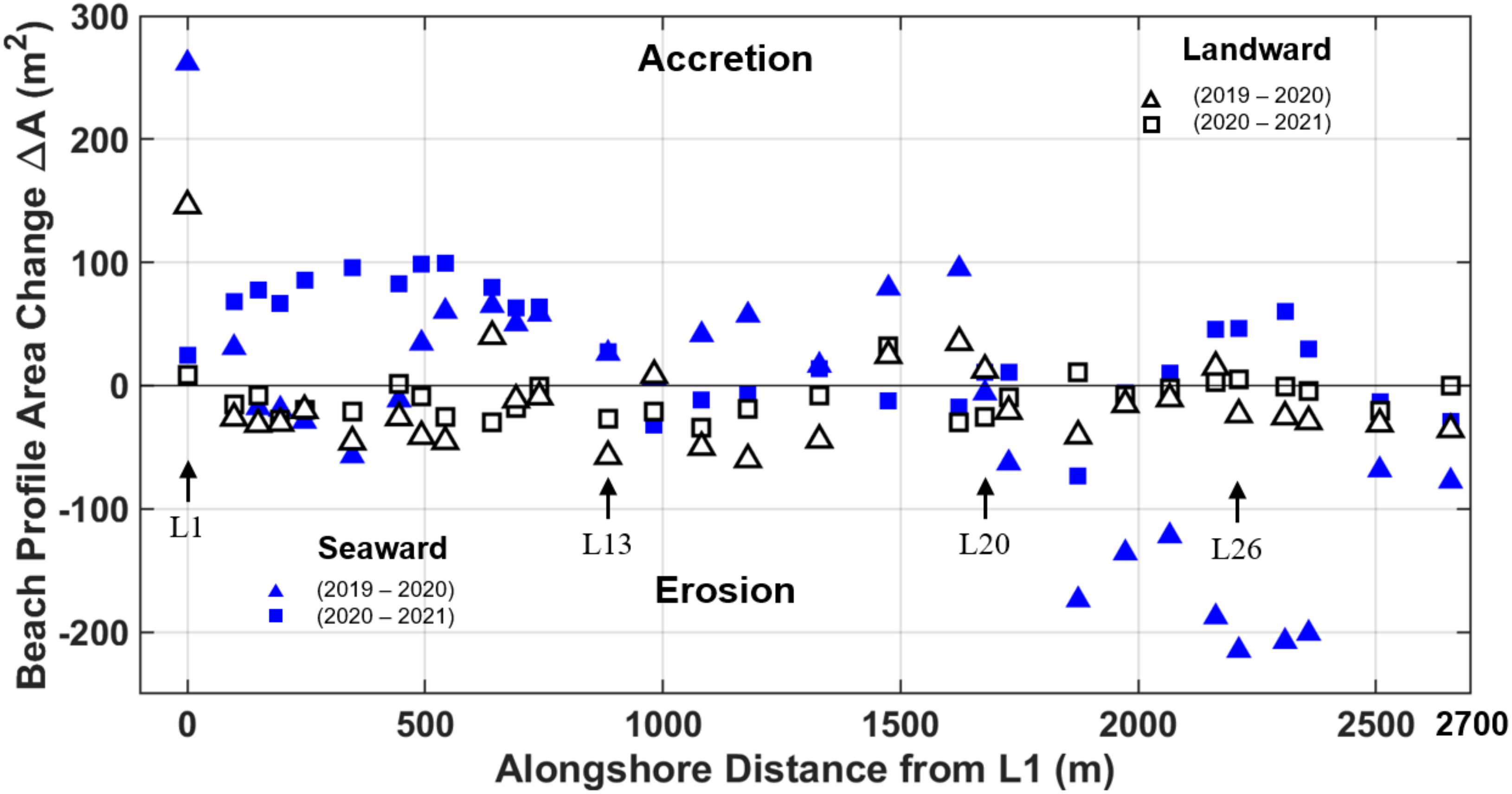


Figure 3.3 Beach profile area change ΔA in landward and seaward zones along L1–L30 during 2019–2020 and 2020–2021.

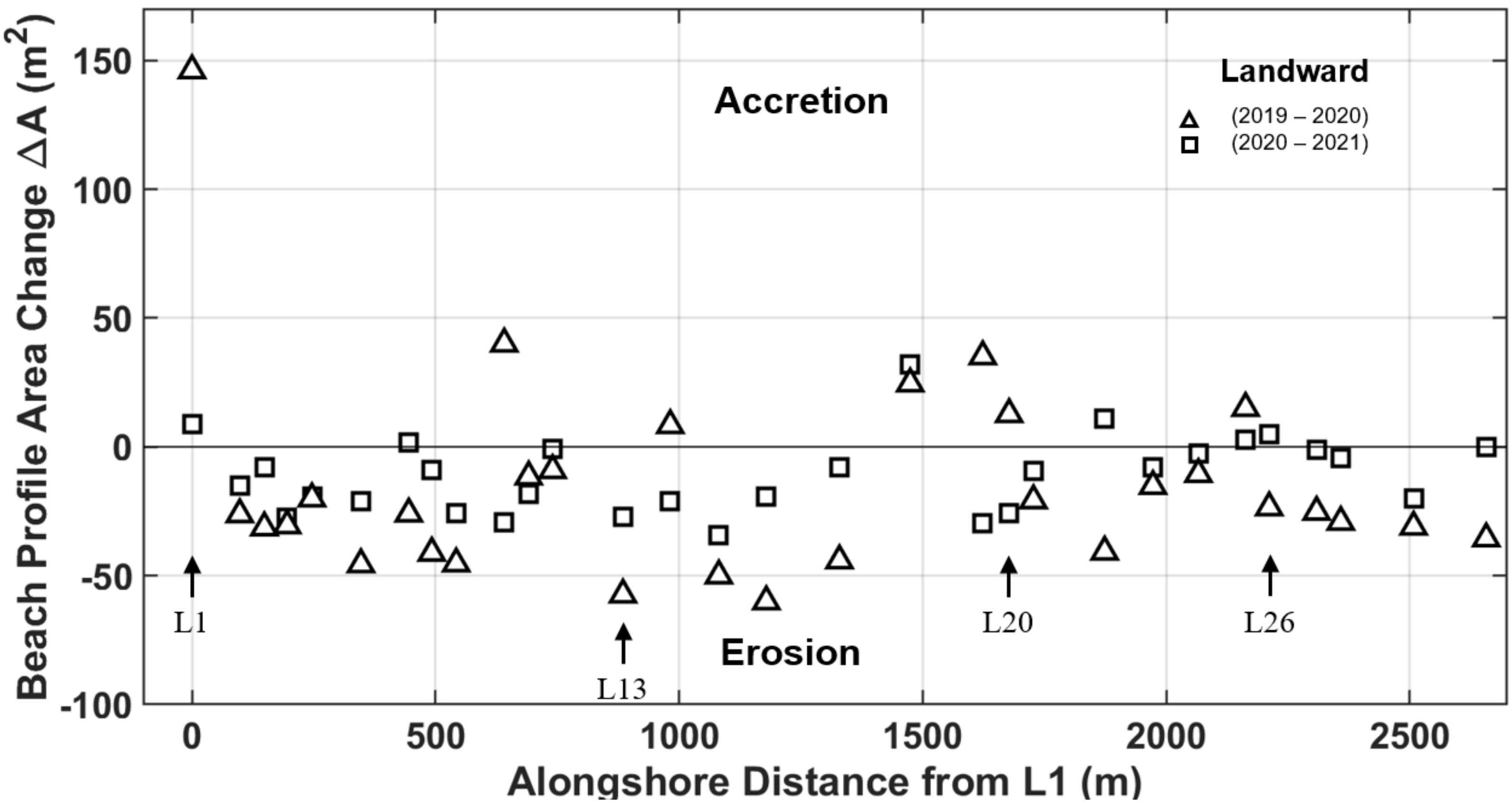


Figure 3.4 Beach profile area change ΔA in landward zone along L1–L30 during 2019–2020 and 2020–2021.

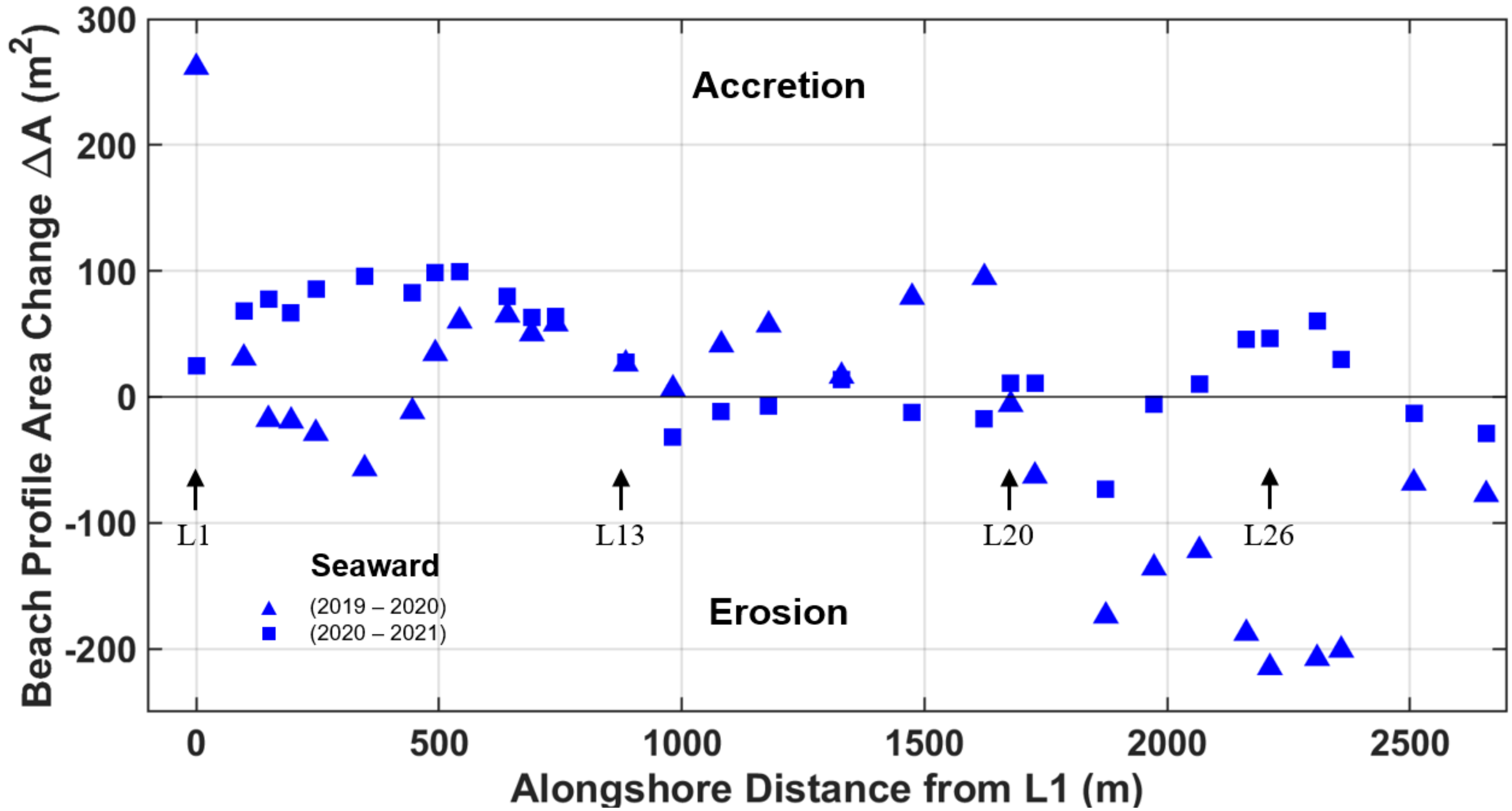


Figure 3.5 Beach profile area change ΔA in seaward zone along L1–L30 during 2019–2020 and 2020–2021.

No sand was placed along L1 during 2015-2019 because sand accretion was expected north of the south groin. The area changes in the landward and seaward zones along L1 were largely positive (accretion) during 2019-2020 and became small, indicating the sand fullness along L1 next to the south groin. The area changes ΔA in the landward zone (Figure 3.4) during 2019-2020 were negative (erosion) except for L1, 10, 14, 18-20, and 25 (Table 3.1) where sand accretion occurred. The area changes in the landward zone during 2020-2021 were mostly negative (erosion) and varied alongshore as explained subsequently. The area changes in the seaward zone (Figure 3.5) during 2019-2020 were mostly positive for L2-L19 and negative for L20-L30. Then during 2020-2021, ΔA in the seaward zone remained accretional for L2-L13 but became slightly erosional for L14-L19. The area changes in the seaward zone for L21-L30 became accretional except L22, 23, 29, 30 with slight erosion.

3.4 Trends of different area changes

The area changes ΔA listed in Table 3.1 and plotted in Figures 3.3-3.5 are explained to understand the trends of the bathymetric changes. L1 is excluded because the profile L1 may have reached equilibrium. Figure 3.6 compares the area changes in the landward zone during 2019-2020 and 2020-2021. The negative value of ΔA implies erosion of sand placed in the landward zone before 2019. The range of ΔA = (-60)-40 m^2 during 2019-2020 was reduced to ΔA = (-34)-32 m^2 during 2020-2021. The range reduction was more apparent for L21-L30. The average ΔA during 2020-2021 was -16 m^2 for L2-L20 and -2.6 m^2 for L21-L30. The landward zone for L21-L30 may be approaching equilibrium.

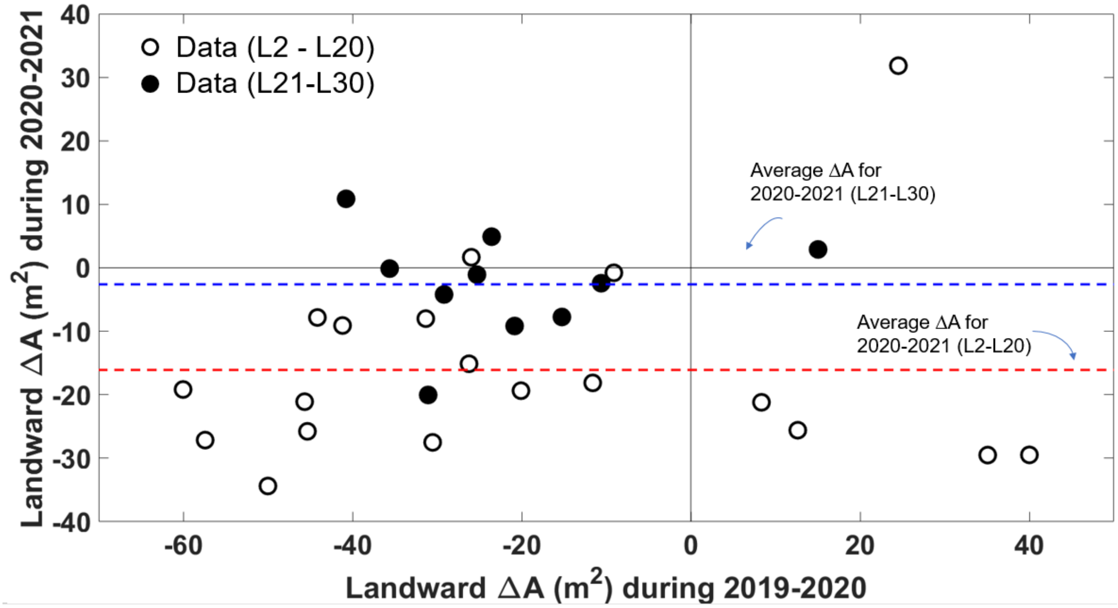


Figure 3.6 Comparison between landward ΔA during 2019–2020 and 2020-2021 where small ΔA for L21-L30 during 2020-2021.

Sand placed in the landward zone may be eroded and transported to the seaward zone or in the downdrift direction (Figlus and Kobayashi 2008). Figure 3.7 compares the area changes in the landward and seaward zones during 2020-2021. The correlation between the landward and seaward area changes was practically zero during 2020-2021 as was the case with the duration of 2019-2020 (Laksanalamai and Kobayashi 2021). The range of ΔA = (-74)-99 m^2 in the seaward zone for 2020-2021 was definitely wider than the corresponding range in the landward zone. The wider range in the seaward zone persisted even for L21-L30. The area changes in the landward and seaward zones were not related on this nourished beach exposed to small waves with the average significant wave height of 0.2 m.

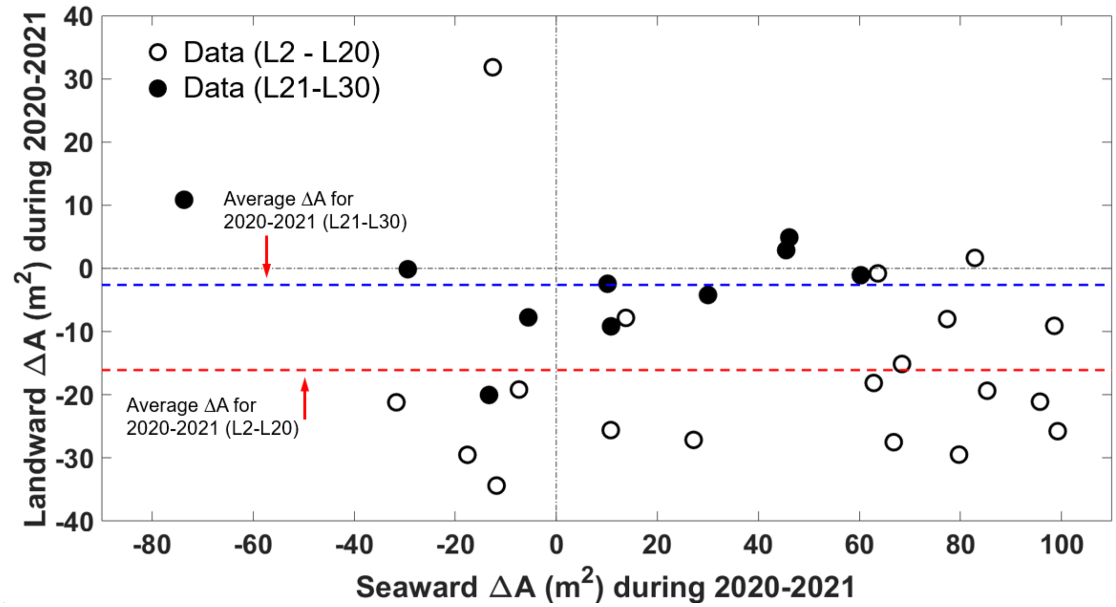


Figure 3.7 Comparison between seaward ΔA and landward ΔA during 2020–2021.

Figure 3.8 compares the area changes in the seaward zone during 2019-2020 and 2020-2021. The range of ΔA in the seaward zone during 2019-2020 was (-57)-95 m^2 with the average = 25 m^2 for L2-L20 and (-215)-(-63) m^2 with the average = -145 m^2 for L21-L30. The area changes were clearly different in the two alongshore zones. The range of ΔA during 2020-2021 was (-32)-99 m^2 for L2-L20 and (-74)-60 m^2 for L21-L30. The range of ΔA for L2-L20 was similar for 2019-2020 and for 2020-2021. The area changes for L21-L30 were very erosional for 2019-2020 but became more balanced between erosion and accretion. The cause of the drastic change in the seaward zone between L21-L30 from 2019-2020 to 2020-2021 is uncertain but might be related to tidal currents. Offshore tidal currents were measured in 1993. Flood and ebb tidal currents were in the range of 0.3-0.5 m/s. The numerical prediction of sand transport by waves and currents is beyond the scope of this study.

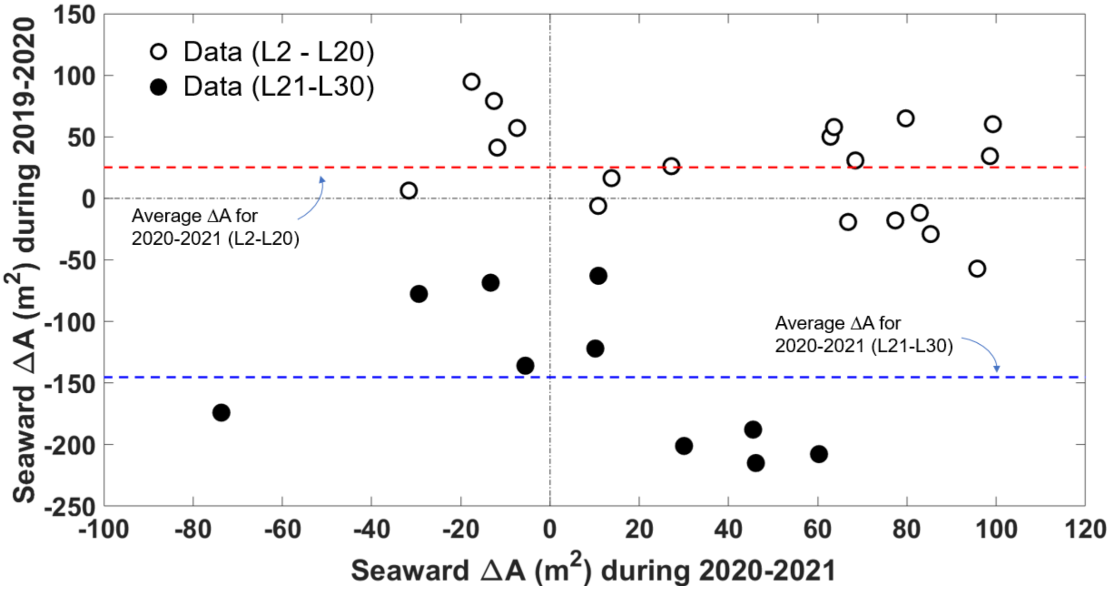


Figure 3.8 Comparison between seaward ΔA during 2019–2020 and 2020-2021.

3.5 Sand volume changes

Sand volume changes (ΔV) for each of the 29 segments are calculated using the alongshore length of each segment (Figure 3.1) and the beach profile area change along each cross-shore line (Table 3.1). Sand volume changes in the landward and seaward zones between L1-L20 and L20-L30 are presented in Figure 3.9. Three points represent all the cross-shore lines at the offshore distance of -10, 100, and 700 m. The curved line of -10 m corresponds to the vertical wall with its crest elevation of 3 m. The curved line of 100 m separating the landward and seaward zones terminates near the head of the north groin. The curved line of 700 m is the seaward boundary of noticeable bottom elevation changes in this study, but the bottom elevation changed somewhat outside the study area (Figure 2.3). The data for 2015-2019 presented by Laksanalamai and Kobayashi (2021) are included in Figure 3.9 to interpret the sand volume changes during 2015-2021.

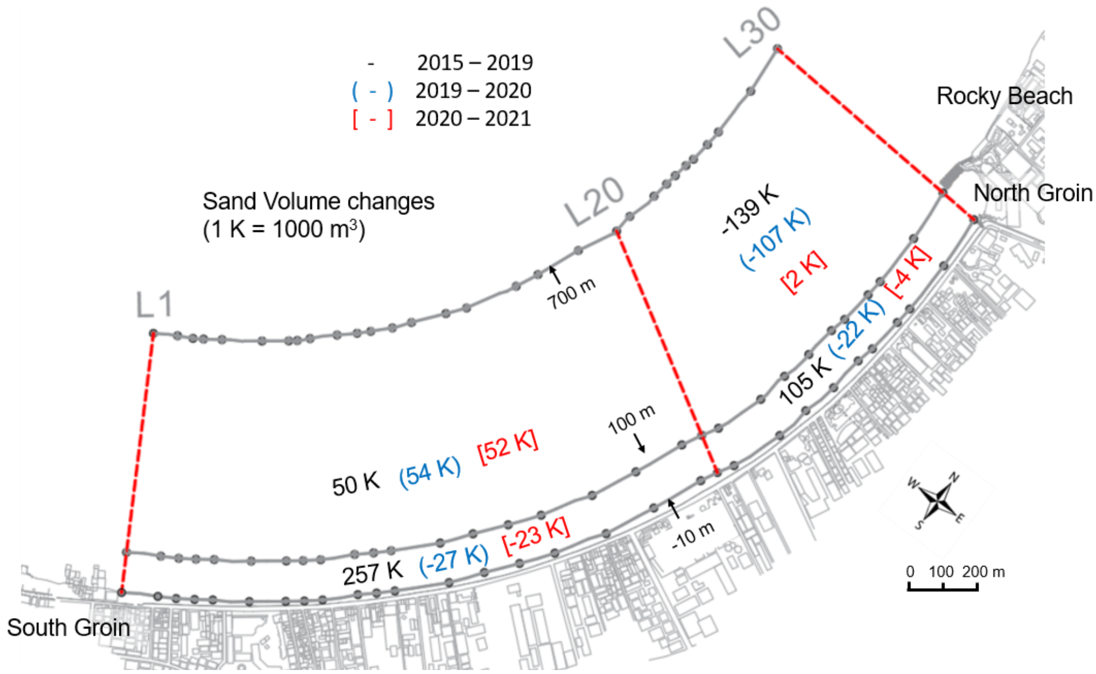


Figure 3.9 Sand volume changes in landward and seaward zones during 2015–2019 in comparison with those changes (in parentheses) during 2019–2020, and (brackets) during 2020-2021, where points (solid circles) along each of L1–L30 are located at the offshore distances of -10, 100, and 700 m.

Figure 3.9 presents the measured sand volume changes concisely. The sand placement in the landward zone before the 2019 survey increased the sand volume by 257K (1K=1,000 m^3) and 105K between L1-L20 and L20-L30, respectively. The negative values in the parentheses and brackets indicate the lost sand volumes during 2019-2020 and 2020-2021. The total lost volume was 49K (13.5% of 362K) during 2019-2020 and 27K during 2020-2021. The destination of the lost sand was searched in the survey data. The lost sand could have been transported northward by waves from the southwest and deposited behind the north groin and north of L30 (Figure 2.2d). However, the sand volume change in this area was -7K during 2019-2020. This area was essentially full because of the sand placement in 2018. The sand loss between L1-L20 was 27K during 2019-2020 and decreased slightly to 23K during 2020-2021. On the other hand, the sand loss between L21-L30 decreased from 22K during 2019-2020 to 4K during 2020-2021, possibly because of the nourished profile approaching equilibrium (Figure 2.4). The erosion trend in the landward zone in Figure 3.6 was continuing between L1-L20 but diminishing between L21-L30.

In the seaward zone, the deposited sand volume between L1-L20 was 50K (54K) [52K] during 2015-2019 (2019-2020) [2020-2021], and the eroded sand volume between L20-L30 of 139K (107K) during 2015-2019 (2019-2020) became practically negligible (2K) during 2020-2021. The persistent accretion trend between L1-L20 and the diminishing erosion trend between L21-L30 are apparent in Figure 3.8. The profile area changes in the landward and seaward zones of a nourished beach are expected to be correlated because of cross-shore sand transport (Figlus and Kobayashi 2008). Figure 3.7 suggests little correlation between the two zones during 2020-2021 as was the case during 2019-2020 (Laksanalamai and Kobayashi 2021). The destination of the eroded sand from the nourished landward zone is uncertain at present. The source of the deposited sand in the seaward zone between L1-L20 is unknown

Chapter 4

Conclusions

The performance of the first major beach nourishment project in Thailand was assessed using the bathymetry and topography survey data after the nourishment. The nourished berm with the foreshore slope of 0.1 was eroded under low wave energy. No bar was formed seaward of the eroded zone. No sand accretion was found behind a terminal groin filled with sand. Morphological changes associated with breaking waves and wave-induced currents were subdued or absent in the low wave energy environment. The destination of sand eroded from the nourished foreshore was uncertain. In the seaward zone outside the surf zone, bathymetric changes were affected little by the foreshore erosion. Measurements of currents, waves, and sand transport are required to trace the fate of the nourished sand on the foreshore and to clarify the causes of the bathymetric changes in the seaward zone. The bathymetry and topography survey should be continued to improve the design of beach nourishment in the environment of low wave energy and limited availability of sand.

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