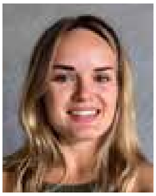
IMPACT OF SAND FENCES ON DUNE EVOLUTION AT VEJBYSTRAND

SANDSTAKETENS PÅVERKAN PÅ DYNUTVECKLING VID VEJBYSTRAND



Anna Hamilton
Robert Jacobsens Vej 44C, 2300 Copenhagen S, Denmark
Email: ahamilton635@gmail.com

Abstract:
Ängelholm's coast has eroded considerably in the past decade in part due to a period of frequent storms. As climate continues to change, parameters that increase erosion such as sea level rise and storm frequency will become exacerbated. Adaptation measures must be put into place in order to mitigate the impacts of coastal erosion. This study aims to test the viability of sand fences as an adaptation measure on Vejbystrand in Ängelholm municipality by considering sand volume change, development of backshore morphology, and vegetation presence. Two types of fences were put up in the south of Vejbystrand. This study tested for any difference in volume accumulation between fence types and found that there was no significant difference. Eight survey measurements over the course of two years were analysed and compared to an area with no fence. The rate of accumulation was shown to be significantly faster at all four fence sites than at a site with no fences. All of the fence sites have established an incipient dune and gained vegetation during the study period though no notable difference in species richness was found. The results show that sand fences are a viable adaptation measure for coastal erosion on Vejbystrand.

Key Words: coastal erosion, Vejbystrand, sand fences, LiDAR, remote sensing, climate change adaptation

Sammanfattning
Under en period av frekventa stormar de senaste tio åren har Ängelholms kust drabbats av kraftig strand-erosion. Parametrar som förstärker erosionen, som stigande havsnivåer och frekventa stormar, kommer att öka i takt med klimatförändringar. För att mildra kusterosionen måste kommuner börja anpassa sig. Syftet med studien är att testa effekten av sandstaket som ett anpassningsalternativ på Vejbystrand i Ängelholms kommun. Studien har sett till volymförändringar, förändringar i morfologin på den övre strandzonen, och vegetationens mångfald. Två olika typer av staket har satts upp. Studien testade om det fanns skillnader i volymförändringar under studieperioden mellan de olika staketen och hittade ingen signifikant skillnad. Åtta mätningar tagna under två år analyserades och jämfördes med ett område utan staket. Takten av sandackumulationen visades vara snabbare vid områden med sandstaket. Alla staketområden har börjat etablera en frontdyn och mer vegetation, men ingen signifikant skillnad i mångfalden hittades. Resultaten från studien visar att sandstaketen är en bra anpassningsmetod mot den kusterosion som pågår på Vejbystrand.

1 Introduction

Coastal erosion is an ongoing problem in Ängelholm municipality and across coastal communities in southern Sweden. Ängelholm's coast, situated in the Skälderviken bay, is made up both of sandy and rocky beaches. Gradients in longshore sediment transport subject sandy beaches in Skälderviken bay to local erosion and accretion (Almström and Fredriksson, 2011). Due to the low-pressure zone along Sweden's West coast, the area experiences a winter storm period which further exposes the coast to erosion (Gyllenram, Johansson, and Nerheim, 2017). During storms, erosion occurs, and the sediment is deposited in the nearby coastal system. During calmer wave conditions the sediment transport is directed onshore. This helps rebuild the beach while wind transports the sand towards the dunes. The combined effect of storm surges and large waves have caused dune erosion almost every year in the past decade (Palalane et al. 2016). The recent period of frequent storms (between 2011 and 2016) has drawn attention to the vulnerability of the coast as well as put into question what the future holds as climate continues to change.

Dune systems protect developed areas near the coast from high wind speeds and flooding. Previous studies have pointed out vulnerable areas along Ängelholm's coast (Almström and Fredriksson, 2011; Fredriksson and Larson, 2015; Ising et al., 2016; Hamilton, 2018; Hamilton, 2019), and some adaptation measures have since been implemented. Across Europe it is widely agreed that soft, as opposed to hard, measures are most effective in the long term (Salman et al., 2004). Soft measures, such as beach nourishment and vegetation planting, attempt to mimic natural processes whilst hard constructions, such as gabions or seawalls, are more permanent and prevent erosion in a specific location. Hard constructions, however, often come at the cost of displacing erosion elsewhere (de Vriend et al., 2015; Williams et al. 2017).

As infrastructure and residential areas continue to be built near the coast, and the coastline continues to retreat, coastal squeezing occurs. Coastal squeezing is when the space in between manmade constructions and the coastline diminishes (Hanson, Fredriksson, and Larson, 2017). With this in mind, the best way to adapt to erosion is perhaps to give the coast space to develop naturally by implementing managed retreat, which would eliminate the problem of coastal squeezing and increase coastal adaptability (Williams et al., 2017). In areas such as Ängelholm where infrastructure and communities are well established near the coast, this solution is both complex and expensive. Therefore, in places such as Ängelholm, adaptation measures are necessary to protect coastal areas from erosion and degradation. In September 2017 the municipality implemented four sand fences on the south of Vejbystrand beach. Sand fences are more dynamic than traditional hard structures as they attempt to reinforce natural processes. Still, the effect of sand fences on morphology and function is largely uncertain (Nordstrom et al., 2012).

1.1 Aim

The aim of this study is to identify the impact of sand fences as an adaptation measure for erosion by studying changes in sand volume, morphology, and vegetation around two different types of sand fences on Vejbystrand in Ängelholm municipality. This area is of interest because it was damaged by the recent storm period and has been found to be vulnerable to erosion (Hamilton, 2018). Two netted jute and two braided Salix fences were implemented along the backshore near the dune system, and eight survey measurements have since been made at the four fence sites. These measurements provide insight into seasonal differences in backshore development. It is expected that both fence types have helped accumulate sand, develop the backshore of the beach, and increase vegetation area. It is further expected that the majority of accumulation will have occurred during summer seasons when vegetation is present to help bind sand, and winds are calmer and directed onshore.

2 Background

2.1 Coastal dune morphology and erosion

Dune morphology is dependent on a combination of many different processes some of which include wind and wave climate, sediment characteristics, and vegetation growth (Sloss et al., 1993). Dune systems play an important function in protecting the coast from strong winds and flooding, which makes it important to have an understanding of their changing morphology, especially during storms.

Incipient (embryonic) dunes are formed in front of the established dune system as a result of sediment accumulation, and they help build up the existing dune. Vegetation helps establish these incipient dunes but cannot prevent them from being completely eroded after severe storms. If the dunes survive, they may grow to become an established foredune. Thus, where sand is deposited in the beach system matters for long-term dune evolution (Sloss et al., 1993; Hallin, 2019; Hesp, 1989). Additionally, both manmade and natural variability in dune morphology has been shown to encourage species richness which in turn supports ecological resilience (Nordstrom et al., 2012). Vegetation, wind, climate, and seasonal variation all play a role in determining sand deposition. Ice and snow cover inhibit transport during windy periods (winter) whilst vegetation helps bind sand in the summer. Local vegetation differences may also play a large role in landward dune migration (Hesp, 2002).

Sediment placement and dune morphology can give insight into the long-term sediment budget of a beach. Accreting beaches form incipient dunes where vegetation is present because the dunes do not have time to grow in height whilst eroding and stable beaches often form dune ramps (Christiansen and Davidson-Arnott, 2004). Though many factors influence long-term dune morphology and sediment budget, this study will only consider sediment deposition and volume, as well as vegetation species and cover when assessing the effectiveness of the sand fences. Sediment deposition and volume provides insight into the evolution and durability of the entire dune system, and vegetation is a critical component for keeping the sand in place and encouraging dune growth. These factors can help determine the viability of sand fences as a future adaptation measure in Ängelholm and areas with similar erosion problems.

2.2 Sand fences as an adaptation measure

Beach systems attempt to maintain relative balance, so when storms are frequently eroding the dunes, the system does not have time to repair itself. Adaptation measures such as sand fences can help speed up the natural recovery process. Sand fences are a short-term adaptation measure that help bind sand and build up the dune system. They help control the distribution of sediment deposition by encouraging accumulation and may also help protect existing dunes and vegetation by redirecting people around sensitive parts of the beach (Almström and Fredriksson, 2012; Nordstrom et al., 2012). Vegetation growth and sand accumulation create a feedback mechanism as sand accumulation encourages vegetation growth at the same time as vegetation encourages the accumulation of sand (Kuriyama et al., 2005; Durán and Moore, 2013; Schwarz et al., 2018). To expand the understanding on how sand fences impact morphology and function, a study by Nordstrom et al. (2012) identified the impact of sand fences and raking on dune morphology in Avalon, New Jersey. Variables that their study considered important for the protection of the shore and natural habitat included dune crest height, dune and upper backshore volume, beach width, species richness and presence. Due to limited data availability, this study will not consider all of these variables, but will take into account dune crest height, backshore volume and species presence. Nordstrom et al. (2012) found that dune crest heights in managed areas (with sand fences and raking) were found to be higher than in unmanaged areas (no fences or raking), while dune volume and beach volume were larger in unmanaged areas. Ultimately, sand fences sped up dune formation and encouraged a high crest that could reinforce new crests evolving seaward (Nordstrom et al., 2012).

The way in which sediment accumulates and develops around sand fences is poorly understood. Hotta et al. (2015) conducted a study to better understand these processes through a series of wind tunnel experiments testing three fence combinations. The study concluded that when using a single beach fence with a porosity higher than

30% sand mainly accumulates behind the fence, forming a wide dune with mild slope. Other fence porosity and position combinations were tested, however, a fence with at least 30% porosity best describes the fences on Vejbystrand (though exact levels of porosity are unknown).

2.3 Study area

2.3.1 Coastal protection in Ängelholm

Dunes naturally protect the coast by acting as a barrier for flooding and high wind speeds, making them an important function of a balanced coastal system. The dunes in Ängelholm are degraded by frequent storms that prevent self-reparation of the system, by tourism which increases flow of people, and by manmade developments that degrade the dunes (Almström and Fredriksson, 2011). Erosion adaptation methods in Ängelholm have included a mixture of hard and soft measures such as stabilizing dunes with a gabion core, dune replenishment, beach nourishment, and vegetation planting (Hallin, 2019). Dune rehabilitation has been implemented in Havsbaden (in northern Ängelholm beach) and plans are underway for a new beach nourishment project (SGU, 2019; Thiere, 2018).

Vegetation planting along the dunes has been used to prevent erosion and help rebuild the natural dune system after storms. Since the 19th century, Marram and Lyme-grass were planted to help bind sand and prevent sand drift (Gullander, 1975). In the early 20th century, the Rosa rugusa, a beach rose species native to Japan, was largely planted in south Sweden but has since proven to be invasive (Engström, 2007). This demonstrates how it is not only interesting as to whether vegetation is present along the dunes, but which vegetation is present.

2.3.2 Vejbystrand

The southern half of Vejbystrand's dune system is most vulnerable in part because of its position near a primary entry point to the beach, which naturally encourages passage through and near the dunes (Hamilton, 2018). Additionally, there is a difference in vegetation cover from north to south, with the northern dunes dominated by the sand-binding Rosa rugosa whilst the southern dunes are covered by native grasses and other vegetation (Almström and Fredriksson, 2011).

Figure 1: *Sand fence sites and survey measurements are shown to the left, while the fences and the cross-shore profiles are seen in the figure on the right. Study areas stretch up to 10 m from the fence in either direction, and profiles vary between 15 and 20 m in length.*

In September 2017, four sand fences were placed parallel to the dunes in the southern part of Vejbystrand to enhance dune recovery. Two different fences were constructed, one made from jute mesh netting and the other made from braided Salix. Both of these are a natural, biodegradable materials which is important when being placed so near the marine environment. The jute fence is 60 cm in height whilst the Salix fence is 120 cm. The latter was designed by Eva Thulin, a resident to Vejbystrand, who the municipality has continued collaboration with in order to monitor changes. The fences were constructed at four separate sites and are approximately 25 m long. With the exception of the first fence which is placed 100 m north of the other three, the fences are spaced within 10 m of one another. Survey measurements documenting elevation change have been taken approximately four times per year in attempt to monitor seasonal variations, though the amount of time in between measurements is varied. During the last survey in September 2019, an additional measurement was made in the north of the beach where there are no fences. The placement of the fences, as well as the measurement points and cross-shore profiles are seen in Figure 1 below.

3 Data and methods

This study used both GIS and remote sensing techniques to determine volume changes around the sand fences, particularly on the upper backshore. Field visits and photo documentation were used in order to identify and monitor changes in vegetation near the sand fences. LiDAR data, orthophotos, and survey measurements were provided by Ängelholm municipality. Eight survey measurements were taken during the study period using a GPS Total Station with an accuracy of 1.5 cm (September 2017, April 2018, June 2018, September 2018, December 2018, February 2019, June 2019, and September 2019). Survey measurements were also taken at an area in the northern part of the beach in September 2019 to give indication as to how an area of Vejbystrand without sand fences has developed.

ArcMap 10.6 was used to make volume calculations and visualize the data. Volume (before the fences were set up) was calculated using LiDAR (25 cm) scannings from April 2010 and 2017. The raster was clipped to the respective areas and then zonal statistics (table) was used in order to calculate the absolute volume for each section.

To calculate the changes in volume from the field surveys, the XYZ data was imported into ArcMap and converted into a raster with 25 cm resolution (to match the existing LiDAR images) using the natural neighbor tool. Zonal statistics (table) was used to calculate the absolute volume for each section. Backshore volume change is a measure of the volume change along each cross-shore profile. An independent t-test was made to determine whether there was a difference in mean backshore volume change between the two fence types and an ANOVA was conducted to test for significant difference between all fence sites (regardless of type). An additional independent t-test was made to test for differences in sand accumulation between the four fence sites and the control site with no fence. Finally, in order to assess the change in morphology at each site, a cross-shore profile was drawn perpendicular to the middle of each site and a profile graph was created using Scalgo Live. A comparison between the cross-shore profiles and the respective changes in volume was made in order to assess morphological and volumetric changes. The rate of change between survey measurements was analyzed to account for differences in the amount of time between measurements and the corresponding seasonal differences.

Field visits were made each season (either by the municipality or local resident, Eva Thulin) to monitor changes and ensure the durability of the fences. The pictures from these studies are used to assess changes in vegetation cover and morphology. In June 2019, a field visit was made together with a botanist expert on beach vegetation to identify vegetation along the backshore and the dunes surrounding the fences. This information was compiled to assess the species richness, or number of species, at each fence site.

Figure 2. *Photographs from the study area before (left) and 2 years after (right) the fences were set up. These photos were taken from the south side of Vejbystrand in June 2017 and 2019 respectively.*

4 Results

4.1 Estimated change in volume during the study period

The pictures taken during the field visits show that the volume of sand around the fences has increased and the morphology and width of the dune system has changed. Figure 2 below shows the fourth fence before (left) and after (right) the fences were introduced. It is apparent that the morphology of the backshore has changed and that a difference in vegetation cover exists. This will be further expanded upon in section 5 below.

Table 1 presents the total volume for each fence site recorded for each survey measurement. The volume of each site was also calculated for 2010 and 2017 (using the LiDAR data) in order to provide a comparison for how the area has previously dispersed sand, and are shown in red. It is important to note again that there was a period of frequent storms between 2011 and 2016. LiDAR data is also more reliable than the survey measurements because of the higher resolution of the data collection method. Though the same resolution raster (25 cm) was interpolated from the survey points, the original resolution is not the same. The GPS survey still provides a good estimate for volume changes and has the advantage of being a cheaper alternative which can allow for more frequent measurements.

Between 2010 and 2017, there was an overall decrease of 1804 m^3 of sand across the four fence sites, most of which came from fence sites 3 and 4. The amount of sand displaced in between 2010 and 2017 increases progressively in a southward direction, with the control site and fence site 1 being the least affected, and fence site 4 the most affected. The greatest increase in sand volume during the study period is seen at fence 3, followed by 1, 2, 4, and then the control site. Since the fences were implemented in September 2017, approximately 450 m^3 of sand has made its way back to the study area each year (approximately 900 m^3 over the two-year period). Though the overall trend during the past two years has been positive,

Table 1: *Absolute volume (in m^3) for each fence area on Vejbystrand for each measurement during the study period.*

	LiDAR 2010	LiDAR 2017	17/09	18/04	18/06	18/09	18/12	19/02	19/06	19/09
1	1632	1604	1651	1796	1781	1810	1839	1858	1883	1889
2	2388	1948	2027	2181	2147	2117	2221	2235	2249	2255
3	2160	1554	1564	1656	1634	1701	1759	1766	1788	1820
4	1779	1049	1048	1080	1079	1130	1162	1176	1204	1215
Control	1549	1399	X	X	X	X	X	X	X	1426

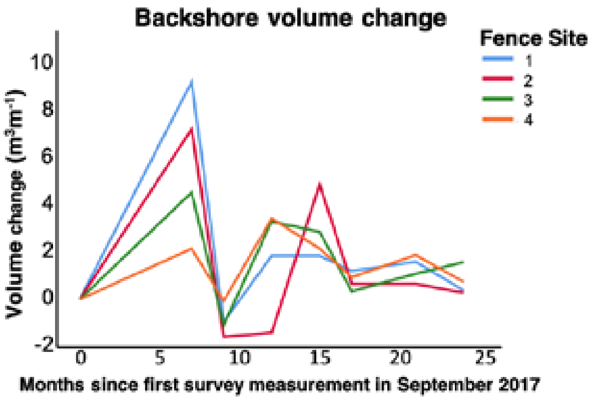


Figure 3: *This figure shows the rate of volume change between each survey measurement since the first survey measurement in September 2017.*

the volume lost between 2010 and 2017 has not yet been recovered. Since the LiDAR scanning in April 2017, the control site gained a significantly less amount of sand (27 m^3) compared to the areas with fences (mean across the four fence sites = 256 m^3) during the study period ($p<0.05$).

Differences between the jute and Salix fences were analyzed using an independent t-test. No significant difference was found ($p>0.05$). Additionally, the ANOVA test did not find any significant difference between any of the fences ($F_{3,28}=0.081$, $p>0.05$). Volume change was calculated between each survey measurement. Figure 3 shows the rate of change (in m^3 m-1) between each measurement. The initial rate in volume change between September 2017 and April 2018 is highest during the study period. Between the second measurement in April 2018, and the third meas-

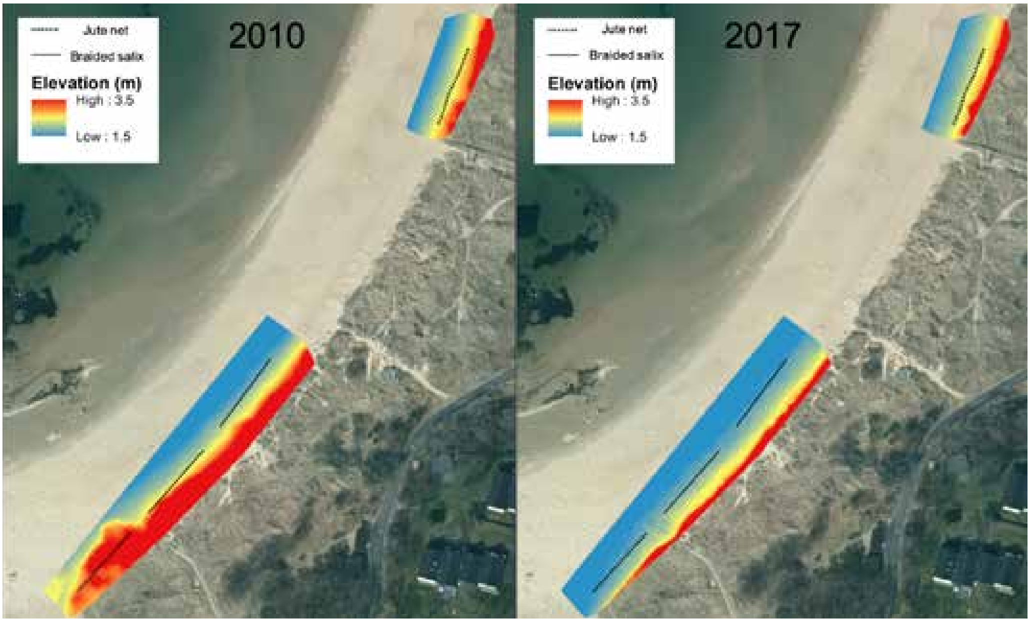


Figure 4: *Elevation before (left) and after (right) a storm period in the areas surrounding the sand fences which were set up in September 2017.*

Figure 5: *Pictures showing the seasonal differences in sand accumulation along the sand fences on Vejbystrand during 2018. Fence 1 in March 2018 is seen in the top left corner. The same fence is seen in September 2018 on the top right. Fence 2 in March 2019 is seen on the bottom left and the same fence is seen in September 2018 on the bottom right. The pictures taken in March are by the author and the pictures from September are taken by Geraldine Thiere, Ängelholm municipality.*

urement in June 2018, all fence sites experienced a decrease in volume. By December 2018 the second fence has rapidly gained sand. Sand continues to accumulate throughout the winter season for the remaining fences but at a slower rate. Between February 2019 and June 2019, the rate of accumulation begins to increase again and is slowed down during the summer.

4.2 Morphological changes during the study period
A visual representation of the area in 2010 and 2017 is presented in Figure 4 below. The elevation is delimited to visualize heights between 1.5 and 3.5 m in order to provide a relative comparison for all of the measurements (both LiDAR and survey). The morphological change during this period highlights the impact of frequent storms on dune morphology. Though the entire dune system has

Figure 6: *Pictures showing the seasonal differences in sand accumulation along the sand fences in Vejbystrand during 2019. Fence 3 in April 2019 is seen in the top left corner. The same fence is seen in June 2019 in the top right. Fence 4 in March 2019 is seen in the bottom left and the same fence is seen in June 2019 in the bottom right. The pictures taken in June are by the author and the pictures from April/March are taken by Eva Thulin, resident in Vejbystrand.*

retreated, the southern-most study sites were the most heavily impacted.

The following images show the change during the first year of the study. The pictures to the left show each of the fence types in March (after a winter season) and in September (following a summer season).

During the second year of the study period, even more drastic morphologic changes are seen:

Most of the change is seen behind the fences, close to the existing dune system. Figure 7 below shows the different fence sites and total elevation between 1.5 and 3.5 m.

These figures highlight where the majority of sediment is being dispersed and give indication to how the foredunes are being formed. There has been an overall seaward extension of the foredunes and though it appears that most of the change has

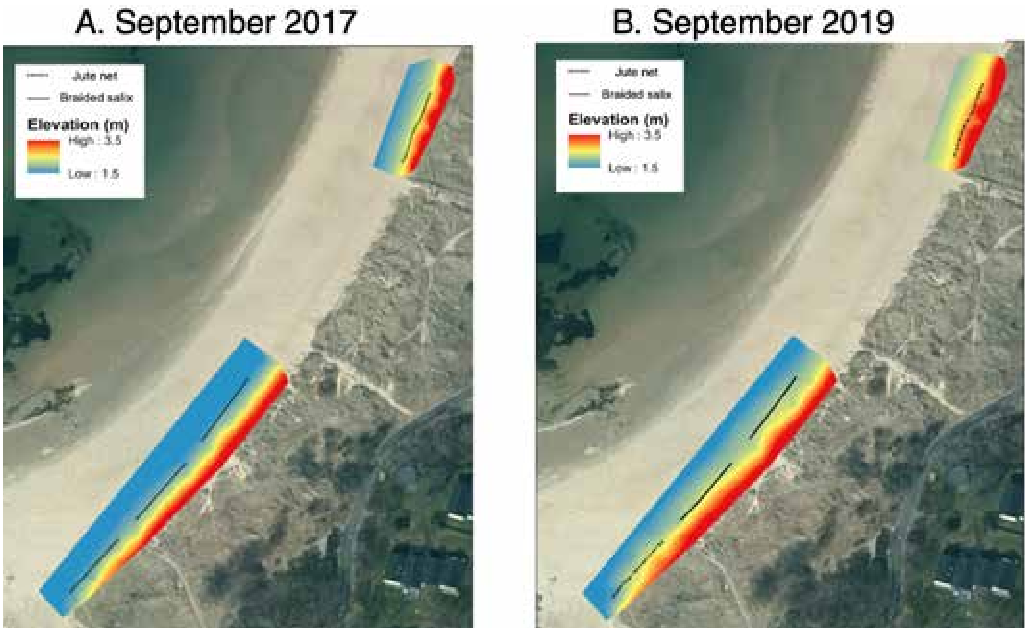


Figure 7: *Elevation model for the first (A) and last (B) survey measurement of the study period.*

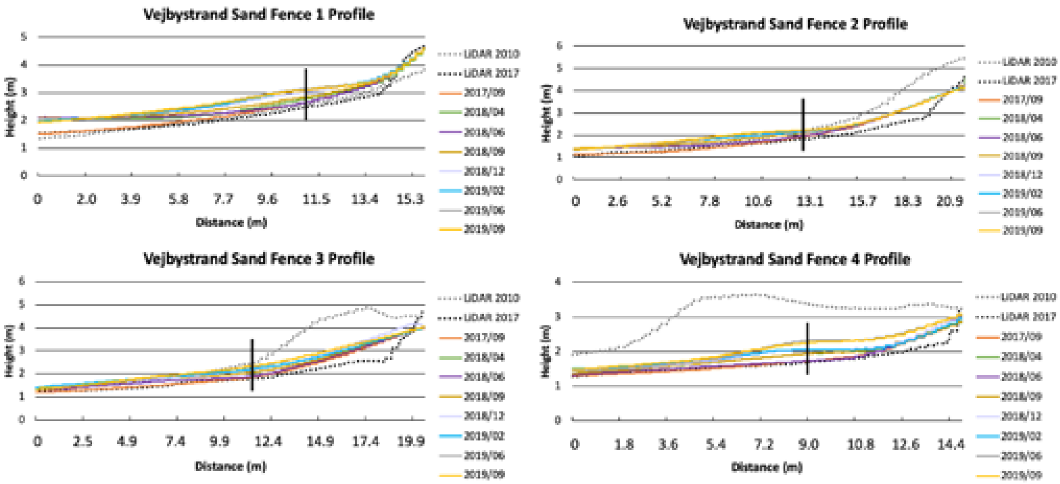


Figure 8: *Vejbystrand sand fence cross-shore profile progression. The vertical black line shows the sand fence placement along the profile (height of fence is not to scale).*

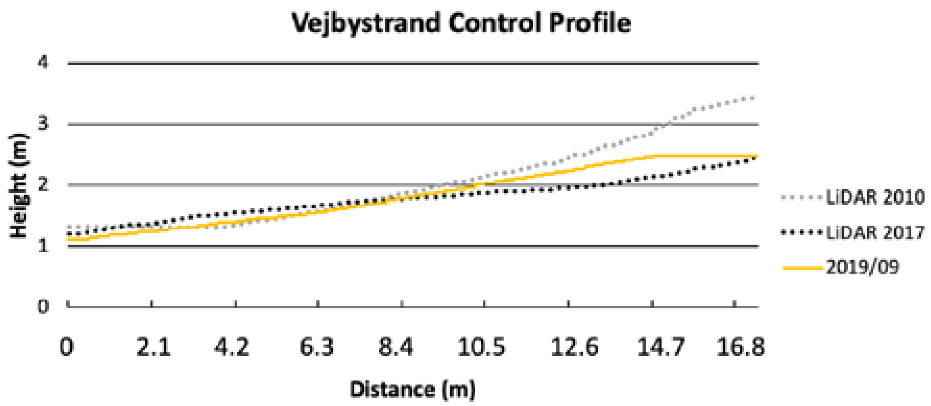


Figure 9: *Vejbystrand control site cross-shore profile*

occurred along the first fence, fence 3 has experienced the greatest increase in volume as shown in section 4.1. This is further discussed in section 5.2.

Cross-shore profiles were drawn perpendicular to the middle of each fence in Scalgo Live. The profile placements are seen in Figure 1. The profile graphs seen in Figure 8 highlight the drastic change between 2010 and 2017, especially for fences 3 and 4. The 2017 LiDAR profiles are much steeper at the dune foot showing inundation from the recurring storms. The 2010 LiDAR profiles for fence 3 and 4 extend further seaward than the profiles at fence 1 and 2. All of the graphs show that there has been a positive progression of the profiles since 2017.

Figure 9 below shows the profiles at the control area in the northern part of Vejbystrand. Similar to the sites with fences, the cross-shore profile at the control site eroded between 2010 and 2017 and has since begin to build up.

4.4 Change in vegetation cover and species diversity

The pictures in Figure 10 show the change after one and two summer seasons for each of the fence types. Despite seasonal differences in blooming of certain vegetation types between these two months, there is a clear increase in vegetation area.

By analyzing aerial images, we can see how the vegetation cover has changed and even get some insight into species presence. Identifying specific species, however, requires observation in the field . Figure 11 shows the sand fence placement in relation to how the beach looked in 2010 (left), 2017 (middle) and 2018 (right). The vegetation line, as well as the entire dune system, retreated between 2010 and 2017. By 2018 some strips of vegetation can be seen behind the fences and parallel to the dune system.

These results coincide well with the profiles in Figure 8 above which show drastic changes to the profiles perpendicular to fence sites 3 and 4 between 2010 and 2017, and a relatively fast recovery since the fences were implemented in 2017. Besides vegetation cover, present-day species richness was also considered. A vegetation inventory was done in June 2019 and the results are found in Table 2 below. Ten different species were found at the sites surrounding fence 1, 2, and 4, and twelve species were found at site 3. No significant difference in species richness was found. The most common beach grasses are present at all four fence areas, with other vegetation spread out randomly among the fences.

Figure 10: *Pictures showing the differences in sand accumulation along the sand fences in Vejbystrand from Summer 2018-2019. Fence 2 in September 2018 is seen in the top left corner. The same fence is seen in June 2019 in the top right. Fence 3 in September 2018 is seen in the bottom left and the same fence is seen in June 2019 in the bottom right. The pictures are taken by the author.*

5 Discussion

5.1 Changes in sand volume

The volume calculated for 2010 is used as a relative comparison because the storm period had not yet begun and no other elevation data for the entire beach exists prior to this. The amount of sand accumulated has not been replenished to what it was in 2010 at fences 2, 3, 4, or at the control site. However, fence site 1 has reached a volume greater than it was in 2010. The northern part of the beach is known to be less vulnerable than the south because of wind and wave climate that erode the southern dunes. Additionally, less sand was initially lost from the storms at this site. Though only one survey measurement was made at the control site, the data shows that the sites with fences have accumulated sand at a significantly faster rate. The decrease in volume at all of the fence sites between April 2018 and June 2018 is likely due to the lack of sand-binding vegetation during this time. Over the summer, sand begins to accumulate except at fence site 2 which continues to lose sand but at a slower rate. The continued loss of sand at fence site 2 is interesting and could be because of yearly differences in vegetation, however, more data over a longer period of time is needed to confirm this. Calmer winds and blooming vegetation otherwise help bind sand during the summer. All of the fences continue to gain sand into the winter but at a slower rate with the exception of fence site 2 which accumulates sand faster than the rest. The generally slower pace of accumulation can be explained by the lack of sand-binding vegetation into the fall and winter seasons, offshore winds, and presence of ice which discourages accumulation. During the following spring, the rate of accumulation picks up at all fence sites which is best explained by the increase in vegetation during the spring and calmer, onshore winds. It is interesting that sand was lost during the previous spring (between April and June 2018). This could be due to yearly variation in vegetation but could also be attributed to the feedback mechanism between sand accumulation and vegetation presence which strengthens as more sand accumulates. Between June 2019 and September 2019, the volume continues to increase as expected during the summer.

There was no significant difference in volume change between fence type or between fences; thus, it cannot be said that sand accumulation is dependent on fence type. Instead, it may have more to do with geographic location, morphology, and other factors. Additionally, the Salix fences are taller and sturdier, and therefore may outlast the jute fences. Until a storm tests this, however, no concrete conclusion can be drawn as to which fence is more resilient.

5.2 Changes in backshore morphology

Most of the volume is concentrated behind the fences themselves, close to the existing dune system which is likely related to the porosity of the fences (Hotta et al., 2015). This accumulation of sediment around the fences has led to the buildup of incipient dunes rather than a dune ramp, which according to Hallin (2019) happens when vegetation is present and is indicative of an accreting beach.

The elevation models in Figure 7 show that the first fence has experienced the greatest increase in volume, however, this apparent increase is because the initial elevation is higher at this site, as seen in Figure 8. The profiles at each of the fence sites show a general accretion trend and the formation of an incipient dune just behind the fences. As explained by Hotta et al., (2015), this is due to the high porosity of the fences which allows sediment to pass through and accumulate on the dune side of the fence. The formation of the incipient dunes, and the general increase in crest height and width indicates an expansion and strengthening of the dune system, as seen in the study by Nordstrom et al. (2012). There is still a large gap between the profiles from September 2019 and those from 2010. How these profiles will continue to develop and whether or not they will replicate the 2010 profile would be interesting for future studies to consider.

5.3 Changes to vegetation cover and species diversity

The Salix fences were the first to have vegetation establish around them, nonetheless, the difference in vegetation cover at the end of the study period

Figure 11: *Sand fence placement in relation to 2010 (left), 2017 (middle), and 2018 (right) orthophotos*

Table 2: *Species presence along the sand fences in Vejbystrand*

Name (English)	Name (Swedish)	Fence Site Presence
Sea rocket	Marviol	1,2,3,4
Prickly Saltwort	Sodaört	1,2,3,4
Oak	Ek	4
Lyme-grass	Strandråg	1,2,3,4
Sand Couch	Strandkvickrot	1,2,3,4
Marram	Sandrör	1,2,3,4
Sea Sandwort	Saltarv	1,2,3,4
Lady's Bedstraw	Gulmåra	1,2,3,4
Orpine	Kärleksört	1
Frosted Orache (red listed)	Sandmålla (rödlistad)	3
Spear-leaved Orache	Spjutmålla	1,4
Wild Pansy	Styvmorsviol	1,2
Canadian Fleabane	Kanadabinka	2
Mugwort	Gråbo	2
Smooth Sow-thistle	Mjölktistel	2,3
Canadian hawkweed	Flockfibbla	2,3,4

is small. It is more interesting that the fences appear to perpetuate the feedback loop of vegetation growth and sand accumulation by encouraging sand to settle around the fences.

The results show that there is no difference in species richness; however, two interesting species were noted in the field: Oak and Frosted Orache. Oak is uncommon on beach faces but is a natural flora in the region which has positive implications for biodiversity. Frosted Orache is a red-listed species and therefore rare to find. The lack of Rosa rugosa likely contributes to the biodiversity in this region of the beach. Still, it is not possible to say exactly how the species richness is affected by the fences as no previous inventorying has been done. However, it is known that a difference in vegetation exists between the north and south and that the south was hit harder during the storm period.

5.4 Critique and future studies

The results from the study show that both fence types influenced sand accumulation. Comparing the results of the four fence sites to an area without fences show that the fences have helped speed up the restoration process. The results from the study confirm that the sand fences have helped accumulate sand in comparison to an area without fences, regardless of fence type. Still, there is question as to where the sand would otherwise have ended up if no fence was in place. More comprehensive elevation data (such as LiDAR) in addition to bathymetric data would be needed to determine this. With such data, future studies could account for the distribution of sediment along the entire beach as well as the underwater movement of sediments. Additionally, a sandbar exists at the south end of Vejbystrand. Because sandbars often form after a severe storm, it would be interesting to study the migration patterns of the bar along with accumulation patters at the fences to see if any correlation exists. Further analysis could also be made between areas with and without fences to get a better idea of how areas with fences would otherwise have developed.

This study was delimited to a small area of beach surrounding the fences. Limitations exist with the data as well. The measurements were unevenly spread throughout the year and no survey measurements exist prior to fence implementation. Additionally, the profiles only represent a very small section of the entire sand fence can therefore not be said to represent the entire fence site. Changes in species richness and vegetation cover should be further analyzed because of the importance vegetation has for both a healthy dune system and ecosystem. This study had limited data to work with, but future inventories and use of near infra-red data could help better understand the relationship between vegetation and sand fences.

5 Conclusion

The results from the study show that the sand fences have had a positive influence on the backshore system of Vejbystrand. The fences have contributed to sand accumulation which perpetuates the feedback loop of vegetation growth and sand accumulation. During a frequent storm period before the fences were implemented (2010 to 2017), nearly 2000 m^3 of sand was displaced from the four sand fence areas. Though the total volume of sand lost after 2010 has not been fully recovered, since the fences were implemented in September 2017, the trend has been positive with approximately 900 m^3 gained across the fence sites over the two years. No significant difference between the jute and Salix fences was found. All fences gained more sand during the spring and summer than during the rest of the year which can be attributed to the wind and wave climate as well as presence of sand-binding vegetation. The results also show that the fences have helped establish an incipient dune and help strengthen the existing system. Ultimately, beach fences are a viable adaptation measure that should continue to be implemented in Ängelholm. Follow up is needed, especially after storms, in order to test fence durability and the permanence of the incipient dunes. If the incipient dunes are ephemeral, and are washed away during a storm, the fences will still have served the purpose of building the dune system. If they survive, then the new foredunes will continue to strengthen and expand the dune system.

Acknowledgements

I would like to thank Ängelholm municipality for financing this project and providing all of the data. Specifically, I would like to thank Geraldine Thiere for her support and guidance throughout the project. I would also like to thank Carline Hallin for all of her suggestions and comments, as well as Eva Thulin for her dedication and contributions to this project.

6 References

Almström, B., and Fredriksson, C. (2011) Stranderosion i Ängelholms kommun — Inventering av nuvarande förhållande och rekommendationer för framtiden. Sweco. pp. 1-42.

Almström, B., and Fredriksson, C. (2012) Hållbar strandförvaltning för Ängelholms strand. Sweco. pp. 1-29.

Christiansen, M.B., and Davidson-Arnott, R. (2004) Rates of Landward Sand Transport over the Foredune at Skallingen, Denmark and the Role of Dune Ramps. Geografisk Tidsskrift-Danish Journal of Geography, vol.104, pp. 31–43.

de Vriend, H.J., van Koningsveld, M., Aarninkhof, S.G.J., de Vries, M.B., and Baptist, M.J., (2015) Sustainable hydraulic engineering through building with nature. Journal of Hydro-Environment Research vol. 9, pp. 159–171.

Durán, O., and Moore, L.J. (2013) Vegetation controls on the maximum size of coastal dunes. Proceedings of the National Academy of Sciences of the United States of America, 110, 17217–22.

Engström, R. (2007) Att inventera rosor: en handledning. Lund: Centrum för Biologisk Mångfald.

Fredriksson, C., and M. Larson. (2015) Behovsanalys för strandfodring vid Ängelholms strand. Faculty of Engineering, LTH. pp. 1-46.

Gullander, B (red). (1975) Linné i Skåne: Carl Linnaeus dagboksmanuskript från Skåneresan 1749, utdrag ur den publicerade reseberättelsen 1751 – huvudsakligen där dagboksark är försvunna – samt ur andra tryckta arbeten: en antologi. Stockholm, P. A Norstedt & Söners förlag.

Gyllenram, W., L. Johansson, and S. Nerheim, (2017) Oceanografi 125. Lokala effekter på extrema havsvattenstånd. SMHI. pp. 1.54. ISSN: 0283-7714.

Hamilton, A. (2018) Coastal erosion in Ängelholm: a case study tracking recent and historical changes to Vejbystrand. Lund: Lund University.

Hamilton, A. (2019) Metoder för systematisk uppföljning av kusterosion i Ängelholms kommun. Ängelholm: Ängelholm Municipality. Available at: https://www.engelholm.se/download/ 18.7ede-207416ca2ab8ec550c3/1567435971346/2019%20%C3%84ngelholms%20kommun.Metoder%20f%C3%B6r%20systematisk%20uppf%C3%B6ljning%20av%20kusterosion%20i%20%C3%84ngelholms%20kommun.pdf. (Accessed 19 July 2019)

Hallin, C. (2019) Long-term beach and dune evolution: Development and application of the CS-model. Lund: Water Resources Engineering, Lund University.

Hanson H., Fredriksson C., and Larson M. (2017) Kustordlistan.se – An Eng-Swe-Eng Coastal Dictionary for engineers and planners. VATTEN – Journal of Water Management and Research, vol. 72, pp.79-90.

Hesp, P. (1989) A review of biological and geomorphological processes involved in the initiation and development of incipient foredunes. Proceedings of the Royal Society of Edinburgh. Section B. Biological Sciences, 96, 181-201. doi:10.1017/S0269727000010927.

Hesp, P. (2002) Foredunes and blowouts: initiation, geomorphology and dynamics. Geomorphology, vol. 48, pp. 245–268.

Hotta, S., Sunamura, T., and Larson, M. (2015) Wind tunnel study on two-dimensional sand accumulation forms around sand fences. Coastal Sediments Conference 2015. DOI:10.1142/ 9789814689977_0044

Ising, J., J. Nyberg, K. r. Persson, and L. Rodhe (2016) Skånes känsliga stränder – erosionsförhållanden och geologi för samhällsplanering. SGU. Pp. 1-61.

Kuriyama, Y., Mochizuki, N., and Nakashima, T. (2005) Influence of vegetation on aeolian sand transport rate from a backshore to a foredune at Hasaki, Japan. Sedimentology vol. 52, pp. 1123–1132.

Nordstrom, K. Jackson, N., Freestone, A., Korotky, K., and Puleo, J. (2012) Effects of beach raking and sand fences on dune dimensions and morphology. Geomorphology, vol. 179, pp. 106-115.

Palalane, J., Fredriksson, C., Marinho, B., Larson, M., Hanson, H., and Coelho, C. (2016) Simulating cross-shore material exchange at decadal scale. Model application. Coastal Engineering vol. 116, pp. 26–41.

Salman, A., Lombardo, S., and Doody, P. (2004) Living with coastal erosion in Europe: Sediment and Space for Sustainability: A guide to coastal erosion management practices in Europe. EUCC. Available at: http://discomap.eea.europa.eu/map/Data/Milieu/OURCOAST_195_DE/OUR COAST_195_DE_Doc1_EurosionGuideEurope.pdf (Accessed: 05 August 2019)

Schwarz, C. Brinkkemper, J., and Ruessink, G. (2018) Feedbacks between biotic and abiotic processes governing the development of foredune blowouts: a review. Journal of Marine Science and Engineering, vol. 7(1), 2.

SGU. (2018) SGU Map Viewer. Retrieved April 18 2018, from https://apps.sgu.se/sgumapviewer/ tmpout/sgupdf1849165658916019912.pdf.

SGU. (2019) SGU ger tillstånd till begränsat uttag av havssand i Skälderviken. SGU. Available at: https://www.sgu.se/om-sgu/nyheter/2019/februari/sgu-ger-tillstand-till-begransat-uttag-av-havssand-i-skalderviken/ (Accessed: 05 August 2019).

Sloss, C.R., Shepherd, M., and Hesp, P. (2012) Coastal Dunes: Geomorphology. Nature Education Knowledge 3(10):2

Williams, A., Rangel-Buitrago, N., Pranzini E., and Anfuso, G. (2017) The management of coastal erosion. Ocean and Coastal Management. vol. 156, pp. 4-20.