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The Impact of Human Development on Coastal Dune Habitats

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Table of Contents:

Word Count: 8052

1. Acknowledgments:

We would like to acknowledge Nicola Anderson who helped refine the presentation of the results and for sharing her knowledge on the structure and conduction of field work.

2. Abstract:

Coastal dunes are a vital part of several ecosystems, providing a habitat for many coastal species as well as acting as a natural barrier against the ocean's elements. For these reasons, it is important to understand the effects that human development has on coastal dune habitats. The study involved the analysis of 10 dune systems along the south-east coast of Tasmania between July and August, 2020. All of these dune sites had varying levels of human development, including industrial, residential and infrastructure development. Three aspects of each dune were studied; the morphology of the dune (shape of the dune), the vegetation coverage of the dune and the vegetation type succession of the dune. The vegetation coverage and type was measured using transect lines and the morphology was measured by recording the dune's height above sea level at various points. Human development within a close proximity to coastal dunes has the greatest impact on the habitats. Because the vegetation succession and coastal dune morphology are dependent on each other, the impacts of human development affected both of these dune features to similar extents.

3. Introduction:

Australia has the world's largest urbanised coastal dwelling population, with 90% of Australia's population living within 100km of the country's coastline (ABS, 2020**)**. These coastlines act as a significant habitat for many species of flora and fauna and also act as a protective barrier from the ocean's elements, such as swell, wind and tide (MESA 2015). Australia's coastal population has increased by 304% from 1950 - 2015 (Krockenberger M 2015). This substantial increase in human activity along Australia’s coastline has resulted in an increase in human development, causing devastating effects to the integrity of many coastal dune habitats. For these reasons, assessing the relationship between human activity and the welfare of dune habitats is essential for their protection and preservation.

Word Count: 8052

Whilst most Australians do not directly depend on resources provided by these sand dune ecosystems, species of flora and fauna, including threatened and endangered species, rely heavily on these ecosystems, as they provide a major habitat. Because humans do not directly depend on resources provided by sand dune ecosystems, there is a general lack of knowledge and conservation for sand dunes which ultimately results in a 'tragedy of the commons' scenario. This is where no individual sees their impact on coastal dunes as significant enough to contribute to the destruction of these habitats, and therefore they exploit the benefits of these areas, resulting in significant development on coastal dune systems.

Sand dunes provide a significant habitat in coastal regions and in providing this habitat they contribute to the preservation of coastal biodiversity, with dune habitats forming a part of many species' niche. "Biodiversity is the variability among living organisms. It includes the diversity within and between species, and the diversity of ecosystems." (Bayer, 2016). In damaging these dunes and decreasing the size of these habitats, human activity is contributing to the loss of biodiversity. This is because reduced habitat diversity provides species with less opportunities for competition, adaptation and evolution, and overall this weakens the genetic diversity of these species. (Templeton A, et al 2001)

Many of the dune habitats in the Primrose Sands, Dodges Ferry and South Arm regions experience different levels and types of exposure to human development. The sites cover a range of low development and high development areas, as well as a range of types, including infrastructure, residential and industrial development. In recognising that these regions, all within a close proximity to each other, have varying levels and types of human development, this Southern Tasmanian region displayed many traits which provide potential for an analysis which aims to determine the impacts of human development on coastal dune habitats. This paper aims to answer the inquiry question, "to what extent does human development impact on coastal dune habitat destruction?" This study will address the impacts of human development on the coastal dunes. In doing this vegetation coverage, vegetation type and dune morphology will be analysed.

Word Count: 8052

4. Procedure:

Equipment:

- Tape measure
- Meter square
- Tripod
- Phone
- Theodolite app
- Laptop
- Graph paper notepad
- Pen or pencil

Site locations:

Each site was chosen according to its level of human development and thus the level of human activity. Sites 1, 2, 3, 4 and 5 were located at South Arm, sites 6, 7 and 8, were located at Dodges Ferry and sites 9 and 10 were located at Primrose Sands. Each site posed differing levels of human development with the selected locations covering a range of low development types. Being in a similar area (southern Tasmania and south facing) all locations were exposed to similar weather conditions, meaning no beach has been exposed to significantly different wave, wind or tide patterns. These factors were considered when choosing site locations as they are critical in providing valid and comparable data.

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Figure 1: Satellite image of South Arm highlighting site locations 1 to 5.

(Google Maps, 2020)

Figure 2: Satellite image of Dodges Ferry and Primrose Sands highlighting site locations 6 to 10.

(Google Maps, 2020)

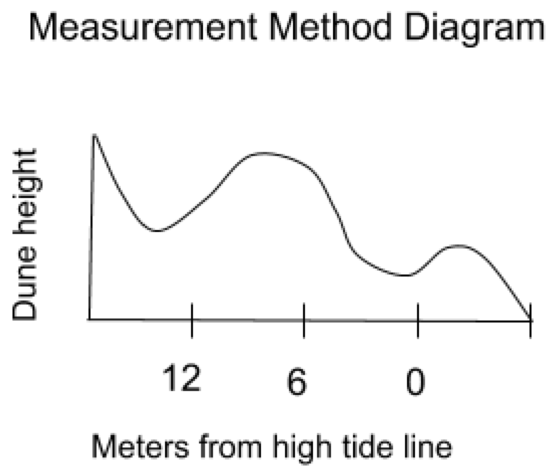
Word Count: 8052

Method 1 - transec line placement and measurement:

The meter square was placed flat on the ground at the high tide line and this position was recorded as position one with a distance of zero meters. The front edge of the meter square was running parallel with the shoreline. A photograph of the meter square was taken from the center of the square using a square framed camera. This photograph was taken from a height of 164cm using a tripod. From the back edge of the meter square a tape measure was used to measure a horizontal distance of five meters perpendicular to the shoreline in a landward direction so that a change in dune height or shape did not alter the distance between each quadrat (refer to figure 3). At the five meter mark the front edge of the meter square was placed flat on the ground running parallel with the shoreline. This position was recorded as position two with a distance of six meters (five meters measured plus one meter to account for the meter square). Using the same photographing technique the meter square was photographed. This process was repeated until it was considered that an accurate depiction of the dune vegetation was recorded. This method was used at all 10 dune locations.

Figure 3:

As seen below, the distance between each quadrat position did not account for change in dune shape.



Method 2 - dune topography recording:

The Theodolite app was used to measure the height above sea level for each quadrat position; these heights were plotted on graph paper. The change in dune shape between each quadrat was then estimated using the Theodolite app and a tape measure taking height above sea level measurements every meter. This shape was drawn to scale on the previously plotted graph paper. This method was used at all 10 dune locations.

Data Analysis:

The data was quantified by isolating the vegetation from the dune sand/sediment. This was done through Adobe Photoshop. The magnetic lasso tool was used to identify the colour contrast between the vegetation and the sand/sediment of the dune. Using the colour contrast, the lasso tool highlighted the areas covered by vegetation. Using the highlighted vegetation area, the number of pixels highlighted was then compared to the total pixels of the image to form a vegetation to sand/sediment ratio, which was then converted into a vegetation coverage percentage. The type of vegetation was categorised into six classes; dead (0), no vegetation (1), grasses (2), herbs (3), shrubs (4), and trees (5).

Word Count: 8052

Risk Assessment:

Table 1: Potential hazards and risk reduction.

What is the hazard	**How is it dangerous?**	**How will the risk be reduced?**
Falling or slipping on gravel car park surfaces	Results in grazes	Take precautions when walking across loose gravel surfaces, especially on slopes. Wear appropriate footwear for grip.
Cuts or abrasion from sharp branches	Cuts or abrasions on body	Wearing long pants and a long shirt. Wearing enclosed shoes will protect feet.
Slipping down face of a sand dune	Can cause injuries such as sprained ankles	Assessing the sand dunes before trekking over them. Carry only a suitable amount of equipment.
Navigating car parks and roads on foot to access beach	Possibility of being hit by moving vehicles	Ensure that precautions are taken when navigating car parks on foot. Stop, look, listen.

Ethical Considerations:

Consideration was taken to reduce the impact on the dune due to trampling and sediment movement. This was achieved by keeping to paths when accessing the beach to choose a site. When recording data, where trekking over the dune habitat was required, additional time and care was taken to ensure that steep dune slopes were avoided to prevent sediment movement. Vegetation was also avoided to prevent trampling. At each site, pollution introduced by humans was also removed. This was done to positively impact the dune habitats by reducing the likelihood of organisms being exposed to this pollution.

5. Results

For the raw data see the appendices (tables 2, 3, and 4).

Figure 4: Comparison of Site 1 dune shape to the corresponding vegetation coverage.

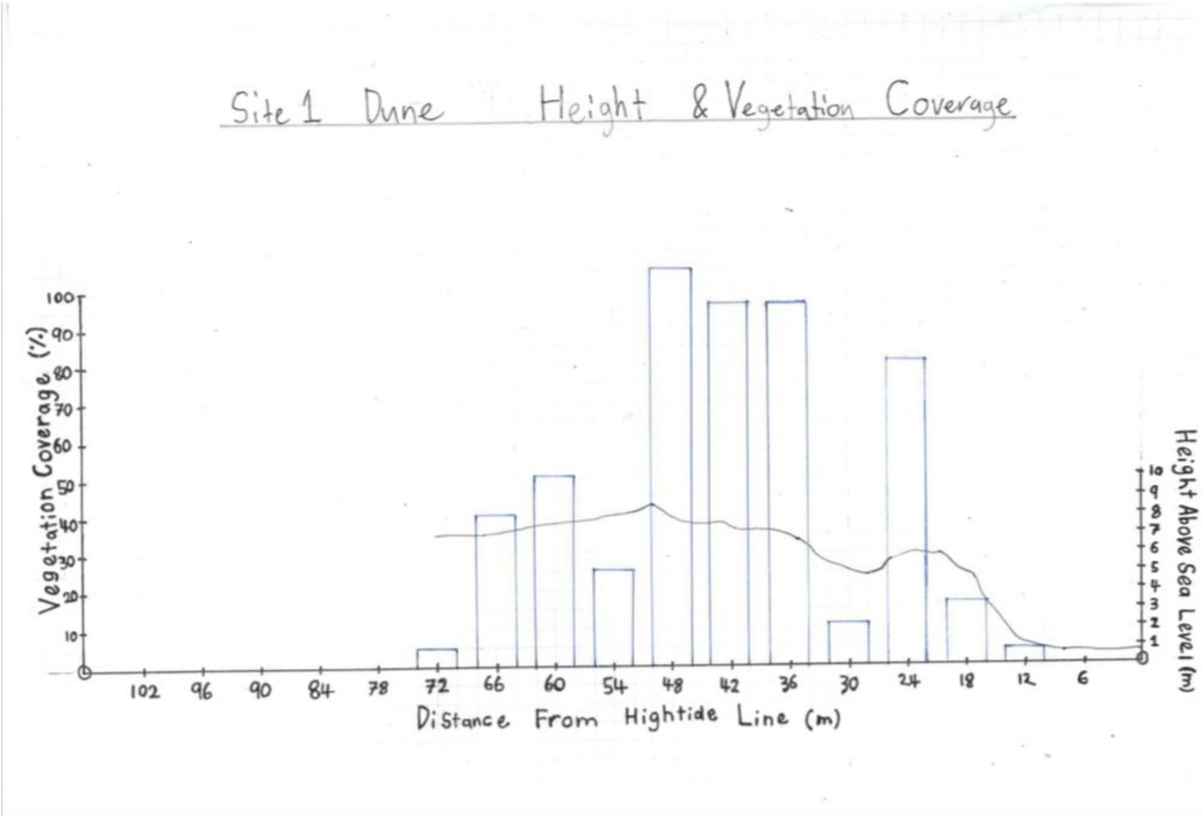


Figure 4 shows a lack of an incipient dune with a small plateau forming the foredune from 12 to 26 meters from the high tide line. The foredune has a maximum height of 6.1 meters. The trough forms from 26 to 32 meters with a height of 5.1 meters. The hind dune displays an increasing height from 32 to 50 meters (maximum height of 8.2 meters) and a decrease in height from 50 to 72 meters. Comparing the vegetation coverage to the dune height shows that the front of the hind dune has the greatest vegetation coverage reaching up to 100% coverage The vegetation coverage significantly drops from 54 meters to 72 meters where it was considered the dune ended.

Figure 5: Site 1 comparison of the vegetation type to the distance from the high tide line.

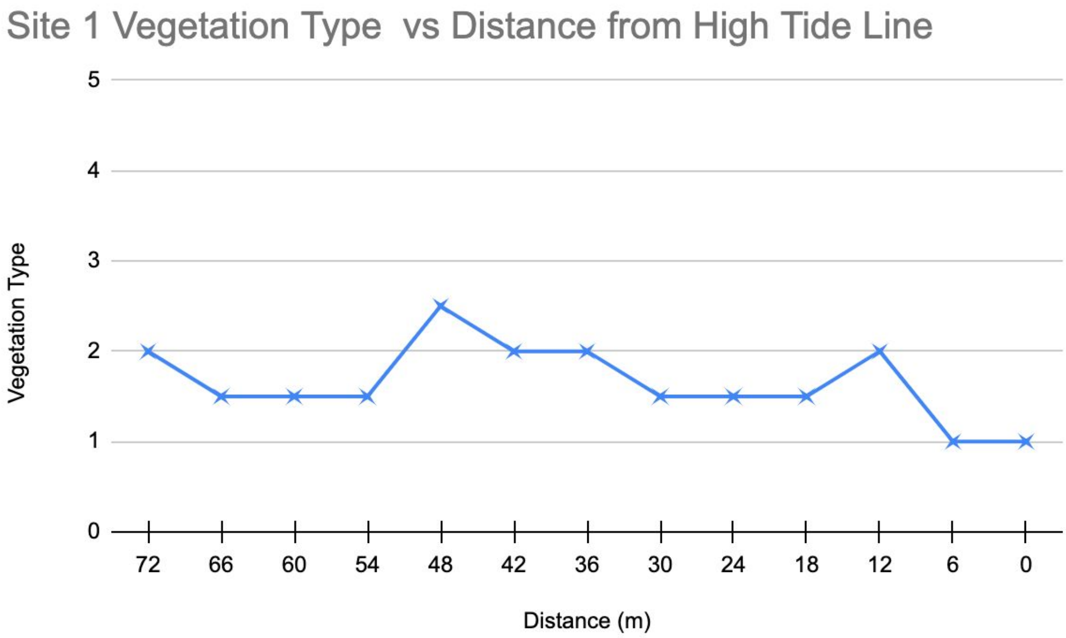


Figure 5 shows that Site 1 held a constant vegetation type trend of 1.5 - 2 for the majority of the dune. The only exceptions are from 0 - 6 meters where the type is 1 and at 48 meters, where the vegetation type increased to 2.5.

Figure 6: Comparison of Site 2 dune shape to the corresponding vegetation coverage.

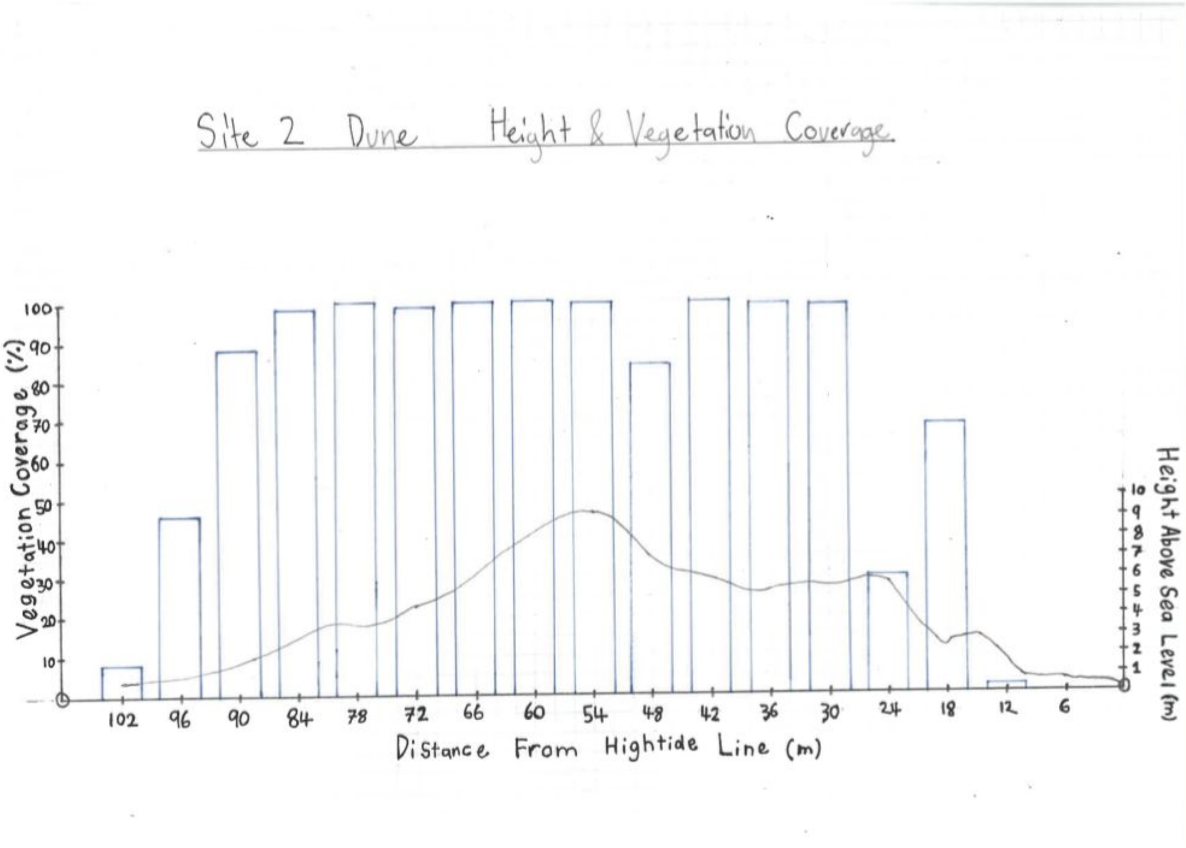


Figure 6 shows that the incipient dune starts at 6 meters from the high tide line and ends at 12 meters. The fordune covers the area from 12 to 26 meters and is separated into two sections by a small trough. The foredune reaches a maximum height of 5.9 meters. A shallow gradual trough then forms from 26 to 42 meters which has a minimum height of 5.0 meters. The hind dune displays a peak at 53 meters with a maximum height of 9.2 meters. The hind then gradually slopes down to a height of 1 meter above sea level at a distance of 100 meters.

The trough and hind dune display the greatest vegetation coverage with these areas ranging from mostly from 84.7% coverage to 100% coverage. The back of the hind dune, however, does see a significant vegetation coverage decrease. The small trough that separates the two foredune sections also has greater vegetation coverage.

Figure 7: Site 2 comparison of the vegetation type to the distance from the high tide line.

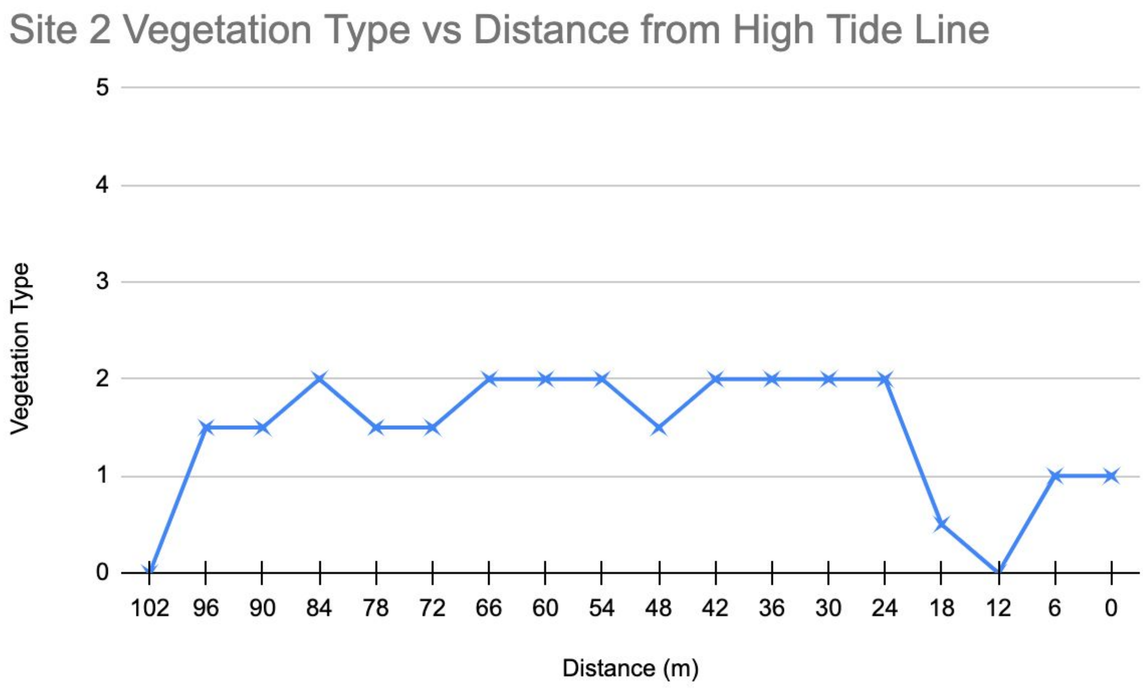


Figure 7 shows the vegetation type remained under 2 for the entire dune. The vegetation type was at 1 or below 1 from distances 0 - 18 meters and 102 meters. From 24 - 96 meters, the vegetation type held a consistent trend of 1.5 - 2.

Figure 8: Comparison of Site 3 dune shape to the corresponding vegetation coverage.

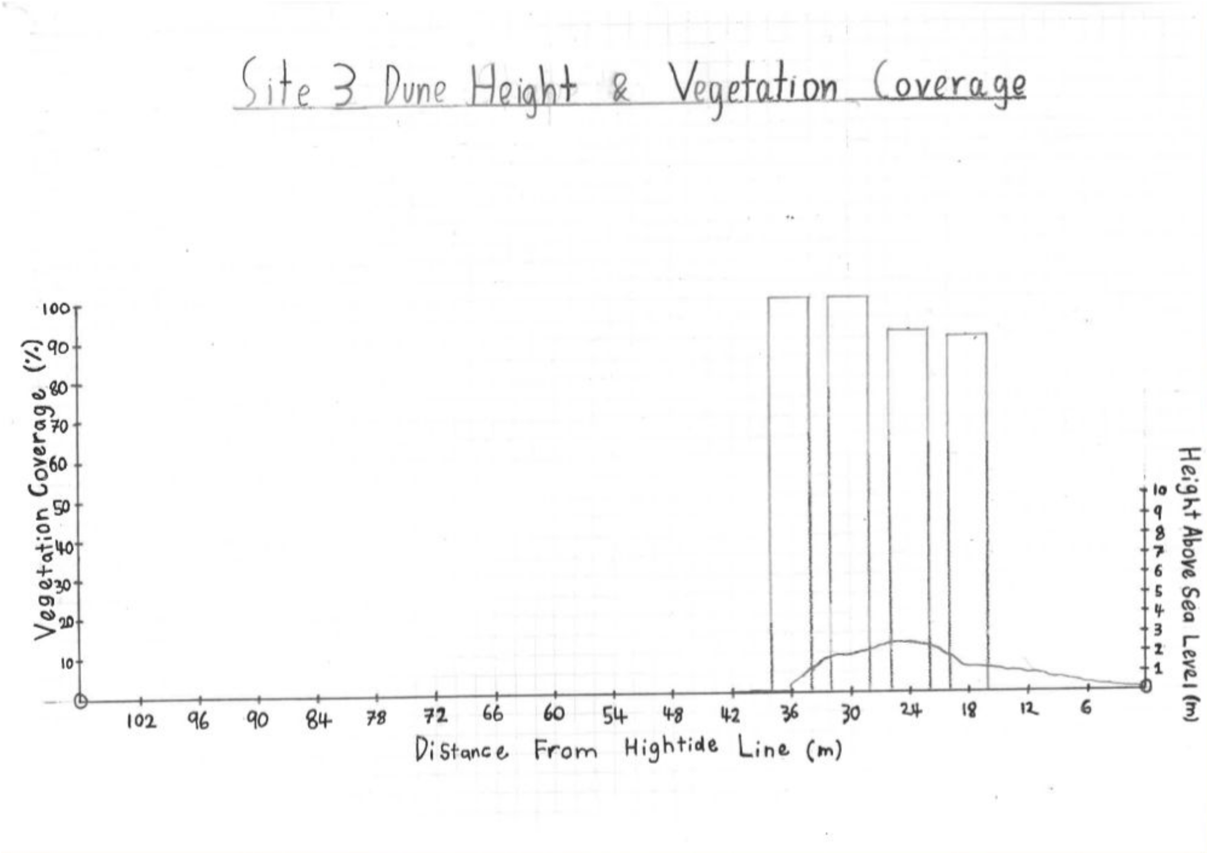


Figure 8 shows a short dune with a gradual and low profile. The incipient dune is positioned at 16 to 18 meters and is then followed by the foredune from 18 to 28 meters. The hind dune is located directly behind the foredune (no trough) from 28 to 36 meters. The maximum dune height of 2.4 meters is reached at 26 meters from the high tide line. The dune has dense vegetation coverage from 18 meters onwards with up to 100% coverage in areas.

Figure 9: Site 3 comparison of the vegetation type to the distance from the high tide line.

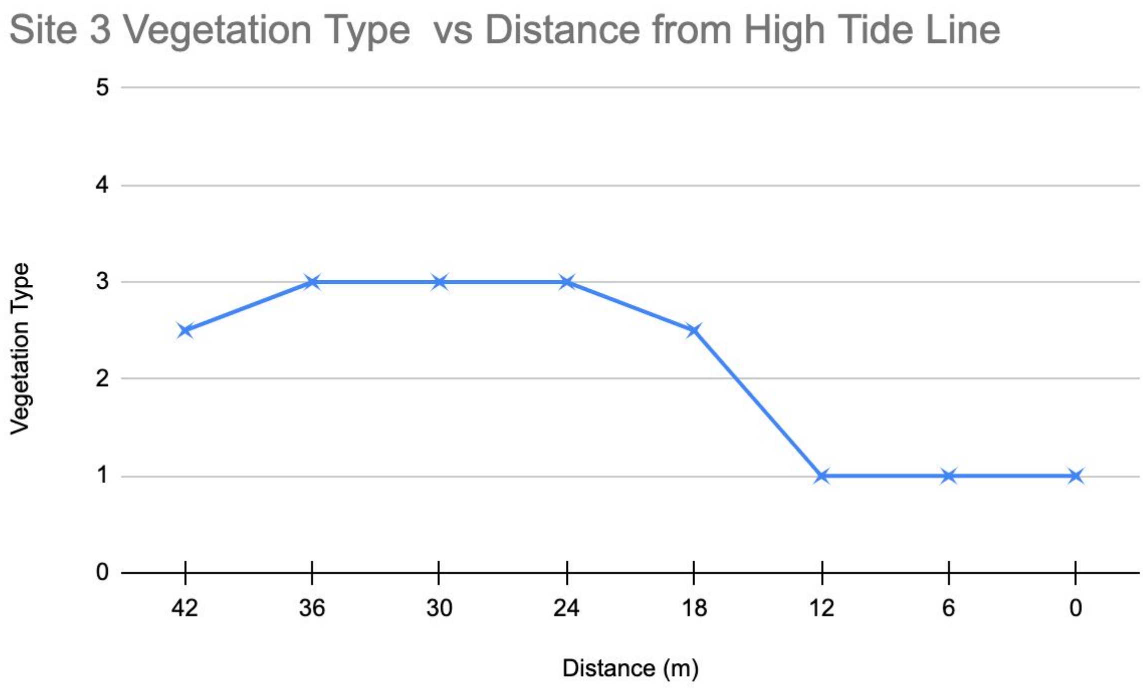


Figure 9 shows the vegetation type (1) remained constant from 0 to 12 meters, from there it increased to type 3 at 24 meters. A constant trend was seen as type 3 was maintained until 36 meters in which it decreased to type 2.5 at 42 meters.

Figure 10: Comparison of Site 4 dune shape to the corresponding vegetation coverage.

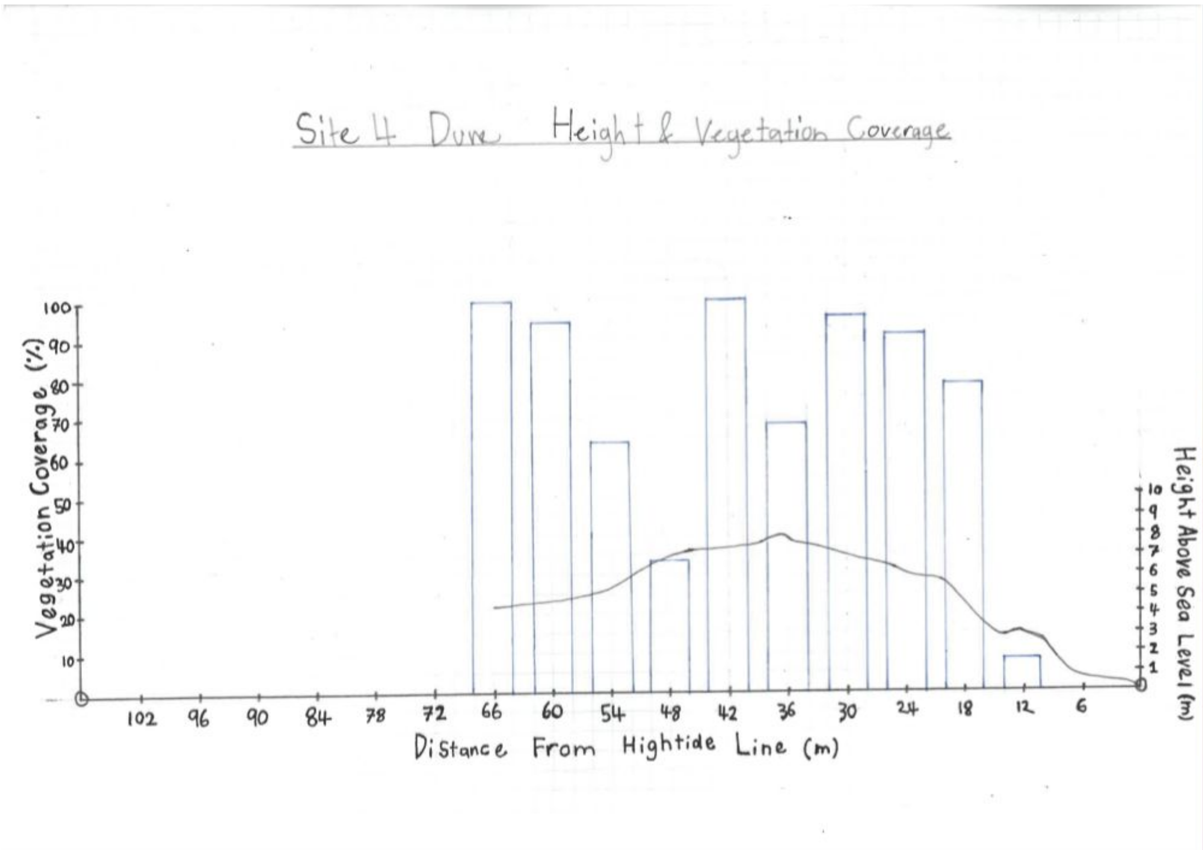


Figure 10 demonstrates a 66 meter dune with a height 7.9 meters. The dune does not have an incipient dune and has a small foredune spanning from 8 meters back from the high tide line to 13 meters back. The foredune reaches a height of 3.2 meters. There is a very small trough between the foredune and hind dune. The hind dune forms a round shape and spans from 16 to 66 meters back from the high tide line. The vegetation coverage is greatest on the hind dune, however the coverage does fluctuate. The coverage on the hind ranges from 34.5% to 100%. The foredune has low coverage of only 7.6%.

Figure 11: Site 4 comparison of the vegetation type to the distance from the high tide line.

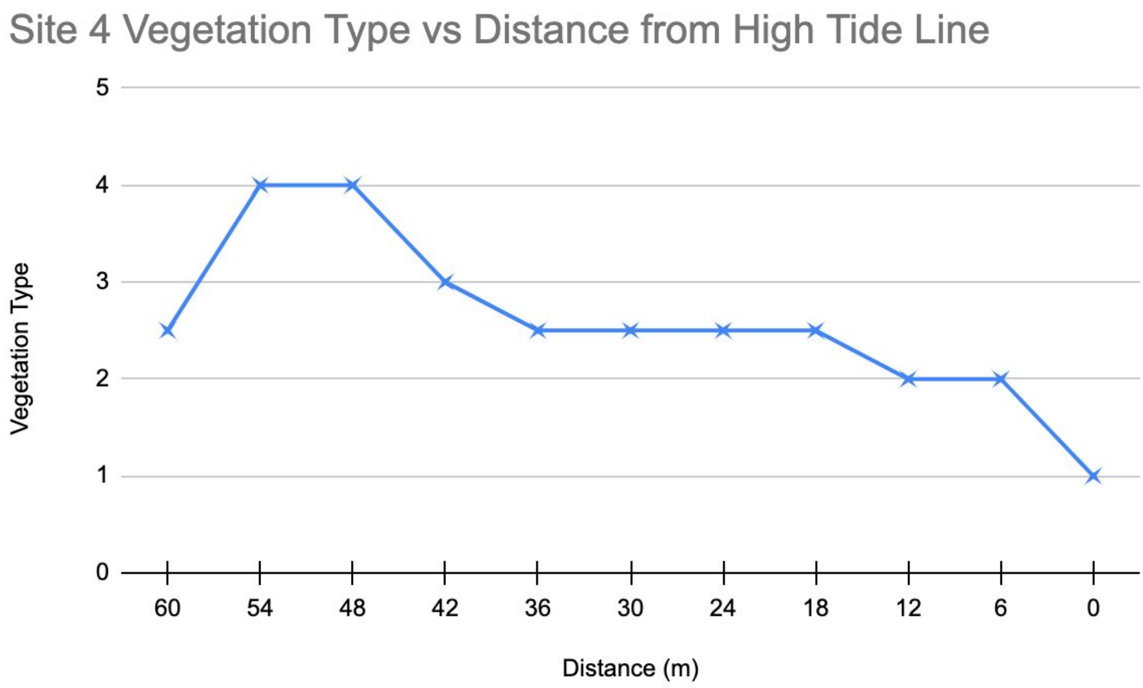


Figure 11 shows the vegetation type had a positive trend, increasing from type 1 to 3 from 0 to 54 meters with one point of regression at 60 (type 2.5) meters.

Figure 12: Comparison of Site 5 dune shape to the corresponding vegetation coverage.

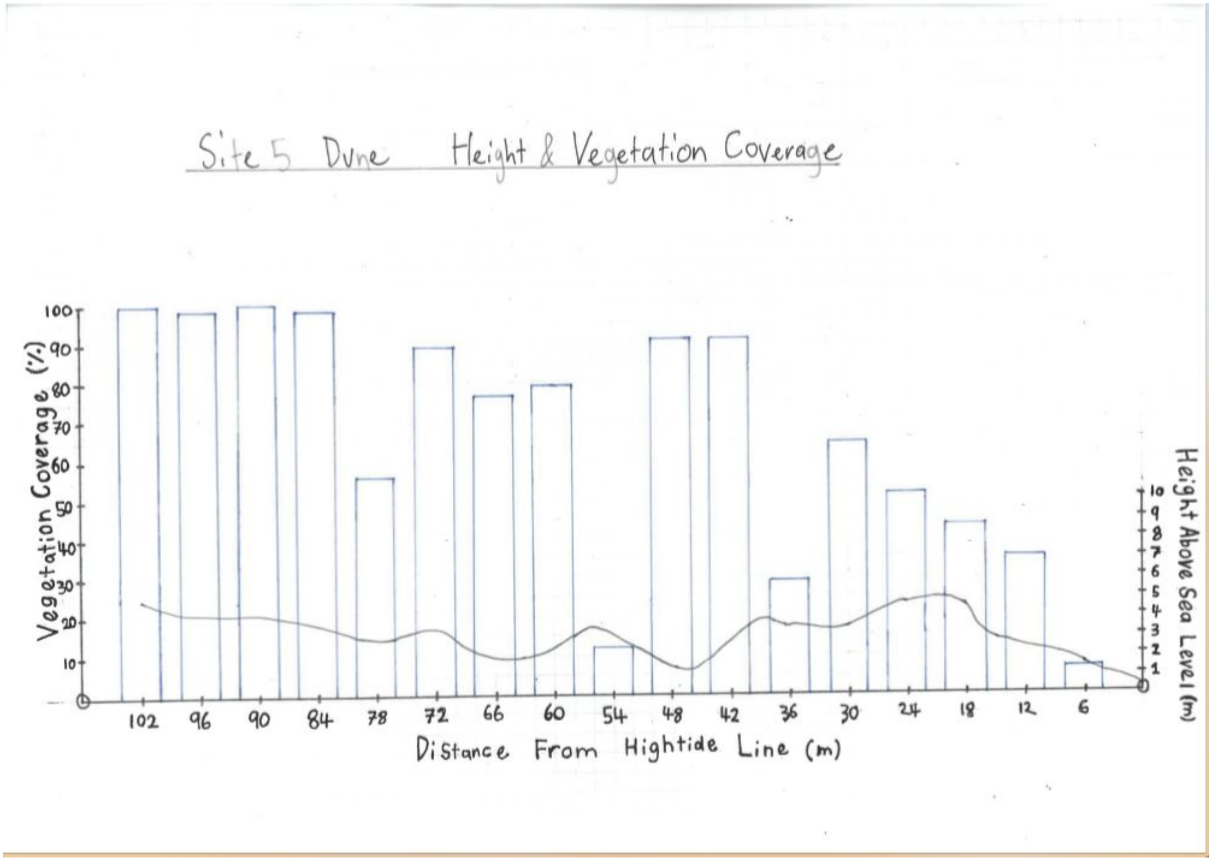


Figure 12 displays a dune with a fluctuating dune shape. The dune has an incipient from 6 to 14 meters back from the high tide line. The foredune ranges from 14 to 25 meters back from high tide, and reaches a height of 4.9 meters. This is the highest point of the dune. A small trough follows the foredune and a deeper trough follows this. The hind dune ranges from 56 to 102 meters back from the high tide line. The hind dune sits below the height of the foredune and gradually increases in height. The vegetation coverage ranges from 12.1% to 100% excluding the incipient dune.

Figure 13: Site 5 comparison of the vegetation type to the distance from the high tide line.

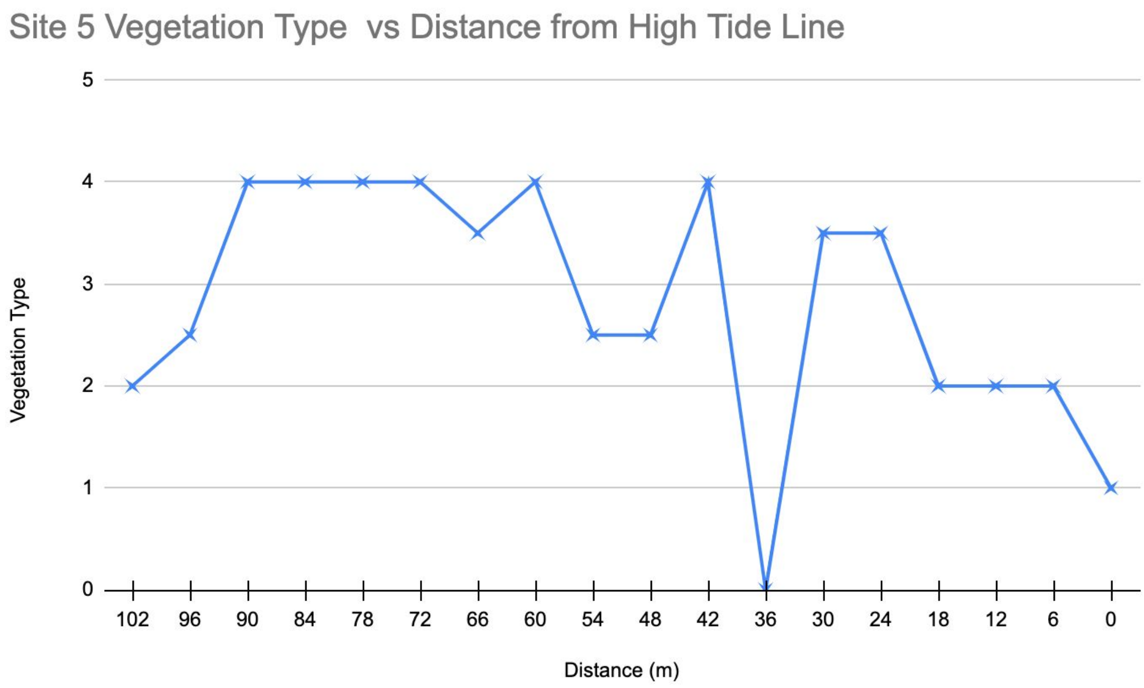


Figure 13 shows that there is an increasing trend in vegetation type, increasing from 1 at 0 meters to 3.5 at 30 meters. At 36 meters, the vegetation type was 0. The vegetation type generally stayed at 3.5 - 4 after the 42 meter mark with an exception at 48, 54 and 96 meters where the type was 2.5, and at 102 meters where the type was 2.

Figure 14: Comparison of Site 6 dune shape to the corresponding vegetation coverage.

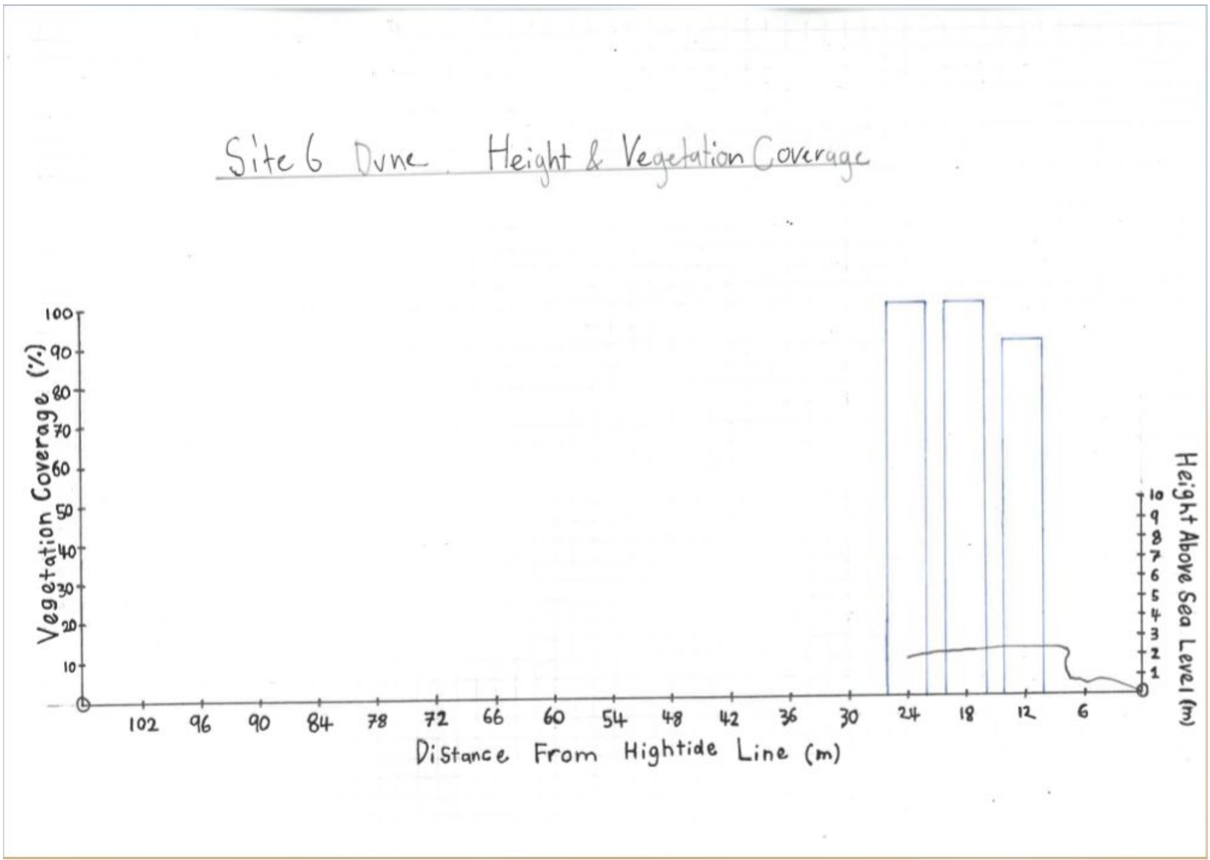


Figure 14 shows a short and low lying dune, with a length of 24 meters and height of 2.6 meters. There is no incipient dune or trough and the foredune and hind dune have merged to form a plateau. The foredune has a sharp increase in height at 8 meters where it increases from 1.0 to 2.6 meters. The vegetation coverage is greatest on the plateau, ranging from 90.3% to 100%.

Figure 15: Site 6 comparison of the vegetation type to the distance from the high tide line.

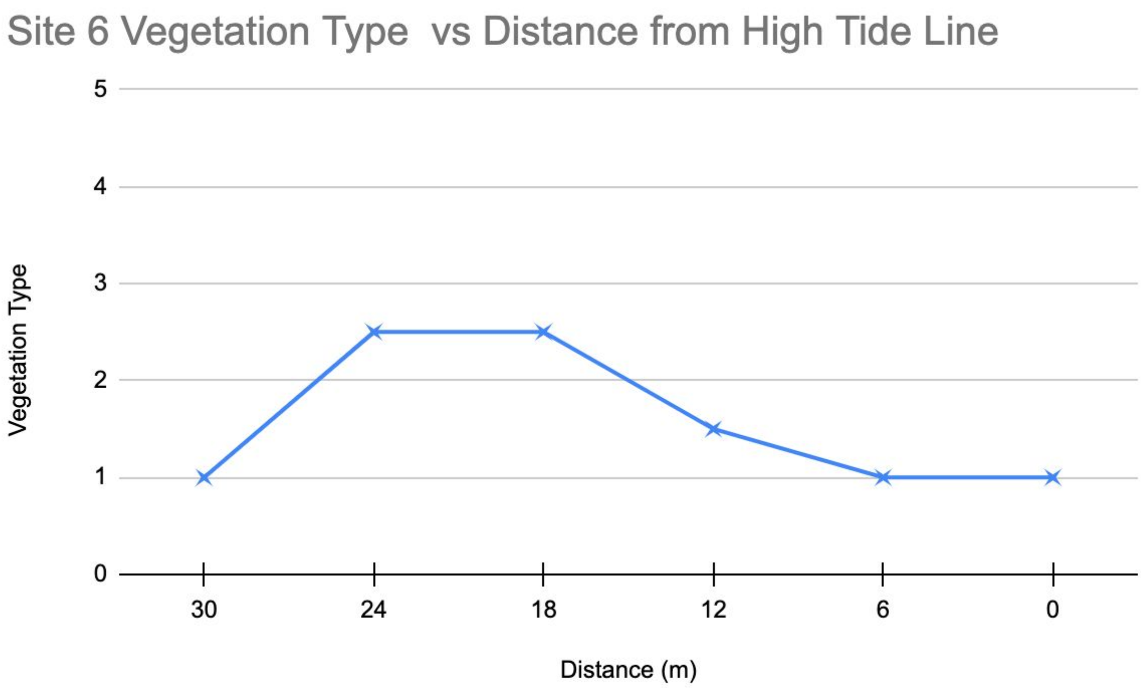


Figure 15 indicates that the vegetation type increased in a positive linear trend from 1 to 2.5 from 0 meters to 18 meters. It then decreased to 1 from 24 to 30 meters.

Figure 16: Comparison of Site 7 dune shape to the corresponding vegetation coverage.

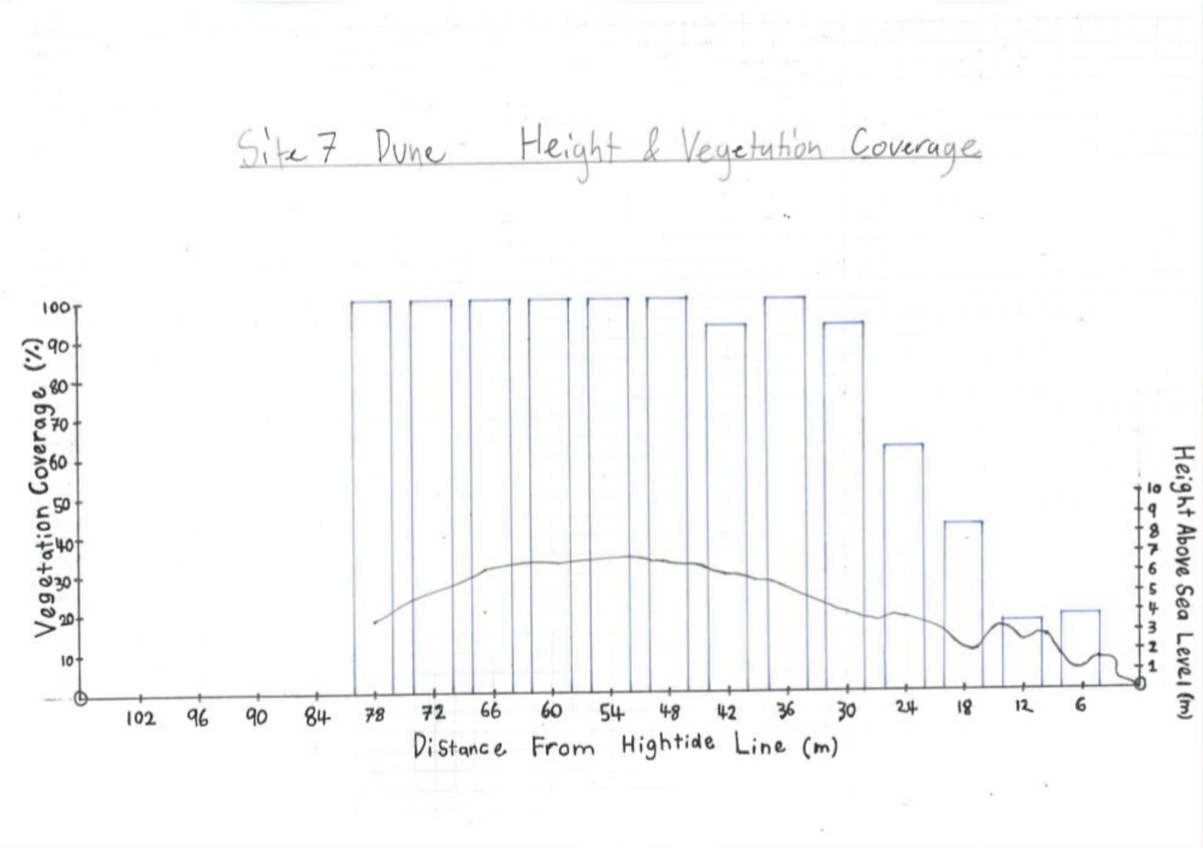


Figure 16 demonstrates an undulating incipient dune shape from 3 to 7 meters in from the high tide line. The foredune displays a small drop in height at 12 meters and reaches a maximum height of 3.3 meters. The foredune begins 7 meters back from the high tide line and ends at 16 meters where the trough begins. The trough reaches a minimum height of 2.0 meters and ends at 20 meters from the high tide line. The hindune then begins at 20 meters and ends at 78 meters. The hindune demonstrates a gradual increase and decrease in height. The maximum height of the hindune is 6.5 meters at 52 meters from the high tide line.

There is an increasing trend in vegetation coverage from 6 to 36 meters. The vegetation coverage then plateaus on the hindune at approximately 100%.

Figure 17: Site 6 comparison of the vegetation type to the distance from the high tide line.

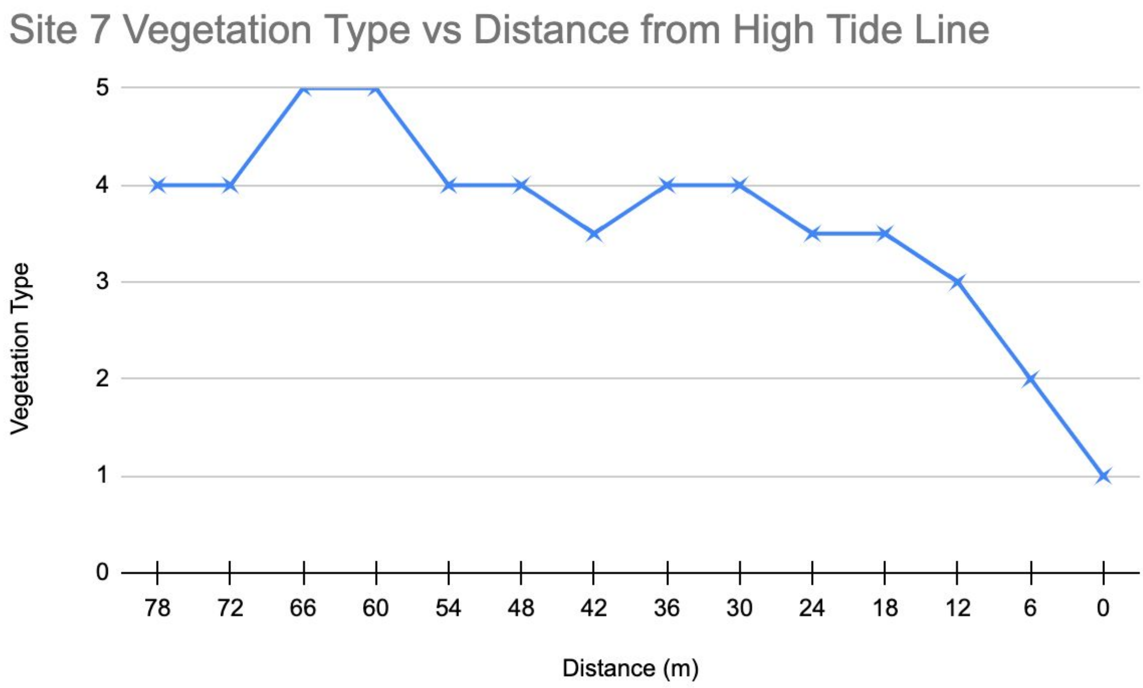


Figure 17 shows that the vegetation type has an increasing trend from type 1 - 4 from 0 - 78 meters. The vegetation type begins at 1 at 0 meters, and then increases to type 3 at 12 meters in a positive linear fashion. The vegetation type then maintains a consistent trend type of 3.5 - 4 until 54 meters which it then reaches type 5 from 60 to 64 meters. The vegetation then decreases to type 4 for the remaining 12 meters.

Figure 18: Comparison of Site 8 dune shape to the corresponding vegetation coverage.

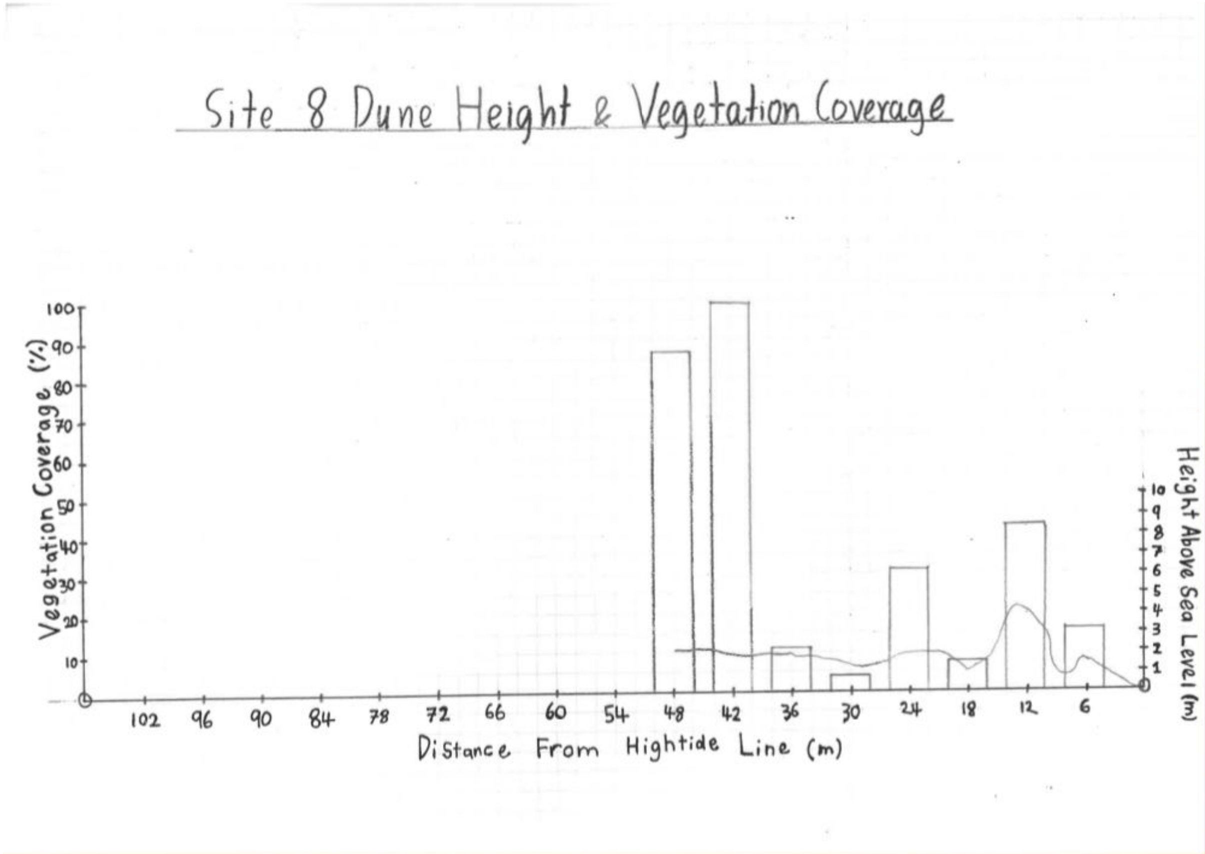


Figure 18 demonstrates a dune with a rapidly changing incipient dune, foredune and trough heights. The incipient dune has moved further towards the high tide line. It reaches 1.6 meters in height at 6 meters from the high tide line and is followed by a small trough. After this small trough, the foredune rapidly increases to reach a height of 4.5 meters at 12 meters from the high tide line. The back of the foredune then rapidly decreases in height to form a trough before the hind dune begins at 20 meters from the high tide line. The vegetation coverage is mostly light, however, at the back end of the hind dune between 42 and 48 meters there is up to 99.1% coverage.

Figure 19: Site 8 comparison of the vegetation type to the distance from the high tide line.

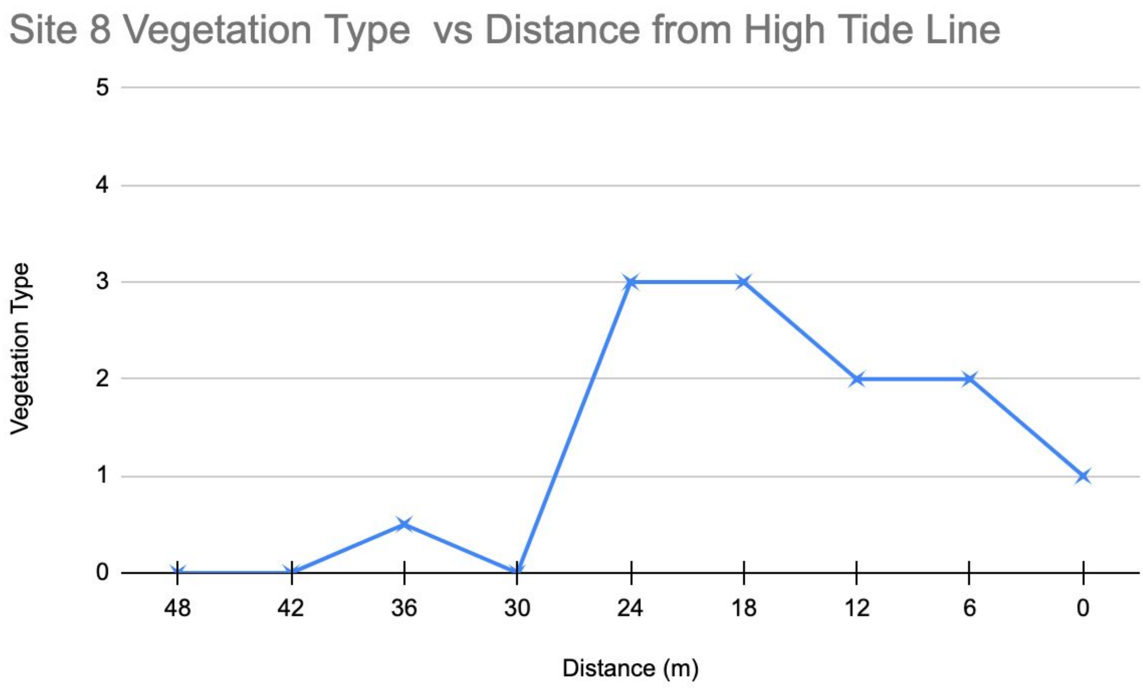


Figure 19 shows that vegetation type had an initial upwards trend from type 1 - 3 at 0 - 24 meters, however, then had a low trend from 24 - 48 meters with the vegetation type remaining equal to, or below 0.5.

Figure 20: Comparison of Site 9 dune shape to the corresponding vegetation coverage.

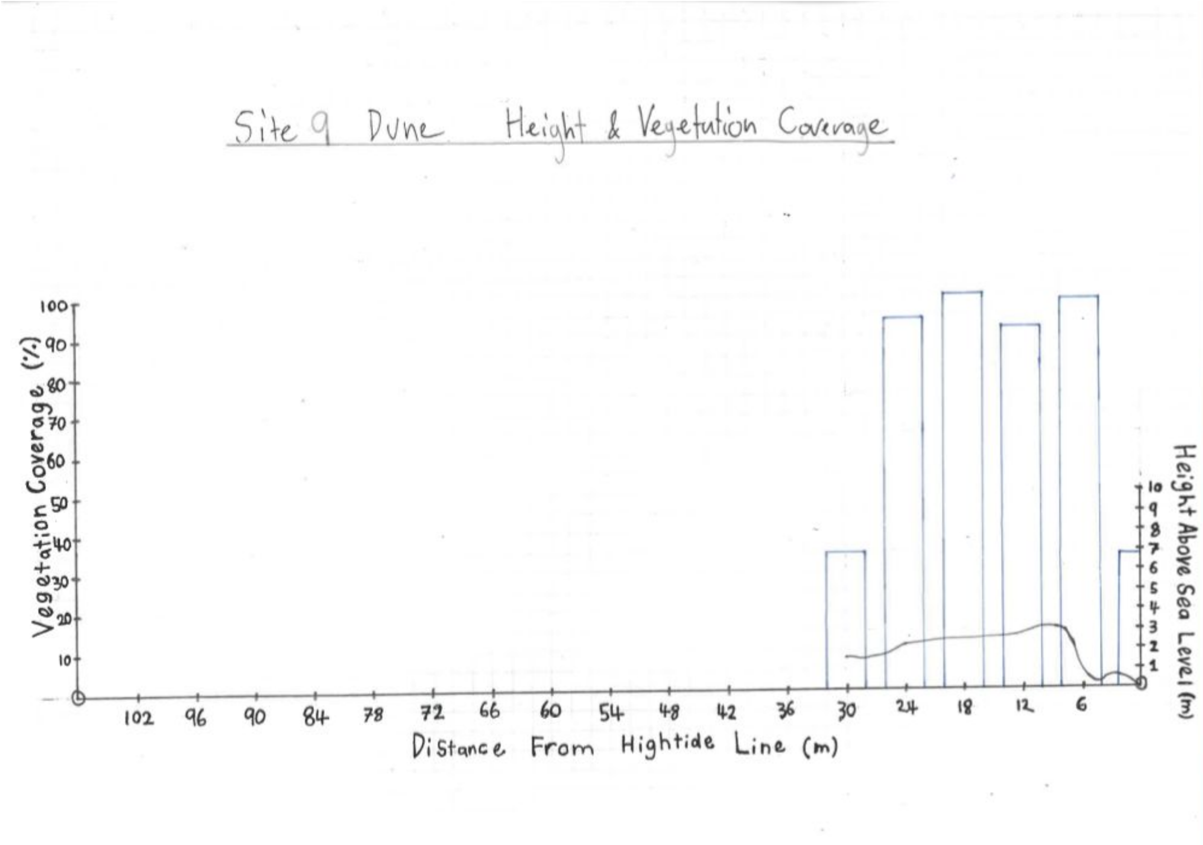


Figure 9 displays a small and low dune with the incipient dune starting at the high tide line. There is then a small drop in dune height before the foredune starts at 6 meters. The foredune dune has a steep gradient from 6 to 8 meters and reaches a height of 3.2 meters at 9 meters from the high tide line. The hind dune then demonstrates a gradual decrease in dune height until the dunes end at 30 meters at a height of 1.9 meters. The vegetation coverage is greatest at the back edge of the incipient dune and on the hind dune. At 30 meters the vegetation coverage drops to 34.7%.

Figure 21: Site 9 comparison of the vegetation type to the distance from the high tide line.

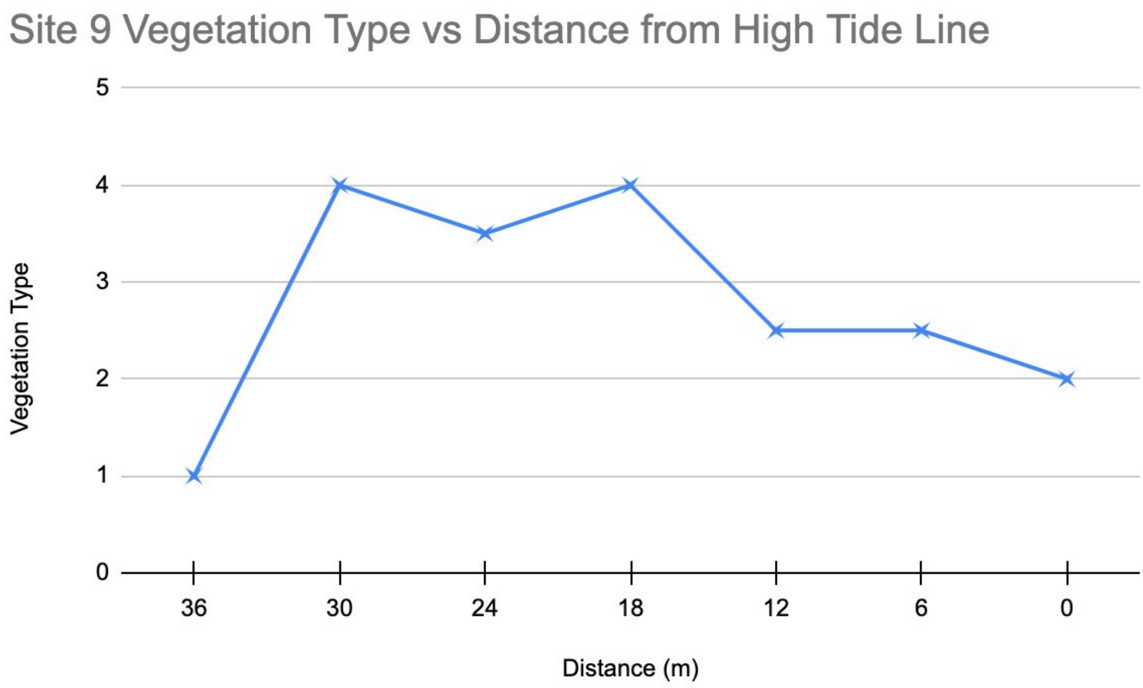


Figure 21 indicates that Site 9 had a positive trend from 0 - 30 meters, with the vegetation type increasing from 2 - 4. At 0 meters, the vegetation type is 2, this then increases to type 2.5 which is maintained for the next 12 meters. The vegetation type from 18 - 30 metres is on average 3.75. The vegetation type then regresses to 1 at 36 metres.

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Figure 22: Comparison of Site 10 dune shape to the corresponding vegetation coverage.

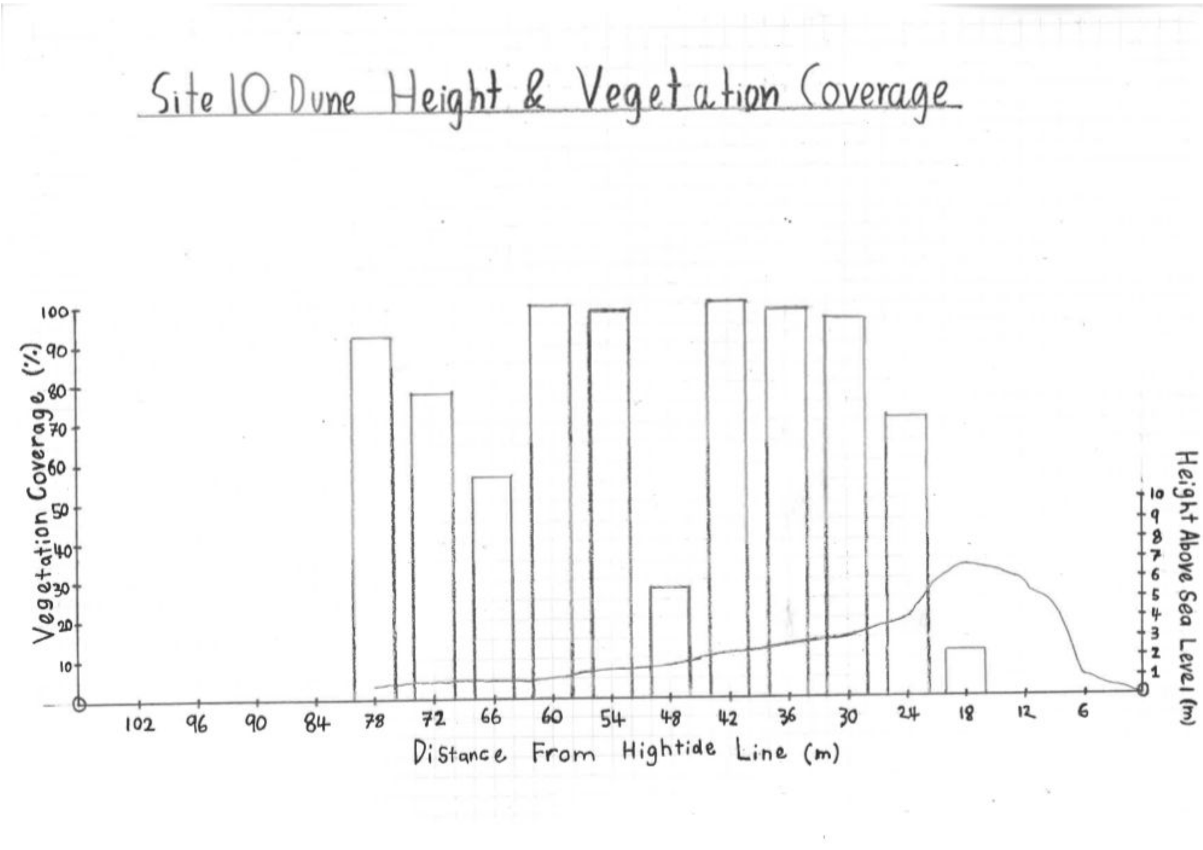
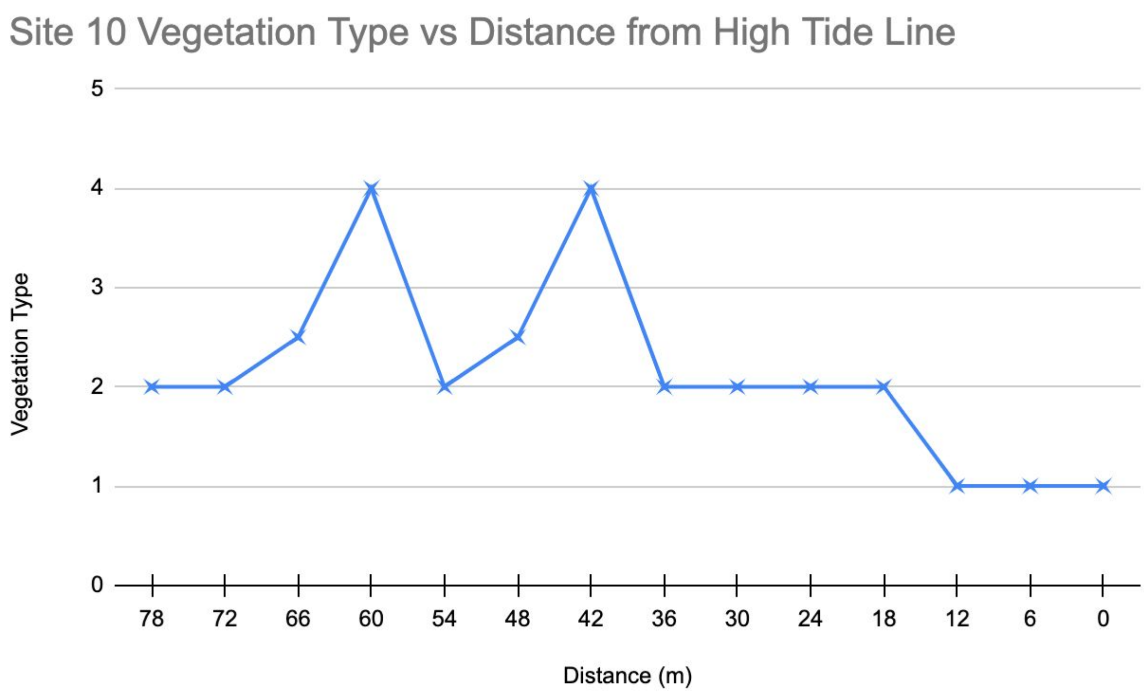


Figure 22 displays an incipient dune rising to 1 metre for the first 6 metres from the high tide line. It then has a foredune that steeply rises to from 1 to 6.5 metres over the next 12 metres. There is minimal hind dune definition as the trough continues to recede for the next 60 metres to a height of 1 metre. Vegetation coverage fluctuates over the foredune with no apparent pattern being visible.

Figure 23: Site 10 comparison of the vegetation type to the distance from the high tide line.



Site 10 consists of type 1 vegetation type for the first 12 metres of the dune. Type 2 maintains from 18 metres to 36 metres. At 42 metres, type 4 decreases to class 2 over 12 metres. This vegetation type regression is repeated from 60 - 72 metres, with type 2 maintaining for a further 6 metres (72 - 78).

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Discussion

Results Analysis

The investigation involved the use of transect lines over numerous Southern Tasmanian coastal dunes to observe the changes in vegetation type and coverage. The investigation also involved assessing the morphology of these coastal dunes by recording the height above sea level at various points along the dune. To assess the extent of human development on each of the 10 sites, each has been categorised into one of the following classes:

- Class 1 Infrastructure - carparks or roads in close proximity to the dune.
- Class 2 Development - Commercial or residential buildings in close proximity to the dune.
- Class 3 Industry - Where the dune has been used as a resource or to assist in producing resources

This study investigates the composition of the four primary components of a coastal dune, and the corresponding vegetation as the dune succeedes landwards. As seen in Figure 24, the components of an ideal coastal dune habitat comprises of an incipient dune; a small mound with grass vegetation, a fordune; a tall and narrow mound with the grass vegetation receding to small herbs, a trough; a depression in which shrubs emerge, and a hindune; a plateaued mound containing shrubs and small trees. All 10 sites will be assessed against, and compared to an ideal coastal dune morphology and vegetation succession.

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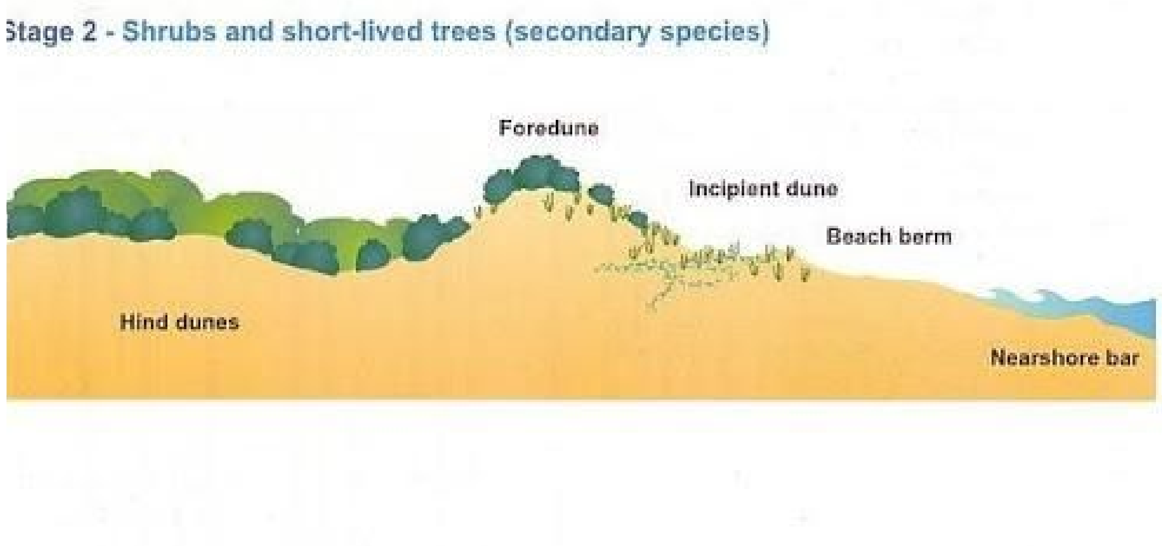
Figure 24: Diagram of an ideal coastal dune (Newman S, 2015).



Sites three, four and five can be categorised as dunes which are exposed to infrastructure and therefore provide the experimental data for class 1 dunes. These sites demonstrated varying vegetation coverage, vegetation types and dune morphology and the trends in this variation can be linked to the proximity of the infrastructure to the high tide line. All three sites had the same type of infrastructure with each site having a carpark connected by a road. Despite this, the infrastructure at each site was positioned at different distances back from the high tide line. Site three had the closest infrastructure to the high tide line at a distance of 36 meters, site four had infrastructure 82 meters back from the high tide line and site five had infrastructure positioned 328 meters back from the high tide line. The collected data showed that the further back the infrastructure is from the high tide mark, the less the infrastructure impacted on the dune.

Site three demonstrates vegetation coverage that is very dense, with all areas that contain vegetation having greater than 90.2% coverage, and vegetation on the hind dune reaching 100% coverage. The vegetation types at site one were mainly type 3, indicating that a majority of the vegetation was beach herbs (see figure 9). This demonstrates that the dune vegetation succession did not show a natural pattern and was highly disturbed, with no shrubs and minimal grasses. This especially dense herbaceous coverage could be a result of the removal of the previous natural vegetation to make space for infrastructure, leaving only suitable conditions for herbaceous plants to grow and dominate the area, having no competition for space. For example other vegetation types such as shrubs rely on grasses to stabilise significant amounts of sand and create a suitable growth environment, meaning that if the grasses are removed for infrastructure the shrubs will not be able to survive (Gold Coast City Council, n.d.). The morphology of the dune at site one has also been significantly disturbed and showed no natural pattern, with the dune shape forming no distinct separation between the foredune and hind dune. Instead, the foredune, which reaches a height of just 2.4 meters, extends into a flat plateau (see Figure 8). This is likely due to the removal of vegetation, as dunes rely on vegetation to stabilise sediment (Government of Western Australia, n.d.). This site showed the highest level of impact from human development and this can be linked to the positioning of the infrastructure (36 meters back from the high tide line). Being impacted in such a significant way, this habitat is unlikely to support biodiversity and would struggle to support the requirements of many specialist coastal species.

Site four displays vegetation coverage that is less dense than the vegetation at site three, with coverage ranging from 34.5% to 100% coverage over the foredune and hind dune. The vegetation succession demonstrates a more natural trend, with type 2 and 2.5 covering the incipient dune and foredune and types 3 and 4 covering the hind dune (see Figure 11). This trend suggests that human development in this area has still allowed for all (the site contained no trees) vegetation types to continue thriving. This suggests that the removal of vegetation for the car park was small enough that it did not create a cascading effect, where the removal of one vegetation type results in other types no longer being able to survive due to a reliance on other species. This is likely because the car park is positioned in a dense shrub area, meaning the decrease in shub coverage was proportionally less impactful on other vegetation types. The morphology also demonstrates a longer and higher dune (see Figure 10). Although the size of the dune has clearly not been disturbed as significantly as at site three, the foredune and hind dune are difficult to distinguish because there is no trough. Having no trough can make it hard for shrubs to successfully grow due to increased wind exposure, however in this case shrubs have successfully survived (Yang et. al, 2019). The shrubs are positioned towards the back of the dune where the height drops to 6.8 meters. The data for this site suggests that the human impact has been less significant and that the position of the infrastructure (82 meters from high tide line) has less negative consequences.

Site five demonstrates a vegetation coverage trend similar to site four, with coverage on the foredune and hind dune ranging from 28.3% to 100% (see Figure 12). The vegetation succession demonstrates an undisturbed trend (see Figure 13). The dune displays such successful succession that the vegetation meets a marsh which begins at a distance of 96 meters from the high tide line. The dune morphology also displays traits which suggest it has not been impacted on by human development. The dune is mostly of a consistent and structurally stable height, (see Figure 12). The dune demonstrates a clear incipient dune, foredune, trough and hind dune and the measurements of all of these dune sections are proportional to each other. With such successful shape and vegetation the dune habitat displays no signs of negative human development impacts. This can be linked to the position of the carpark and road, being far back (382m) from the high tide line. Being undisturbed this form of human development is unlikely to have a significant effect on biodiversity, with the habitat displaying great variation.

Sites one and two can be classified as Class 3 dunes. The hindunes of Site one were previously a part of a pine tree plantation site. Seen in Figure 25, pine trees are situated behind the hindune. Referring to Figure 4, the morphology of the dune appears to be mostly intact. There is no apparent incipient dune, with the foredune forming from 12 to 26 meters from the high tide line with a maximum height of 6.1 meters. There is an apparent trough receding from the foredune from 26 - 30 meters. A hind dune forms at 30 meters reaching a maximum height of 8.2 meters, 50 meters from the high tide, before decreasing in height for the next 22 meters from the high tide line. The vegetation coverage is at its highest at the beginning of the dune with an average coverage of 77.3%, 24 - 48 meters from the high tide line. The vegetation decreases to an average of 29.3% from the peak of the hindune to the end of the hindune. The decrease in vegetation coverage in the hindune represents a dune that has been impacted by this human development, with the pine trees likely to have caused a deterioration in the density of native plants. This could be linked to the reduced sun exposure for these low lying native plants, with the canopy of pine trees increasing the amount of shading. This lack of vegetation represents an unstable hindune that prevents the growth of larger plants. It can be seen that the pine forest has a relatively significant impact on the dune habitat, however, this does not conclude that all industry development on coastal dunes has the same impact. The reduction in native vegetation and increase in introduced vegetation may impact on biodiversity through reducing population numbers and altering the habitat, which may not suit native species.

Word Count: 8052

Figure 25: Pine trees located behind Site one's hindune.

Site two was previously used as a sand extraction site and this form of human development displayed significant impacts on the dune habitat. The impacts on the dune vegetation can be seen when referring to Figure 7, which demonstrates that the dune consisted mostly of type 2 vegetation, as well as type 0 and 1. This indicates that the dune is struggling to support any vegetation with only small generalist forms of vegetation being able to survive (Brown and Zinnert, 2018). As well as this, the dune was also littered with dead grasses and zero coverage areas. This trend can be expected at this site, with the placement of the sand extraction requiring the removal of large areas of shrubs and trees. A comparison of the dune vegetation on the boundary of the extraction site can be seen in Figure 26. When assessing the morphology of the dune, it is noticeable that hind dune has experienced a significant accumulation of sand, reaching a height of 9.2 meters above sea level, whilst the foredune only reaches a height of 5.9 meters. In understanding the impacts of wind on dune vegetation growth, it is unlikely that this site will experience growth of larger vegetation types in the future, with grasses dominating a majority (98.3% to 100% coverage) of the available space on the wind protected back side of the hind dune. Overall the effects of this industry type have been detrimental to the dune health and destroyed the habitat.

Figure 26: Sand extraction site boundary. It can be seen that the vegetation outside the boundary (right hand side of black line) consists of dense shrubbery (Google Maps,2020).

Sites 6, 7, 8, 9 and 10 can be categorised as dunes which are exposed to Class two levels of human activity. This class of dunes have no apparent trends collectively, however, it can be seen that the closer the development is to the dune, the worse the dune morphology is, hence, the succession in vegetation coverage and type becomes incomplete.

Site nine and six share similar dune morphology and present similar levels of vegetation coverage. Site six spans for 30 meters and Site nine spans for 36 meters with both dunes being halted by residential development. This close proximity to development has affected the morphology of these two dunes. As identified in Figures 14 and 20 the front of the foredunes are near concave, and there seems to be no progression into any form of trough or hind dunes. This reduction of distinct dune features can be directly linked to the close proximity of the residential development. When development occurs on a coastal dune, large segments of vegetation are removed. The roots of this vegetation were holding the dune formation in place, creating a stable dune structure. The removal of a segment of the dune results in the destabilisation of the entire structure. Once the sand becomes less stable, it becomes more mobile resulting in the increased movement of sand and the overall reduction in dune structure (Shoalhaven Council 1988). The close proximity of Class two development at sites six and nine largely contributes to the lack of distinct dune features and overall, the regression of each dune's morphology. The vegetation coverage at Site six is high from 12 - 24 meters from the high tide line. Site nine also has a high vegetation coverage from 6 - 24 meters. Although Site 6 has high vegetation coverage, there is a lack of vegetation type succession, with a majority of the vegetation being type 2.5, indicating a mixture of grass and herbs, before reaching residential development at 30 meters, at which there is no vegetation. This is likely a result of the altered dune morphology, which no longer provides the required shape of many for successful succession. For example there is no wind protection. This Site nine does progress to vegetation type of 4 however, regresses to type 1 once the dune reaches development at 36 meters. This lack of vegetation type succession could be a result of the increased mobility of the dunes' surface, with plants lacking the structural support to survive. Overall, the development at these sites has

Site seven indicates a healthier dune in comparison to Sites six and nine. The dune spans for 78 meters before reaching residential development. The incipient dune reaches a height of 1.5 meters across a six meter distance. As demonstrated in Figure 16, the foredune is partially damaged, having been split into two mounds. This seems to have not affected the remainder of the dune with a distinct trough antecedent to the fordunes, and a profound hindune spanning from 20 - 78 meters. Because there is an increased dune length before residential development interferes with the dune, it appears that the primary features of the dune have remained in Site 7, with a distinct incipient dune, foredune, trough and hindune. The vegetation coverage increases up to the hindune in which it approximately remains at a high level of coverage. This displays that a high density of vegetation is present throughout the dune. The vegetation type for Site 7 has a positive progression, with the vegetation type increasing the further the distance from the high tide line. Displayed in Figure 17, the vegetation type increases from 1 - 3.5 from the incipient dune to the beginning of the hindune. At the hindune, the vegetation type ranges from 3.5 - 5. It is apparent that Site 7's dune morphology is adequate enough to allow for a natural vegetation succession, in which shrubs and trees can constantly prevail at the hindune at a high density. This reinforces that the further human development is from a coastal dune's high tide line, the lesser the extent of damage is to the dune's health.

Site eight appears to have a severely damaged dune, with a deteriorating dune shape, fluctuating vegetation coverage and a vegetation type recession rather than succession. Site eight's dune morphology suggests that the introduction of residential development and trampling caused by human movement has severely altered the shape of the dune. This trampling makes the dune more susceptible to great storm erosion events, with extreme weather contributing to the "undercutting " or the creation of "steep slopes" of the coastal dune (Geoscience Australia 2020). Viewing Figure 18, the incipient dune seems to be a section of the fordune that is eroding away from the main structure. This can be reinforced by the steep trough following the incipient dune, and further reinforced when observing Figure 26. Viewing this image, the tide - facing side of the foredune has a steep face, incapable of supporting any vegetation. This steep face suggests that the foredune has experienced a loss in sand resulting in it sectioning off, adding to the incipient dune. The fordune is steeply followed by a trough at 18 meters from the high tide line. There seems to be a lack of a distinct hindune, with the remainder of the dune ranging from 1.5 - 2.5 meters in height, from 20 - 48 meters from the high tide line. The dune's morphology reinforces the fact that this dune experiences greater amounts of damage from extreme weather events, creating greater sediment instability and providing less vegetation succession, decreasing habitat diversity The vegetation coverage is also irregular, with no apparent coverage consistency. The vegetation coverage from 18 - 36 meters does not exceed 32.7%, further suggesting that the dune in this region is poorly developed and incapable of supporting high vegetation density. A lack of vegetation coverage creates a loop of negativity in regards to the stability of the dune. With a lack of vegetation coverage, there is insufficient support to hold the sediment in place and because there is a lack of fixed sediment, vegetation struggles to consolidate and increase in density. The vegetation type succession graphed in Figure 19 is extremely inconsistent and does not correlate with the vegetation succession seen in a dune that is further away from human development such as Site seven. The vegetation type increases from 1 - 3 from 0 - 24 meters from the high tide line however following the trough, the vegetation type ranges from 0 - 0.5. Having primarily dead vegetation following the trough, the analysis of Site eight's vegetation type further indicates that vegetation cannot sustain life in this poorly developed hindune, further emphasising the impact that the residential development has had on this site. Although not recorded in this data, viewing Figure 27, it is seen that type four vegetation was once situated on the foredune, however, has now died and is eroding towards the tide. Viewing this figure, it is evident that erosion is occurring at this site and that vegetation cannot adapt to the rapid rate of dune morphological change.

Figure 27: Series of dead shrub vegetation situated at the beginning of Site eight's foredune.

Site 10's morphology (viewed in Figure 22) appears to be an outlier since it has no distinct hindune despite spanning a distance of 78 metres from the high tide line before residential development occurs. The foredune spans a distance of 12 meters with no evident signs of deterioration. The trough appears to recede over the next 60 meters. The vegetation coverage also suggests irregularity, as no evident pattern can be seen in response to the change of the dune's morphology ranging from 28.3% - 100% past the foredune. The vegetation type does not progress in an orderly fashion, fluctuating in vegetation. This vegetation progression, in correlation with the dune morphology, cannot be explained to be a direct result of Class two development.

Study Evaluation

Conducting this field analysis has provided many successful insights into the impacts of human development on coastal dunes, however, there were sources of error within the collection and presentation of the data. An error involved in the collection of the data includes the use of inexact measuring processes between each quadrat. This error can be traced back to the method which was used to measure these distances, being measured using a tape measure, which resulted in the dune height affecting the exact horizontal landward measurement. This source of error resulted in the correlation between the vegetation coverage and dune morphology being adjusted. For example, Figure 20 demonstrates vegetation coverage of 98.1% on the slope of the foredune.

Realistically this section of dune is unlikely to have such such a high vegetation coverage. If this field analysis was to be conducted again, more precise horizontal distances would be recorded between each qudrat, possibly through the use of GPS coordinates. Another source of error includes the method of dune morphology measurement. This method involved the use of estimation between each quadrat height, with dense vegetation occasionally preventing the accurate measurement of dune heights. This was because the conductors of the experiment could not access these areas to measure the height above sea level. For example, Figure 16 displays a hind dune shape with limited dune height fluctuation due to dense areas of vegetation coverage. To allow for more accurate dune height measurements in the future, infrared profiling equipment could be used, as this would assist in locating the surface of the dune below the vegetation. It must be acknowledged that this method of morphology measuring can be costly.

Certain limitations were identified when assessing the collated data. One limitation includes having only a small sample size of sites. In order to allow for trends between human development and the welfare of coastal dune habitats to be succinctly identified, it is recommended that the sample size of the sites is increased. This is because a greater sample size will increase the reliability of the results by highlighting outliers and possible errors, as well as increase the likelihood of identifying trends between human development and negative dune habitat impacts. It is recommended that the number of sites is increased to 30 sites. Similar to the previous limitation, it can be identified that the number of transect lines at each site did not portray an accurate representation of the entire dune, as there is often variation in dune vegetation and shape in the areas surrounding each transect. Increasing the sample size at each location to account for this variation will further increase the validity of the experiment. This is because an increase in sample size will eliminate outlier vegetation/morphology trends, allowing for a more reliable and established comprehension of each site. Through this, the conclusion made on each site will be more valid as a greater range of variation at each site is accounted for. It is recommended that 5 transect lines are created over a selected dune with each transect being 4 meters apart from each other.

A change in the categorization of the collected data is recommended, as other methods of analysis can allow for more conclusive trends to be made. Instead of categorising each site into the type of development, it is recommended that human development is categorised by their size and proximity to the high tide line. In doing so, the trends in dune morphology and vegetation will be more easily compared. This is because the data trends show a correlation between the proximity and size of the development, rather than the type of development.

Dune Habitats and Society

Coastal erosion, although a natural process, has been accelerated by human development, resulting in vigorous morphological changes to coastal dunes. In order to reduce current human-enhanced coastal erosion and to prevent future erosion events from creating unadaptable changes for dune habitats, it is recommended that a change in federal legislature should be conducted. This change would affect where human development can occur along the coast, as well as implement a radical change in the priority of dune management. It is recommended that a parameter is created, restricting certain types of human development in a select distance from the high tide line. This would reduce the human-caused impacts on dune stability and vegetation succession. These recommendations on development restrictions have been made based on the collated results of this case study, which show that development of a significant size in close proximity to the dune contributes to the greatest destruction of coastal dunes. This pattern of human-induced morphological and vegetation changes can be further reinforced with international studies. A study of the impacts of human activities on coastal vegetation has concluded that urban development in close proximity to coastal dunes significantly impacts vegetation succession, stating that there is, "a lower number of plant species in comparison to those of stable coastal ecosystems" (Fernanda Pessoa, M et al 2013). The study also states that there was, "a decrease in… stress-tolerant specialist species in over-disturbed foredune communities" (Fernanda Pessoa, M et al 2013).

With the effects of climate change worsening, the magnitude of coastal erosion will only amplify. Global sea levels are rising by approximately 3 milimetres per year, and the continued warming of the Earth will contribute to an, "increase in the frequency and magnitude of storm events" (BGS 2020). The southern regions of Tasmania; Primrose Sands, Dodges Ferry and South Arm, are all areas which will experience the increasing impacts of climate change. A ‘storm bite’ is the landward distance that a shoreline recedes by eroding during a storm or clustered series of storms. Continued human development and its impacts on the integrity of coastal dunes, in alignment with the rising of the sea level and worsening of storms, will worsen the effects of ‘storm bites’ which could result in detrimental impacts to the coastal dunes of the south east coast of Tasmania.

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A study by the Tasmanian Government in 2013 has identified that beaches in the Primrose Sands, Dodges Ferry and South Arm regions, as well as many other southern Tasmanian regions are likely to experience severe future erosion events, with south east Tasmanian coasts likely to experience a shoreline recession of 10m landwards from the storm bite hazard zone by 2050, and 40m by 2100. (Sharples, C et al 2013). For this reason, strengthening coastal dunes through dune protection programs is paramount. A report created for the NSW Government has identified advantageous dune management strategies. The implementation of dune-forming fences (porous fences allowing for the movement of sediment) and the insertion of native dune species have been identified as the most effective dune restoration strategies to maintain the structural stability and integrity of coastal dunes (Kidd R, 2001). By prioritising dune restoration and protection and creating a legislature that protects coastal dunes from excessive human development, coastal dunes will be able to maintain (or reestablish) structurally-sound dune morphology, allowing for complete vegetation succession. Doing so will increase the resilience of coastal dunes to human activity, and the worsening effects of climate change and erosion events.

Conclusion:

The proximity of human development to coastal dunes has been observed to have the greatest impact on coastal dune habitat destruction. It was found that the closer the development is to the high tide line, the greater the impacts are on the dunes' vegetation succession, and morphology, drastically altering the stability of the habitat. It was found that class 1 and class 2 of human development had similar impacts on the dune habitats, whereas class 3 development has varying impacts on the coastal dunes. This is due to the variation in the types of resource exploitation. It was found that the location of human development had significant effects on the dune habitat. This is because all components of the dune depend on each other to maintain a suitable and stable environment, meaning that if the development significantly impacts on one area, the interconnected relationship between the vegetation coverage, vegetation types and dune morphology results in cascading and negative impacts.

Word Count: 8052

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Appendices:

Table 1: Raw data Used to create vegetation coverage and dune shape graphs.

	Distance from high tide (m)																		
Sites:	**0**	**6**	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**60**	**66**	**72**	**78**	**84**	**90**	**96**	**102**	**102**
1	0	0	4.7	18.3	82.1	11.5	96.1	96.8	100	25.2	46.9	40.3	4.9						
2	0	0	2.1	68.4	29.8	98.3	98.6	100	84.7	99.3	100	100	98.3	100	96.9	88.7	46.4	8.8	13.1
3	0	0	0	90.2	93.4	100	100	0											
4	0	0	7.6	77.8	91.3	95.6	68.4	100	34.5	64.9	94.7	99.1							
5	0	6.2	35.3	43.8	51.4	64.7	28.1	90.9	90.2	12.1	79.5	76.6	88.5	56.3	97.4	100	98.2	100	60.2
6	0	0	90.3	100	100	0													
7	0	19.2	17.7	42.3	62.4	93.1	100	93.5	100	100	100	100	100	100					
8	0	15.3	44.8	8.6	32.7	4	11.2	99.1	85.9										
9	34.9	98.1	92.4	100	94.8	34.7	0												
10	0	0	0	10.9	73.2	92.2	99.1	100	28.3	97.7	100	54.5	77.4	93.7					

Table 2: Shows types of vegetation distributed along each transect from Site 1 - 5. This was used to create the dune vegetation type graphs.

	Type of vegetation				
Distance from high tide line (m)	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
0	N/A	N/A	N/A	N/A	N/A
6	grass	N/A	N/A	grass	grass
12	grass/dead grass	dead grass	N/A	grass	grass
18	grass/dead grass	grass/dead grass	grass/herb	grass/shrub	grass

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24	grass/dead grass/herb	grass/herb	grass/shrub/herb	grass/shrub/dead grass	grass/shrub
30	grass/herb	grass/herb	grass/shrub/herb	grass/shrub/dead shrub	grass/shrub
36	grass/herb	grass/herb	herb/dead herb/shrub	shrub/grass	dead grass
42	grass/shrub	grass/shrub	N/A	grass	shrub
48	grass/dead grass	grass/herb/dead grass		Dead grass/shrub/herb	dead grass/herb
54	grass/herb/dead grass	grass		shrub/dead shrub	dead grass/herb
60	grass/herb/dead grass	grass		grass/shrub	shrub
66	herb	grass/dead herb			dead grass/ shrub
72		grass/dead grass/dead herb			shrub
78		grass/dead grass/ herb			shrub
84		grass/herb/dead herb			shrub
90		grass/herb/dead grass/dead herb			shrub
96		grass/dead grass/herb			dead grass/herb
102		dead herb/herb			dead grass

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Table 3: Shows types of vegetation distributed along each transect from Site 6 - 10. This was used to create the dune vegetation type graphs.

Distance from high tide line (m)	Site 6	Site 7	Site 8	Site 9	Site 10
0	N/A	grass	grass	grass	N/A
6	N/A	herb	grass	dead grass/shrub	N/A
12	grass/dead grass	dead grass/herb/shrub	herb	grass/herb/dead grass	N/A
18	grass/dead grass/herb	herb/shrub	herb	shrub	grass
24	herb/dead herb	shrub	herb/dead tree	shrub/dead shrub	grass
30	N/A	shrub	grass/herb/dead shrub	shrub	grass
36		shrub/dead shrub	dead grass/ grass	N/A	dead shrub
42		shrub	dead shrub		shrub
48		shrub			grass/herb
54		shrub			shrub/dead shrub/
60		shrub			shrub
66		shrub			herb/grass
72		shrub			grass
78		shrub			grass
84					
90					
96					

Word Count: 8052

102					