Assessing and maintaining the coastal stability of Weymouth Beach, Tasmania

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Overview of Weymouth Beach from Bellingham dunes (2007), courtesy of Lionel Cooper.

Weymouth Beach is an open, sandy shore located on the North Coast of Tasmania. Like many open, sandy shores across Tasmania and Australia, erosion has become evident and coastal stability a concern and priority. This study aims to assess the erosion and coastal stability of Weymouth Beach and provide recommendations, to enhance its coastal stability and prevent erosion.

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Introduction

Weymouth Beach (WB) is an open, sandy shore (Sharples, 2006; Department of Tourism, Arts and the Environment, Tasmania [DTAET], 2007). WB is also subject to a strong oceanic presence; while wave energy is low at WB (DTAET, 2007), it is prone to seasonal storm and flood events (Survey participant, pers. comm.., 2015; Bureau of Meteorology [BOM], 2015). This can be problematic; low frequency and high intensity events have the greatest influence on a landscape's geomorphology (Ellison, 2015). WB vegetation is dominated by marram grass (*Ammophila arenaria*) and sea spurge (*Euphorbia paralias*), which hold a strong position in dune sediment (Rudman, 2003). For this reason, they have been introduced to many coastal environments to enhance coastal stability (Hayes and Kirkpatrick, 2012), including WB.

Marram grass and sea spurge have dominated Tasmania's coastal landscape and have been too aggressive in retaining sediment (Rudman, 2003). This has left a greater distinction between areas of aggressively retained sediment and loose sediment. As a result, during erosive events such as storms and floods, loose sediment is washed away easily, while the retained sediment forms a steep wall. This makes the WB dunes more susceptible to erosion and the undercutting of dune sediment. Marram grass and sea spurge, as introduced species, are thus counterproductive in maintaining, or enhancing, coastal stability.

However, beaches are naturally replenished from oceanic, estuarine and riverine sediment. This mechanism is known as a 'sediment budget' (Sharples, 2006; French, 2002; Figure 1). Alternatively, this dependence also makes a beach vulnerable to changes in the oceanic, estuarine and riverine environment (Chu et al., 2014). Since WB is dominated by the quartz of the Pipers River's sediment, the events of Pipers River and the estuary are of particular interest; the theoretical and geographic context of Weymouth's sediment budget are displayed below in Figures 1-3.

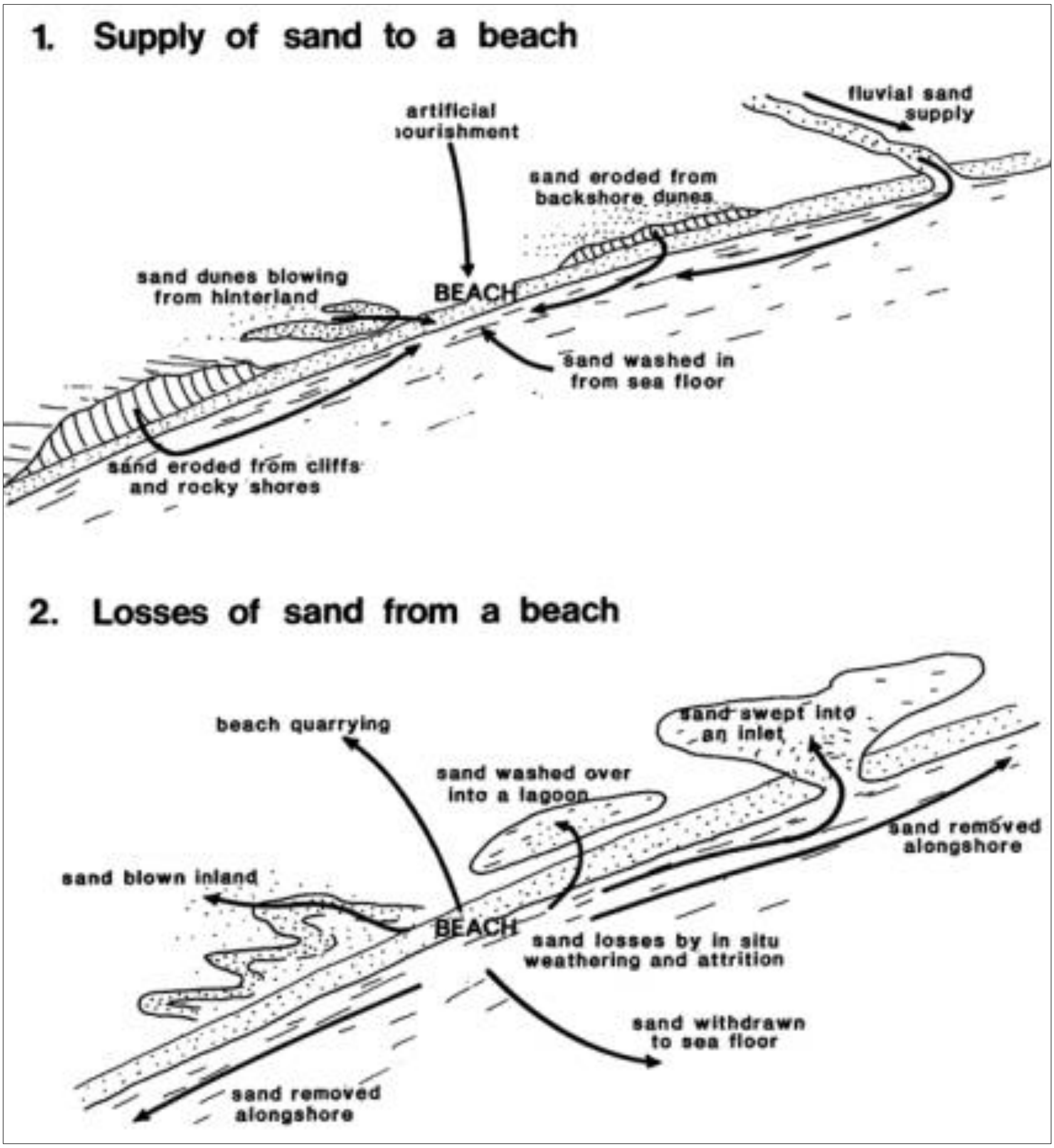

Figure 1: demonstration of the sediment budget mechanism. Source: Bird and Lewis (2015).

Erosion is also a known issue at other beaches along northern Tasmania, such as Turners Beach. While the wave energy of the Bass Strait remains mostly constant along all shores of northern Tasmania (Figure 2), beaches estuarine, catchment and anthropogenic factors are not consistent. This owes to a different context and factors of each beach's sediment budget. Consequently, management of beaches across northern Tasmania should be subjective.

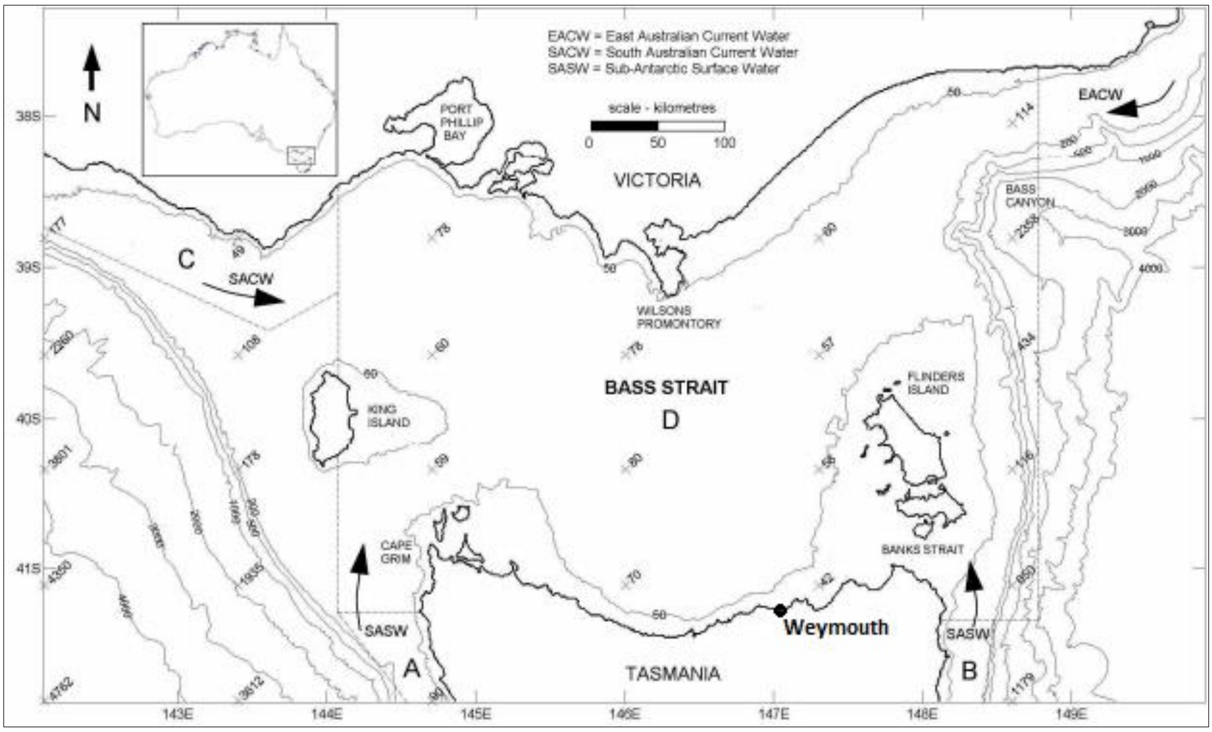

Figure 2. the bathymetry and oceanic movement of the Bass Strait and surrounding region, with the Sub-Antarctic Current Water (SACW) and the South Australian Surface Water (SASW) being the predominant source of Weymouth's oceanic input. Source: Sandery (2006) [edited by Skinner, 2015].

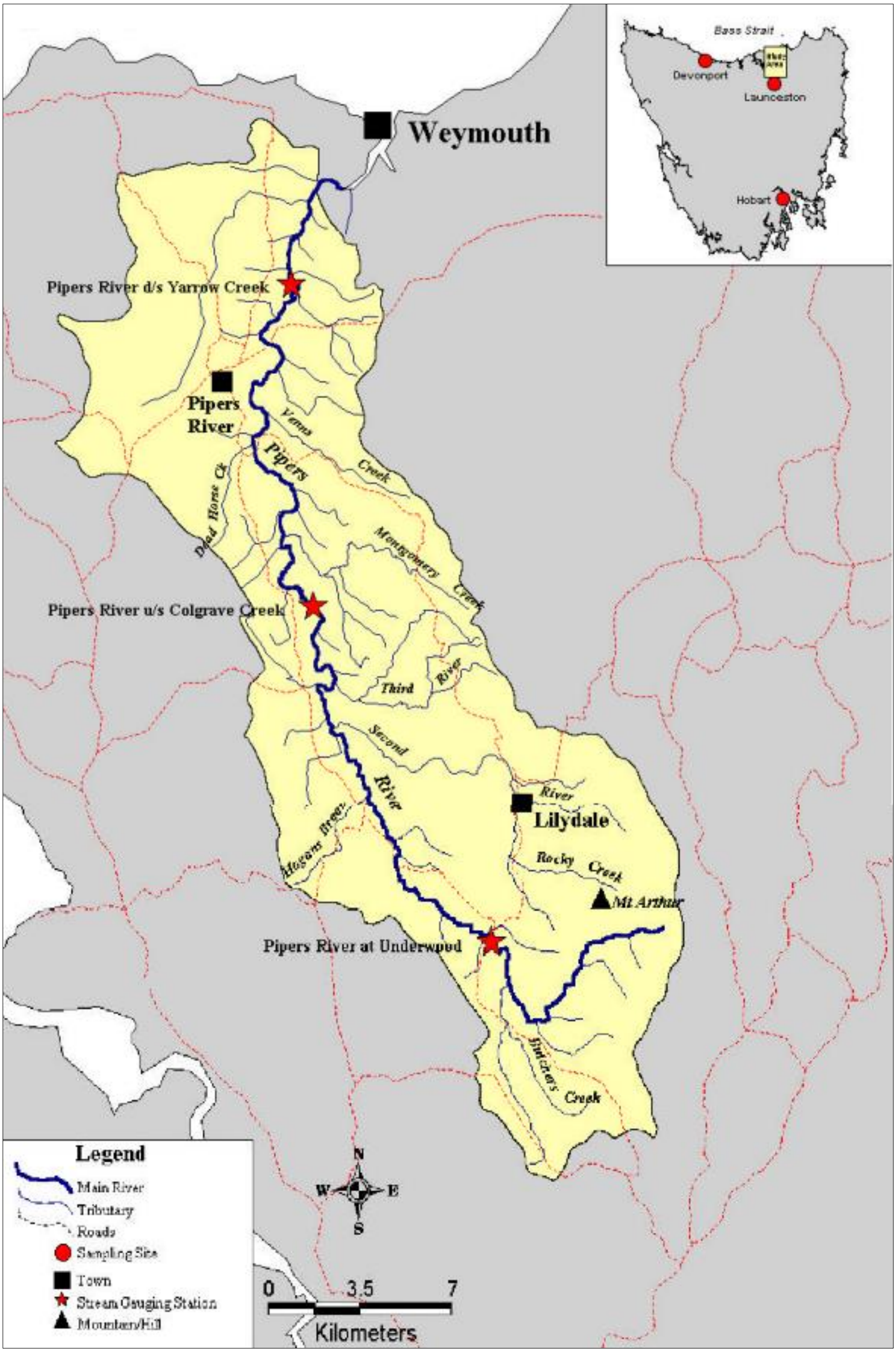

Figure 3: an overview of the Pipers River catchment, a dominant contributor to WB sediment composition. Source: Department of Primary Industries, Water and Environment [DPIPWE] (1999).

Weymouth and Bellingham are primarily towns for the retired and people's holiday 'shacks'. As a result, human impacts are concentrated during summer. Such impacts include the trampling of dunes and the obstruction of rehabilitation efforts.

WB has been classified as an area of 'high risk' and vulnerable to coastal erosion; if Weymouth is to face storm and high tide events directly, the inundation of Weymouth could become a seasonal occurrence. With this being said, while the hind dune remains, the WB dune system can be rehabilitated; the re-stabilisation of coastal systems, through dune system remediation, has proved successful in: France (Roze´ and Lemauviel, 2004), the United States of America (Martínez et al., 2013) New Zealand (Martínez et al., 2013) and Scotland (Scottish Natural Heritage [SNH], n.d.). Yet Australia's limited success in regaining coastal stability (Short, 2008; Rodney, 2000), shows a gap in our understanding of coastal dune systems. In the case of WB, a qualitative and quantitative assessment of WB coastal stability, followed by informed and unobstructed remediation efforts is essential.

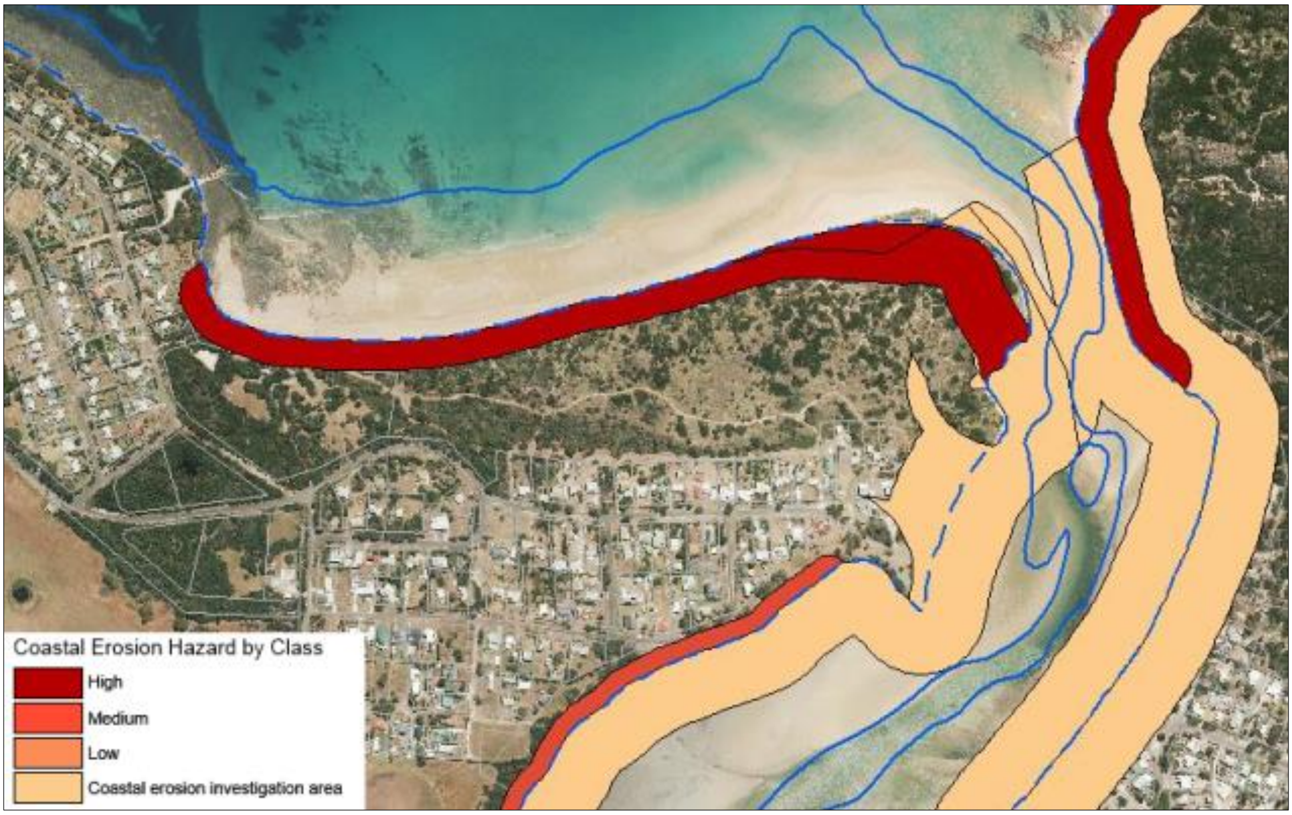

Figure 4: Coastal erosion risk, by class, courtesy of The George Town Council (2015).

As a result, this study aims to assess the coastal stability of WB and provide remediation options. This assessment will contrast the current dune system to the model of a natural dunes system, to discuss the multivariate nature of coastal stability. This assessment will then be able to provide educated recommendations, for positive environmental outcomes in regards to the coastal stability of WB. In this way, Weymouth and Bellingham's environmental, tourist, recreational and real-estate values can be upheld.

Methods

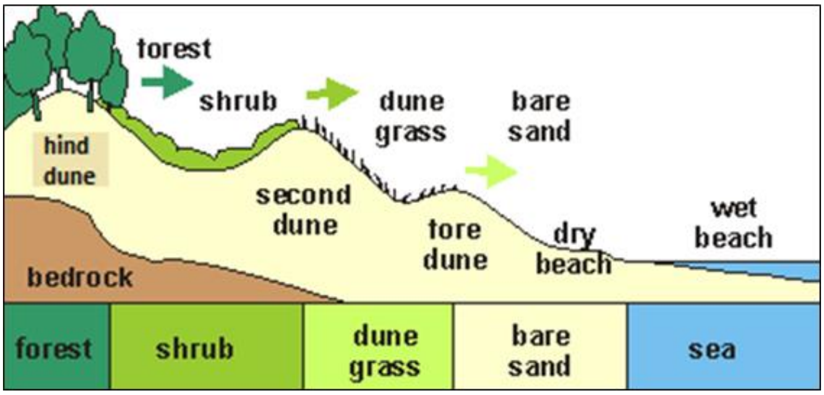

Figure 5: Transect of a healthy dune system. Source: Anthoni (2000) [edited by Skinner, 2015].

The dune system of WB was analysed physically, using: aerial photography, conventional photographs of the landscape, a recent dune cross-sectional survey and sediment analysis. Aerial photographs pre-2000 were obtained from Land Tasmania. Aerial photographs post-2000 were provided by the George Town Council. The conventional photographs of Weymouth have been provided by members of the Weymouth community and members of the Weymouth Progress Association.

Aerial photography of WB was compiled into a timeline, in the results section. This timeline has also been provided further depth through the aid of conventional landscape photography; this imagery is a simple and effective way to communicate and justify recommendations with the community and other stakeholders (Survey participant, pers. comm., 2015). Stakeholders, in this instance include: the George Town Council, the Weymouth Progress Association, Tamar Natural Resource Management, Weymouth locals and tourists to Weymouth.

Figure 6: Location of WB three analysed transects, photo courtesy of The George Town Council (2015) [edited by Skinner, 2015].

Cross-sectional survey

The cross-sectional survey and sediment analysis of WB was conducted under the supervision of Joanna Ellison. This survey was taken from three datum points along WB, set by the Weymouth Progress Association. These transects were taken on the 24th of April 2015 during low tide, at 12:45pm. These transects were completed as a university class study for the unit 'KGA 326: Environmental Geomorphology', to display the distance and variances in elevation, from the datum points/hind dune to the low tide mark. These transects were made by three different groups, which may cause variances. The transects overall purpose is to reaffirm what is seen in the aerial photographs and to provide some context when discussing the sediment analysis and the multivariate nature of coastal stability. Ultimately, these transects aim to provide baseline data for the quantitative analysis of WB geomorphology.

Sedimentary analysis

The sedimentary analysis focused on Transect 3, the eastern most transect; this transects location and geomorphology provides the greatest indication of estuarine and marine influence, at WB. No additional transects or sedimentary analyses have been taken since this time; there have been no storm events since April 2015 (Survey participant, pers. comm., 2015; BOM, 2015) to alter the environment and warrant another analysis.

Social survey

Social science is also important in understanding how natural processes interact with social values (Johnston and Ellison, 2014). In this instance, how the destabilisation of WB and the retreat of its dunes affect: local recreation, housing and other social values. For this reason, members of the Weymouth community and Weymouth Progress Association have been surveyed on: their involvement with WB, their understanding of the history and causes for change at WB and their opinions on coastal management. These surveys will be referenced as 'Survey participant, pers. comm., 2015'. No survey statistics have been provided; survey responses were unanimous.

Results

Aerial photography

The timeline (Figures 7-11) used aerial photography to demonstrate the progression of the WB dune system, in relation to vegetative cover and increasing urbanisation. These factors are highly influential on coastal stability (DTAET, 2007) and are thus significant in the WB coastal stability analysis. Furthermore, the shading of the estuary's channel indicates varying depth. The increased presence of grey silt and quartz in the channel has also been noted by kayakers and locals (Survey participant, pers. comm., 2015).

Figure 7: The Weymouth area (1949) displaying very limited settlement and an un-vegetated dune system. Figure source: Land Tasmania (2015) [edited by Skinner, 2015].

Figure 8: The Weymouth area (1980) displaying increased urbanisation, a vegetated dune system and a receding fore dune. Figure source: Land Tasmania (2015) [edited by Skinner, 2015].

Figure 9: The Weymouth area (2005) displaying a heavily receded fore dune and reduced hind dune vegetative cover, courtesy of The George Town Council (2015) [edited by Skinner, 2015].

Figure 10: The Weymouth area (2010) displaying the absence of a fore dune, courtesy of The George Town Council (2015) [edited by Skinner, 2015].

Figure 11: The Weymouth area (2014) displaying steepening of the hind dune, courtesy of The George Town Council (2015) [edited by Skinner, 2015].

Conventional photography

The available conventional landscape photography compliments Figures 7-11 well; Figures 12-15 provide a logical transition from Figures 7-11 to Figure 16-19 and Table 1, when discussing the process of coastal instability and dune erosion.

Figure 12: Weymouth's eastern most dune (2009), next to the estuary mouth. The dune is undercut and dominated by marram grass, courtesy of Lindal Byard.

Figure 13: Weymouth's eastern most dunes (2009), displaying the widespread undercutting and dominance of marram grass, courtesy of Lindal Byard.

Figure 14: View of Weymouth beach from the Bellingham dunes (early 1960's), displaying a steady slope from the eastern most dune to the estuary mouth, courtesy of Lindal Byard.

Figure 15: View of Weymouth beach from the Bellingham dunes (2007), displaying a steep slope of the hind dune into the high tide mark, courtesy of Lionel Cooper.

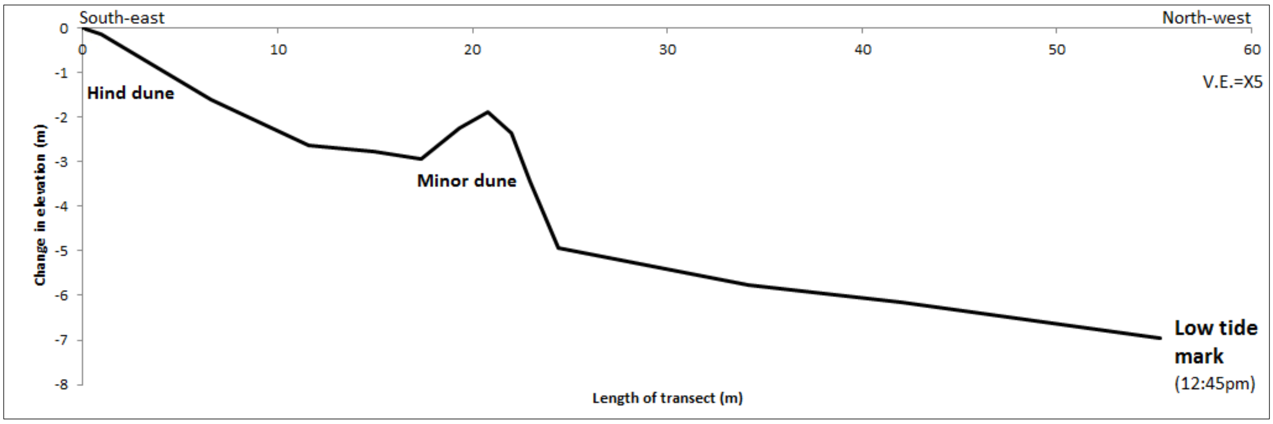

Figure 16: Transect 1: The most western transect of WB (24th of April, 2015) at low tide, displaying the presence of a minor dune.

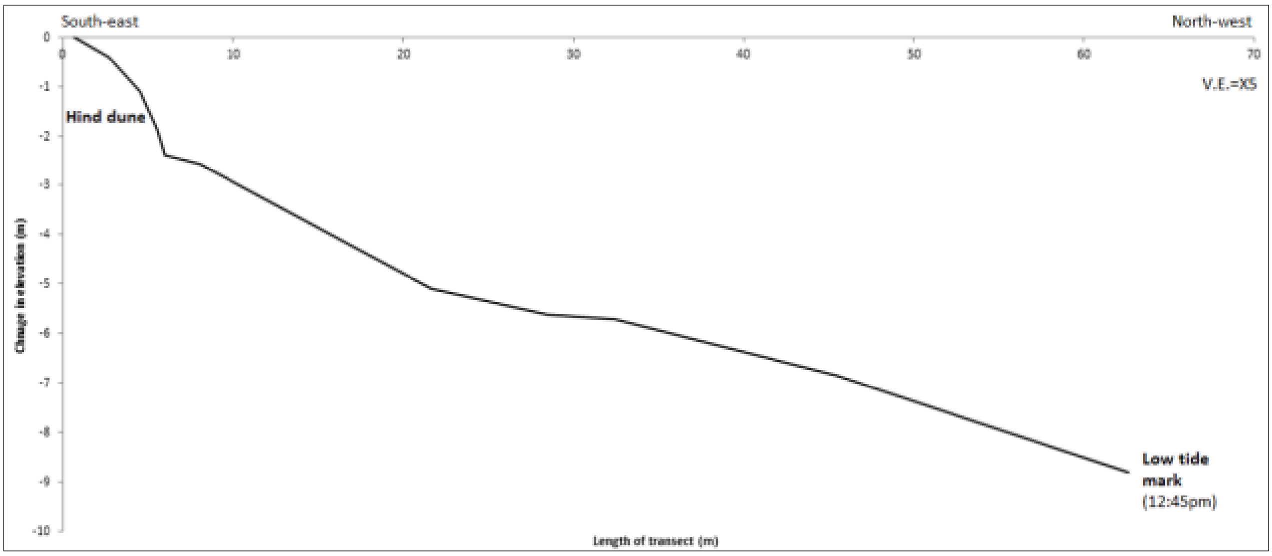

Figure 17: Transect 2: The central transect of WB (24th of April, 2015) during low tide, displaying a relatively steady progression from hide dune to the low tide mark. No minor dune is present.

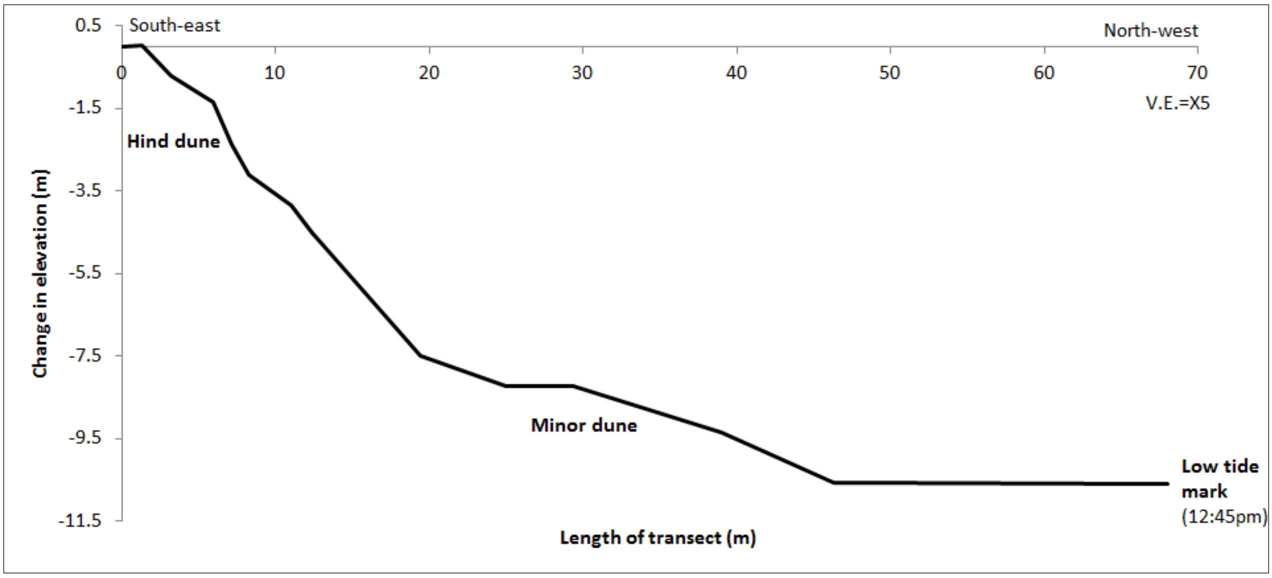

Figure 18: Transect 3: The most eastern transect of WB (24th of April, 2015) at low tide, displaying a relatively steep transition from hind dune to the low tide mark.

Figure 20: Photograph looking upwards of Transect 1 (2015), courtesy of Ian Sauer.

Figure 21: Photograph looking upwards of Transect 2 (2015), courtesy of Ian Sauer.

Figure 22: Photograph looking upwards of Transect 3 (2015), courtesy of Ian Sauer.

These transects (Figures 16-18 and Figures 20-22) display a contrasting transition from the hind dune to the low tide mark. Yet these transects remain comparable, without the conflicting presence of a major dune structure, such as a fore dune. As baseline data, these transects lay down the foundations for present and future studies for the quantitative analysis of WB geomorphology.

The sedimentary result (Refer to Figure 19 and Table 1 in the appendix), show a range of sediment types. These range from very fine sand to granule, as classified in Krumbein and Aberdeen's logarithmic scale (1937). Furthermore, the dominance of quartz in the sediment composition affirms a high riverine and estuarine influence (Figure 19 and Table 1); in this instance, quartz is a mineral found in the Pipers River catchment (Bottrill and Matthews, 2006). Since carbonated sediment indicates an oceanic origin (Biscaye et al,1976), the minor dune's coarser, carbonated sediment indicates a recent storm event.

Figures 23-25 illustrate additional aspects in relation to WB and its sediment budget and other coastal trends, see Figure 1.

Figure 23: Transect 3 (24^{th} of April, 2015) displaying the presence of pioneering, invasive species in the resulting minor dune of a recent storm event.

Figure 24: Reoccurring protrusion of rocks on the Bellingham side of the estuary mouth and the presence of a reoccurring sandbar that can often block out the estuary's mouth (17th of April, 2012), courtesy of Lionel Cooper.

Figure 25: Erosion of the Bellingham dune (10th of July, 2014), contrasting the nature of erosion, derived from dune orientation, courtesy of Lionel Cooper.

Discussion

The aerial imagery of WB (Figures 7-11) has indicated a trend, between increased vegetation and urbanisation to the receding dunes and the coastal instability of WB. Vegetation is often associated with coastal stability; when more people populated Weymouth there was an increased value for the coastal stability of WB. Consequently, vegetation was planted on the dunes to stabilise WB and to protect its inherent values (Figure 7 and 8). At the time, marram grass was understood to enhance coastal stability, through its effectiveness in retaining dune sediment (Rudman, 2003; Hayes and Kirkpatrick, 2012). Understandably, the contrast between Figures 8 and 9 display a change in vegetation density. Marram grass is known to naturalise its new coastal environment (Jenks, 2014), in doing so it has dramatically altered the dune system of WB (Figures 8-11); The vegetation increase (Figures 8-11) indicates the change in the hind dune's presence (Figure 5); the naturalisation of WB, by marram grass, has seen the forest and hind dune replace the fore dune of 1949 (Figures 7-11). As a result, the previous location of the hind dune in 1949 has de-elevated and the now undercutting hind dune of marram grass, consequently leaves Weymouth increasingly vulnerable to flooding. Evidently, this plantation has become counterproductive for coastal stability (Figures 7-15 and Figures 23-25). Understandably, this vulnerability and exposure has made WB reliant on the nourishment of its sediment supply.

Figure 26: the remains of the groynes in the Weymouth/Bellingham estuary, facing towards the Bellingham dunes, courtesy of Lindal Byard.

One source of beach nourishment, the estuary (Figure 19 and Table 1), has also been implicated by increased urbanisation; decreased estuarine and riverine vegetation has seen the channel's depth (Survey participant, pers. comm., 2015), width and structure change (Figures 7-11). Estuarine groynes were implemented (Figure 26) in the late 1980's to regain environmental stability (Survey participant, pers. comm., 2015) (Figure 27), yet when locals and tourists began stubbing their toes on the groynes they were removed in 2008 (Survey participant, pers. comm., 2015). This is disappointing, since the groynes were proving successful in retaining sediment (Survey participant, pers. comm., 2015).

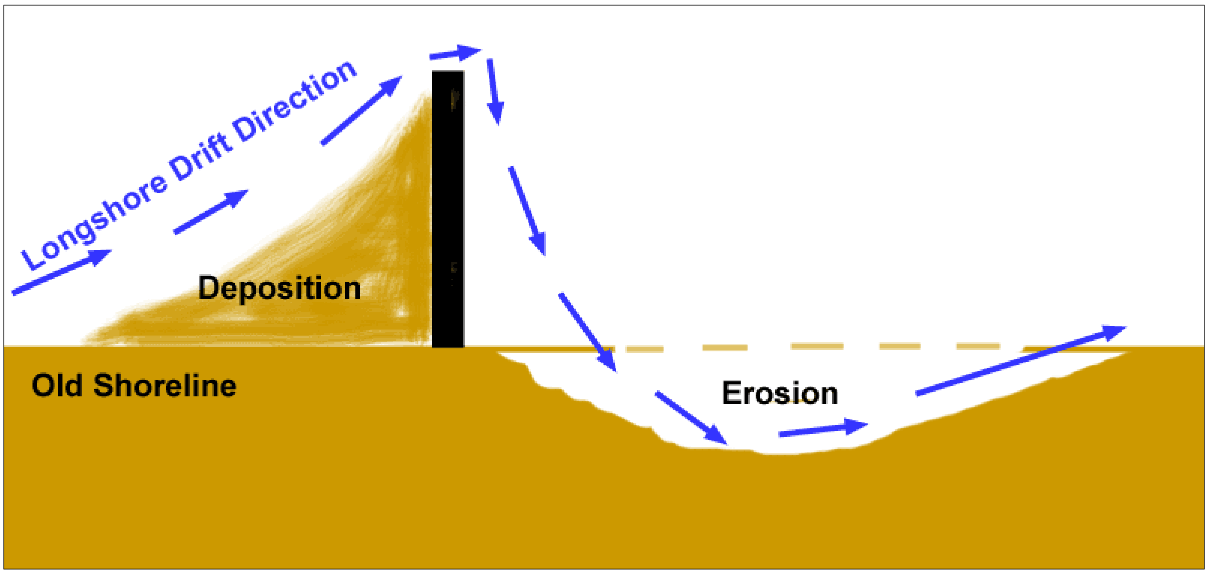

Figure 27: the function of a groyne in retaining sediment, albeit for open shores, the mechanism is the same. Source: College of Charleston (n.d.).

As mentioned previously, the retention of sediment in the estuary is important; the stabilisation of the estuary is directly correlated with sediment supply to the beach (Sharples, 2006). As a result, the lack of vegetation to retain composure of the estuary has resulted in sediment both choking the estuary and eroding its shoreline (Figures 7-11). This displacement of sediment has directly taken away from the sediment supply to WB.

Unfortunately, attempted plantations of Tea tree, further upstream, have been uprooted and snapped (Survey participant, pers. comm., 2015). This is evidence of a gap in understanding of geo-conservation efforts, between those who understand the value of native plantations and those who do not.

From what has been discussed previously, this gap is testament to the value of conventional landscape photography. This photography (Figures 23-25), is qualitative evidence for relating marram grass and other invasive species, to coastal instability. Figures 20-22 are also important in this gap, which depict the impact of vegetation trampling. The trampling of vegetation often leads to damage of vegetation (Schalcher et al., 2014 in Maslo and Lockwood, 2014, 60-69; Hayes and Kirkpatrick 2012; Johnston and Ellison 2014); vegetation trampling is known to increase vulnerability to erosion (Purvis et al., 2015; Johnston and Ellison, 2014). As discussed previously, in the absence of vegetation, dune sediment is bare and increasingly vulnerable to erosion. This is especially the case when directly contrasted against highly aggressive, highly sediment retentive species, such as marram grass.

The advantage and disadvantage of vegetation trampling, is that trampling is a human impact. The advantage of this human impact, is that people can be influenced, educated (Islam, 2000) and act, when in their interest to protect the environment (De Martino et al., 2015). The disadvantage is that people may not listen or want to change (Islam, 2000; De Martino et al., 2015), especially if information is not communicated clearly. For this reason, an illustrative timeline at community events is an essential way in communicating the scientific concepts of geo-conservation to the stakeholders of WB.

Concerns for the coastal stability of WB are justified in Figures 16-18, especially when paired with Figures 7-11; Figures 7-11 and Figures 16-18 have shown that while the low tide mark has not changed dramatically, the WB dune structure has been reduced to an eroding hind dune. From this, it can be deduced that storm events have had a greater impact on WB dune structure and coastal stability, than any change in sea-level rise. As mentioned previously, low frequency and high intensity events have the greatest influence on a landscape's geomorphology (Ellison, 2015).

WB is an open, sandy shore (Sharples, 2006; DTAET, 2007). Open, sandy shores are highly dynamic and heavily influenced by their sediment budget (Hanley et al., 2014; Sharples, 2006); any change in these dynamics will have a corresponding effect on the coastal stability of WB and its geomorphology. In this instance, these dynamics are the frequency and intensity of these oceanic events.

According to White et al. (2010) and McInnes et al. (2012), as the climate changes, there will be more extreme events, flooding and increased sea-level rise across Tasmania. This means there will be greater pressure from both high intensity, low frequency events, as well as low intensity, high frequency events.

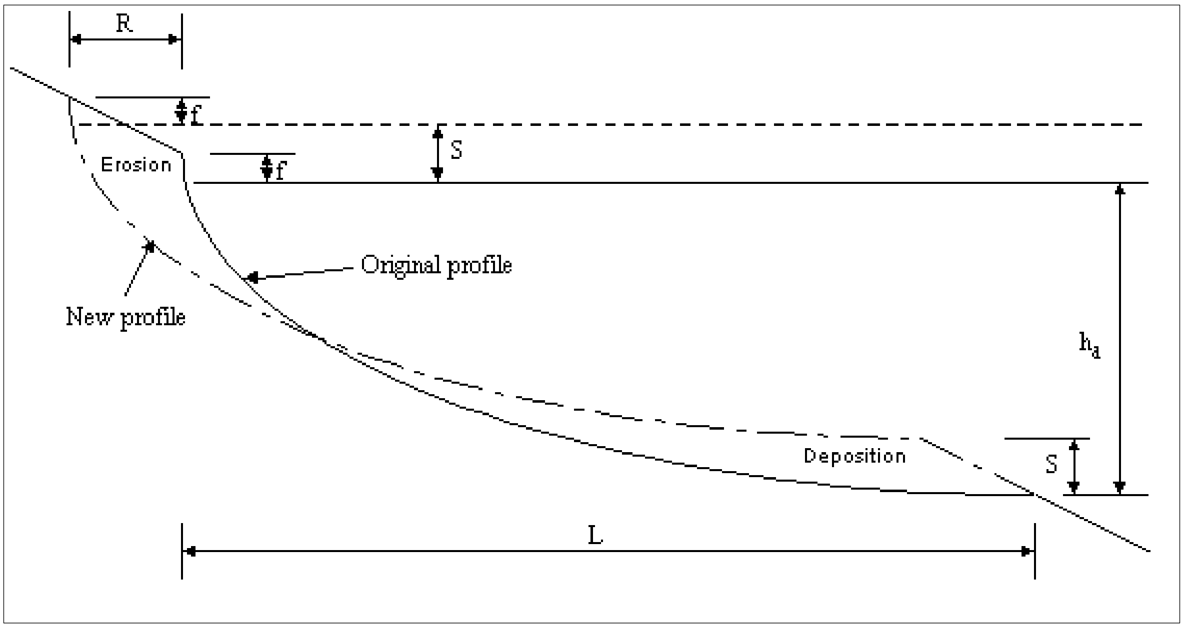

Figure 28: Diagram of the Bruun Rule (Bruun, 1962), indicating the relationship between sea-level rise and coastal erosion.

Sea-level rise, in itself, is a low intensity event for progressive landward erosion. The calculation of landward erosion for the Bruun Rule is as follows: the landward translation of sea-level rise is given by geometry and is expressed as R = SL/(hd+f), where S is the amount of sea level rise, L is the active length of the profile, hd is the closure depth, and f is the freeboard. S= .003(Church et al., 2008 in Government of Tasmania, 2009); L= 68 (Figure 18); hd= 9 (Figure 18); f=2 (Figure 18). Consequently, progressive erosion from sea level rise = .019 m, or 19 cm, per annum.

Figure 11 indicates there is approximately 120 m of dune system remaining at WB. As a result, the WB dunes would take 63 years to erode away from sea-level rise, per se. Understandably, sea-level rise will bring added pressures to maintaining coastal stability (Bosello and De Chian, 2014; White et al., 2010; McInnes et al., 2012).

With this being said, the Bruun Rule: "does not account for longshore interactions and assumes the wave climate is steady and hence the equilibrium profile remains the same – simply translated landwards and upwards with the rise in mean sea level" (Commonwealth Science and Industrial Research Organisation, 2008). Furthermore, this is a broad rule that does not take into account the adaptive capacity, or physical response of every beach. For example, dominant vegetation varies. Vegetation is a dominant factor in dictating adaptive capacity, in a beach's ability to retain sediment during a storm event. Thus vegetation has a greater influence over the rate of dune erosion than sea-level rise.

WB physical response to these storm events has proven to be poor (Figures 12 and 13). At present, Figure 16 and 18 show the presence of a minor dune. When compared to Figure 19 and Table 1, it is confirmed that these minor dunes are the product of a recent storm event; coarse sediment is indicative of a recent deposition (Krumbein, 1941) and the calcium carbonate depicts an oceanic origin (Biscaye et al., 1976). Evidently, WB is prone to storm events which can both erode and dispose sediment. This is important in managing the coastal stability of WB, since pioneering species, can take advantage of this new disposed sediment quickly (Figure 23). The issue is thus to compose WB with the right pioneering, native species, such as spinifex (*Spinifex sericeus*) and austrofestuca (*Austrofestuca littoralis*).

The oceanic influence is still only one aspect to the sediment budget and the coastal stability of WB. The sediment analysis (Figure 19 and Table 1) confirms the current composition of WB is dependent on the nourishment of the Pipers River. This dependence adds another aspect of vulnerability to the coastal stability of WB. As discussed earlier, the estuary has become implicated by increased urbanisation and coastal erosion. Furthermore, Locatelli (2001) found that a 'flash-flow' hydrological regime, accounts for approximately 90% of Pipers River bank erosion; the quartz and silt eroded from the high intensity, low frequency events of the Pipers River, have been found in the shallowing channel of the estuary (Survey participant, pers. comm., 2015). Summer sinkholes composed of course sediment, a sandbar that can block out the estuary's mouth and the exposure of rocks in the estuary, all of which can appear and disappear in a day or two have also been documented (Figure 24; Survey participant, pers. comm., 2015). This owes to the complexity and dynamics of the WB and estuarine sediment budget and the need for further investigation, in all aspects of the WB sediment budget.

Evidently, the stability of the estuary and WB are multivariate in nature; management of the Pipers River catchment should be made in consultation with the management of WB. In doing so, the management of WB requires environmentally stable alternatives to retain newly deposited sediment, from riverine, estuarine and oceanic events; the management of WB vegetation and the sediment budget, are consequently vital in maintaining coastal stability and remediating the WB dune system. Extreme climatic events are becoming more common

(White et al., 2010); building adaptive capacity through coastal management will become increasingly important, as the climate changes and these high intensity events become more frequent.

Recommendations

There are a number of actions that can be taken, in regards to the coastal stability of WB: hand removal, burning or poisoning of marram grass and re-establishment of native species, the implementation of beach and estuarine groynes, the implementation of dune fencing/thatching, the implementation of boardwalks and signage, no action, or finally, integrated management.

Marram grass and sea spurge management

Hand, or manual removal, poisoning and burning, as methods of marram grass and sea spurge removal, vary in cost and effectiveness. As outlined by the Invasive Species Specialist Group (ISSG) (n.d.), both manual removal and burning are "effective but also hugely cost and labour intensive" (Pickart, 1997 in ISSG, n.d.). The costs of manual removal and burning can include the: transport of people and equipment and the cost of labour and equipment. These cost are known to range from US$ 36,600/ha (Peterson, 2004 in Hyland and Holloran, n.d.) to US$ 86,703/ha (Pickart, Andrea and Sawyer, 1998 in Hyland and Holloran, n.d.).

The extensive rhizome network of marram grass makes it notoriously difficult to eradicate. For this reason, thatch removal and re-sprout control are two key essential and effective control efforts in eradicating marram grass (Hyland and Hollorand, n.d. in ISSG, n.d.). While fire is an effective means of eradicating marram grass, it also stimulates its regrowth (Pickart and Sawyer, 1998 in ISSG, n.d.). Consequently, hand removal and monitoring or chemical control of regrowth will be required after burning is undertaken. Chemical control is not recommended for small amounts of re-sprouting (ISSG, n.d.), since not enough of the plant is exposed and will require further manual control. Fire can also stimulate the growth of many native coastal vegetative species (Parks and Wildlife Service, 2010); burning, followed by the hand removal of re-sprouting marram grass, can promote growth of native species and the re-naturalisation of the WB dune system.

Groynes

The present vegetative composition of WB has effectively disabled WB capacity to retain sediment (Figure 12 and 13). As shown in Figure 25, the Bellingham dunes orientation makes it susceptible to coastal erosion from the prevailing SACW and SASW currents (Figure 2). A north-south orientated groyne, positioned on the western side of the estuaries mouth would retain sediment for WB, while breaking the wave energy of the prevailing currents on the Bellingham dunes. The construction of groynes, such as the previous Tea tree groynes in the estuary, can be both low in cost and effective. Yet locals are concerned that groynes: hinder recreational value, are easy to stub their toes on and provide a navigational hazard (Survey participant, pers. comm., 2015). This can be overcome with a fluorescent flag protruding from the groynes, though this may degrade WB aesthetic value. Furthermore, since WB

sediment composition is dominated by the Pipers River, the obstruction of its sediment to WB by the groynes could prove counterproductive in dune remediation efforts.

Fencing and thatching

Dune fencing and thatching has proven successful, as far away as Scotland (SNH, n.d.) and in Turner's Beach, Tasmania (Johnston and Ellison, 2014). As noted by SNH (n.d.), dune fencing and thatching has "minimal [adverse] impact on the natural system… and does enhance natural dune recovery", especially when re-vegetation is present. The issue is that dune fencing and thatching provides little resistance to storms (SNH, n.d.); dune fencing and thatching requires on-going maintenance costs (Page and Thorp, 2010; SNH, n.d.). Furthermore, it is vital that invasive species are not present when fencing and thatching take place; the invasive colonisation of this new structure would only advance current erosive issues.

Another issue is that locals may feel their beach access is restricted, or that WB aesthetic value is degraded. Yet as discussed by Gomez-Pina et al. (2002) in Johnston and Ellison (2014) and SNH (n.d.), these issues can be overcome using: boardwalks for alternative beach access and informative posters for the public in regards to coastal damage and fencing effectiveness.

Boardwalks and signage

At Turners Beach, Tasmania, it was found that signage was the least effective remediation effort, with only 17% of respondents considering them as effective (Johnston and Ellison, 2014). Among the Weymouth community, installing boardwalks is considered an appropriate action to take, in reducing human impact on the dunes (Survey participant, pers. comm., 2015). These boardwalks would also provide an alternative route, to wading through the irritative spinifex. Johnston and Ellison (2014) also found 94% of their respondents considered boardwalks an effective means in reducing dune instability. Essentially, boardwalks are an effective means in reducing dune instability, though are only effective when dune management strategy is understood and in the interest of the public (SNH, n.d.).

Consequently, the effectiveness of both signage and boardwalks require coastal stability to be in the interest of beach users and for coastal management practices to be understood. Signage is often a method for engaging the public and justifying the use of management practices. Yet as mentioned, they are considered ineffective; alternative educational methods, such as field days or barbeques, should be considered.

No action

As discussed and qualified by the Bruun calculation, no action will inevitably result in the erosion of the entire WB dune system, leaving Weymouth to face storm events directly.

Integrated management

As discussed, each management option has advantages and disadvantages; fire is effective yet requires the monitoring and manual removal of invasive species, of which is labour intensive. Groynes can be relatively cheap, yet do not have the community's support and can restrict WB riverine nourishment to further choke the estuary. Fencing and thatching are effective in restabilising coastal dunes, yet are vulnerable to storms, requiring ongoing maintenance, community support and the absence of invasive species. Boardwalks and signage, as discussed, can be effective in reducing dune destabilisation caused by human traffic, yet require holistic community support and understanding.

Integrated management aims to employ the advantages of each practice, with the available financial and human resources and community support. SFM Environmental Solutions (2005) notes in the 'George Town Coastal Management Plan' that, in Weymouth, "intervention would require significant expenditure of resources". Consequently, it is essential that remediation efforts are cost effective.

Using limited resources, burning, followed by the hand removal of invasive species and boardwalk construction should be undertaken. While this practice can be expensive, as discussed previously, it is also highly cost effective. Costs can be further reduced using volunteers to remove invasive species after the burning. Furthermore, Page and Thorp (2010), note that burning should only be undertaken in consultation with biodiversity, vegetation, wildlife and fire specialists.

To integrate management practices, dune fencing, thatching and boardwalk construction should follow dune burning and removal of marram grass; fencing will provide some protection for this exposed sediment, as well as an opportunity for native pioneers, such as spinifex and austrofestuca to consolidate the sediment. To reduce the vulnerability of dune fencing, exposed sediment and the risk from fire hazards, it would be recommended that fencing establishment and burning takes place in spring; storms have passed after spring and fire bans are usually not in place at this time; dune fence installation after storms will reduce the cost of maintenance, making it a viable option to coincide with burning and manual removal. While the costs of burning are subjective, the ISSG (n.d.) state that burning is less costly than both manual removal and herbicide use on their own; burning appears viable if manual removal or herbicide use is already practiced. Manual removal, as noted, can be voluntary and dune fencing/thatching installation can be as low as AUD$834/ 100 m (SNH, n.d.). In perspective, WB is approximately 1,083 m in length (Figure 11); this recommended course of integrated management could be as low as AUD$ 9032. This cost could be reduced further, based on the materials used for fencing. Furthermore, the cost of burning has not been accounted for; since the WB dunes are crown land, burning should be at the expense of the Tasmanian Government, especially if this project is in their interest, of which it should; the cost of remediation now is much less than the cost of dikes, which can cost US$0.9 to 29.2 million per metre rise in height, per km length (in 2009 US dollars) (Hillen et al., 2010 in Linham and Nicholls, n.d.)

Burning, manual removal and dune fencing/thatching are the first three recommended remediation efforts to take with limited resources; maintaining sediment at WB will also reduce the choking of the estuary, based on the sediment budget in Figure 7. To fully address the issues of the estuary and to enhance the transport of riverine sediment into WB, erosion in the Pipers River catchment and the estuary, should be investigated further. At present, the community and other stakeholders should be educated on the significance of Tea tree plantations in the estuary and catchment.

Furthermore, the community should be made aware that while spinifex causes irritation, it is essential for dune remediation. Understandably, education should also be an integral part of WB remediation efforts; the community needs to value and understand the effectiveness of dune fencing/thatching and dune burning, as well as the effect of dune trampling. The cost of education and community engagement can be as low as a community barbeque, or another community event.

Conclusion

If no action is taken, sea-level rise has the capacity to fully expose Weymouth. While dynamic, not all open, sandy shores are the same; the timing of full exposure is based on WB inherent adaptive capacity to increasingly erosive and frequent events. The Pipers River catchment and the SACW and SASW currents are contributors to the WB sediment budget, of which depose sediment in high intensity, low frequency events. The proposed recommendations for integrated management can work with these dynamics and be both effective and low in cost. Yet these efforts cannot be obstructed and require the support of the community to be successful. This discussed form of integrated management would not only result in safeguarding Weymouth's social and environmental values, but would also avoid the Government to choose between sacrificing these values and the costly construction of dikes.

Furthermore, the sinkholes at Weymouth and Bellingham are enigmatic and showcase the dynamic nature of open, sandy shores. There is consequently a need for further investigation to assess whether or not they are indicative of a greater threat to Weymouth's social and environmental values. Furthermore, the open sandy shores of northern Tasmania rely on the same oceanic sediment budget; the issues discussed previously could be indicative of greater problems. There is consequently a need for further analysis across northern Tasmania, to form a framework that attracts greater resources and understanding for later coastal geo-conservation efforts. This analysis should be thorough, using social science and take into consideration the varying inputs from each beach's different riverine and estuarine sediment budget.

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Appendix

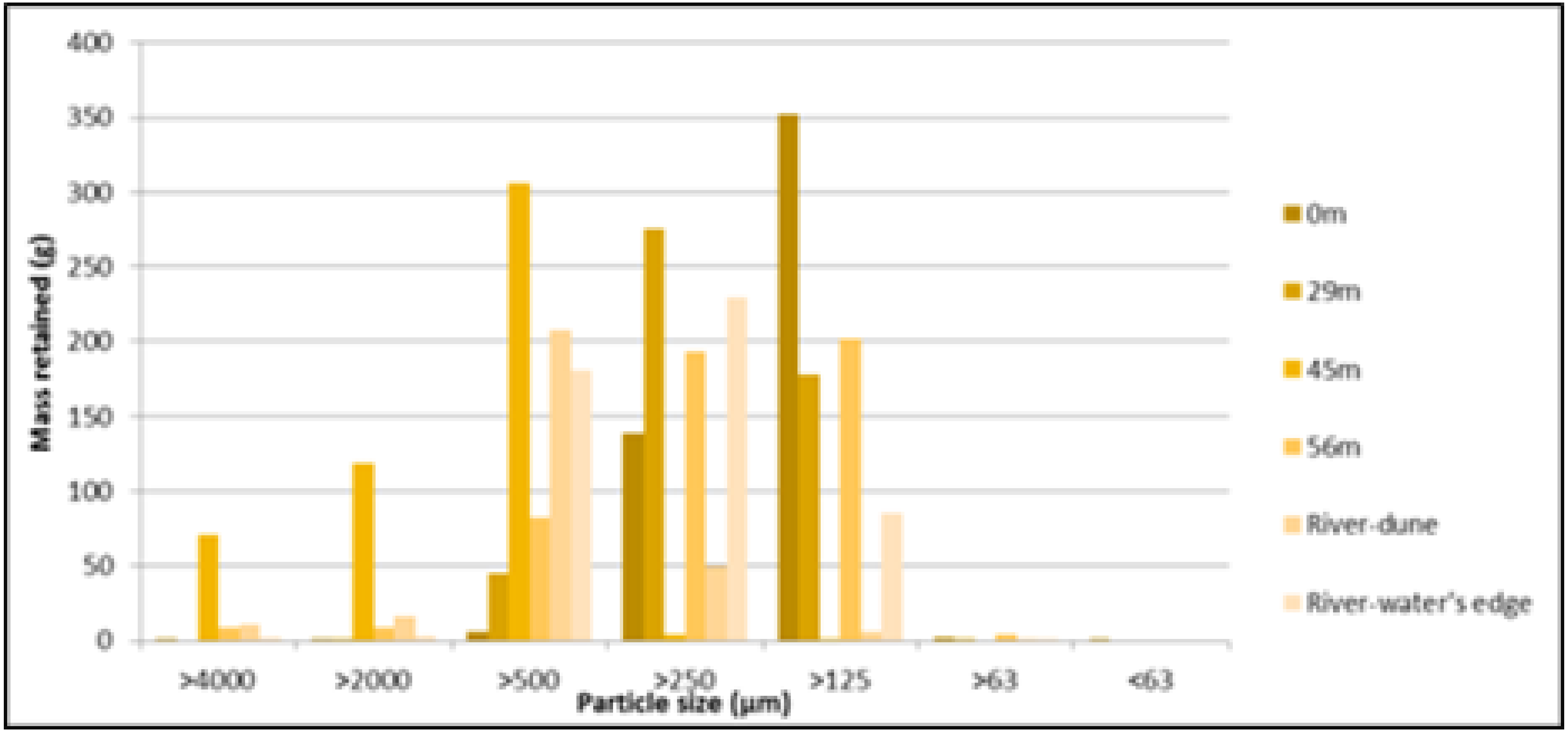

Figure 19: Transect 3 sediment size comparison, displaying differences in particle size along Transect 3 and locations at the estuary's mouth.

Table 1: Transect 3 sediment compositions.

Analysis/Sample	Hind dune: 0m	Minor dune Top: 29m	Minor dune bottom: 45m	Low tide range: 56m	Estuary-dune	Estuary-water's edge
Partical Composition	Sub-rounded	Sub-angular	Rounded/Sub-angular	Rounded/Sub-rounded	Sub-rounded	Sub-rounded
Colour	7/2 2.5Y	7/4 2.5Y	8/5 2.5Y	6/3 2.5Y	6/4 10YR	6/4 2.5 y
Carbonate (%)	17%	17%	30%	<10%	25%	<10%
Dominate mineral	Quartz	Quartz	Quartz	Quartz	Quartz	Quartz