Purpose of this paper:

This paper reviews the coastal change data for Village Bay (St Kilda) in support of Historic Environment Scotland and National Trust for Scotland's Climate Vulnerability Assessment on 13th to 15th September 2022.

1. Summary

a. Coastal erosion occurs naturally within Village Bay, although it has been modified through human intervention in places. Earlier assessments suggest erosion rates have been modest, though all noted implications for adjacent assets. For nearly twenty years, researchers have called for systematic monitoring of the coastline and, given the current and anticipated erosion risk mapping (Figure 1), **it is now essential to develop a monitoring strategy and develop adaptive planning for the WHS**. This review collates readily available data and updates our understanding to 2021.

b. Change is greatest within the beach fronting Village Bay and this assessment estimates that, between 1968 and 2011, the Mean High Water Springs (MHWS) line has retreated landwards up to 10m in front of the gabion seawall (Figure 2 Section D), whilst the beach in front of the fuel tanks advanced seawards up to 10m. To arrest past erosion, some 145m of coastal defences have been installed, repaired and extended. In some cases these defences have be installed at a late stage (eg gabions at Feather Store). Whilst changes to the vegetation edge are more modest than MHWS, this analysis shows that numerous assets are currently within the reach of, and at risk from, wave processes. Climate change will exacerbate these risks further.

c. Since 2022, at least two sets of gabion walls have been compromised (main gabion wall & Feather Store); these and other assets are likely to be increasingly affected by wave and slope processes as climate change continues to impact. Within the natural shore (ie beyond coastal defences), most coastal assets are already impacted by wave thrown debris, or are expected to be affected over the coming decades as sea levels continue to rise.

d. The extremely high wave energy on the beach, combined with rising sea levels, means that coastal retreat, undermining of defences, defence-flanking and a widening of the wave-thrown debris-field are likely. Figure 1 summarizes these risks, showing in blue the anticipated extent of **wave debris field** (including 1m sea level rise above current extent); Orange area depicts the current **active beach area**, where increased instability is expected. Adjacent to this, the pink area is a nominal 10m buffer where **landslips** are also increasingly likely.

e. The steeply rising topography partly mitigates these risks. For assets that have (and must continue to have) a coastal location, increased intervention (using nature-based or artificial approaches) or adaptation by avoidance is inevitable.

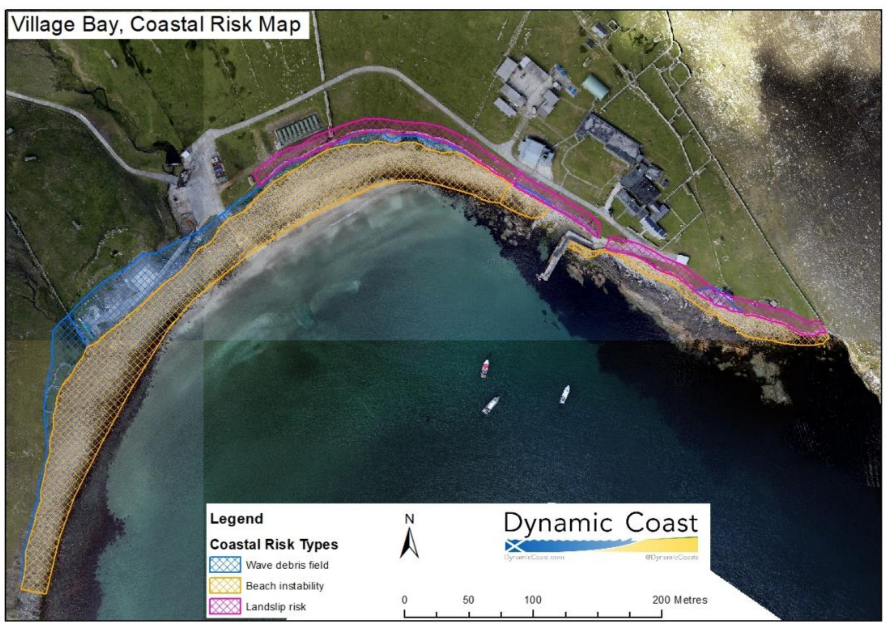

Figure 1 Coastal risk map. Wave-thrown debris field = Blue, Beach instability = Orange, Landslip = Pink

f. As a result of coastal change, the **management burden and risks to assets are set to increase further in coming decades**. In line with (forthcoming) Scottish Government Guidance, a **Coastal Change Adaptation Plan should be undertaken**, which would provide the monitoring baseline to track change, define trigger points for prompt action, and allow management strategy to flexibly respond to the risks.

g. The following interactive tools are available: Webmap of results, 3D Viewer & partially updated X-Ray.

2. Introduction & Scope

Since 1996, several research studies have investigated coastal change at St Kilda, some as by-products of archaeological mapping exercises. The intention here is not to summarize these assessments, but to compile recent data to supplement them, and provide some key points and supporting material for the Climate Vulnerability Investigation.

3. Datasets & reports

Table 1 Reports & Datasets used within this assessment.

Name	Date	Licensed / source	Data Type	Processing
GetMapping aerial imagery	2014, '18 '21	NatureScot / Get Mapping	Vertical RCG images	Geo-rectification improved to align with LiDAR
LiDAR & Aerials	2011	Historic Environment Scotland	LAS & Vertical RGB images	LAS processed into 0.5m raster.
MHWS & MLWS	1968	Ordnance Survey (MasterMap)	Shapefiles	None
CMAC data	2014	NTS	Shapefiles	
GUARD	1999	NTS	Report	
NTS report (S. Bain)	2002	NTS	Report	
NTS report (J. Hansom)	2003	Jim Hansom	Report	
NTS report (S. Dennis)	2006	NTS	Report	
NTS report (I. McHardy)	2011	NTS	Report	
NTS report (CMS)	2014	NTS	Report	

4. Methods

The brief coastal change assessment presented here was undertaken with a Geographic Information System (qGIS) to allow the quantification of any spatial variations between assembled datasets. The method included the following steps:

a. **Mean High Water Springs.** Comparisons were made between Ordnance Survey MHWS surveyed and published in 1968. Where MHWS crossed rocks near the feather store, the average elevation was extracted (1.82mOD) from the LiDAR surface. This assumed MHWS elevation was then extracted from the HES LiDAR surface to provide a 2011 MHWS. Such an approach is reasonable in the absence of long-term tidal monitoring; however some of the identified changes may be due to errors in this method.

b. **Vegetation Edge.** The seaward edge of the terrestrial vegetation 'veg edge' can be used as a readily identifiable feature to track coastal change. It may also be influenced by periodic storm deposits (i.e. by burying vegetation with beach sediments as within Village Bay), or seasonal vegetation changes. The veg edge was manually digitized in each set of aerial photography (2011, 2014, 2018, 2021), allowing qualitative comparisons. The indicative error was also noted per line: in optimum conditions this can be <0.2m, but may rise above 1-2m where there is shadow or diffuse boundaries. A row of virtual points at 10m intervals was created seaward of the veg edge lines to allow the distance to each of the lines to be calculated and the changes to be quantified.

c. **Coastal Risk Map.** The elevation difference and distance to assets was also used to develop a coastal risk map (Figure 1). The 'beach instability' area (orange hatching) shows the beach extending from MHWS to the mapped limit of current wave thrown deposits. Within these areas wave driven processes operate and beach levels are expected to fluctuate, with associated risks to built structures. As sea levels rise by up to ca 1m by 2100, the 'wave debris field' is expected to increase in elevation too. The blue hatching (Figure 1) highlights land elevations within 1m above the current limit of wave throw. Within steep areas, coastal erosion is likely to result in over-steepening and 'landslips'. This pink hatched area is extends a nominal 10m landwards of slope foot.

d. **Air photo Interpretation.** A visual comparison of the 2011, 2014, 2018, 2021 imagery was undertaken, noting the different scales.

5. Results

a. In line with earlier assessments Village Bay has been divided into sections (Figure 2) with amounts of change presented in Table 2. The approach taken here is an amended version than that used by McHardy (2011), which adds in Section C2, to the east of the Pier and widens Section D to include the entire Gabion seawall.

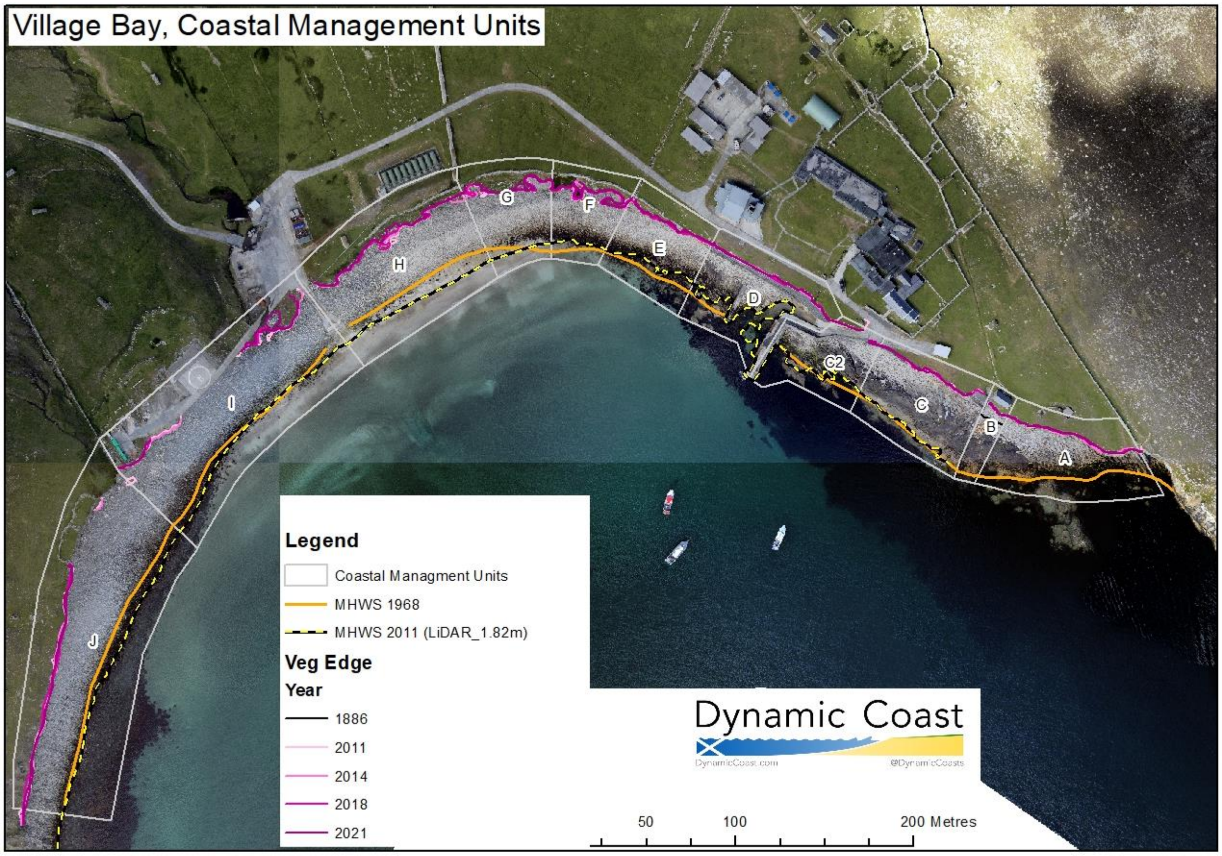

Figure 2 Coastal sections within Village Bay (amended from McHardy, 2011).

b. Changes between the 1968 MHWS (orange line) and 2011 MHWS (black & yellow line) are shown, alongside vegetation edge lines (pale pink to purple between 2011 & 2021). The 1886 estimated veg edge is also shown adjacent to the Feather Store (black line).

c. Table 2 summarizes the results; noting the maximum, average and minimum changes to MHWS and vegetation edge, alongside elevation comparisons between the average elevations of wave throw limit and the minimum elevation of built assets. The results are also available within the following interactive tools: Webmap of results, 3D Viewer & partially updated X-Ray (further updates expected following CVI).

d. There is a clear split in the results for changes to MHWS between 1968 and 2011, with eastern sections of the beach dominated by erosion (landward retreat of MHWS). At the Dyke (section E & F) the average retreat of 4.0m and 4.3m (min change / max retreat of 6.3m and 5.3m, respectively). At the Gabion seawall (Section D) the average retreat was 5.2m (min change / max retreat of 9.8m) and more modest change east of the Pier (section C) with average retreat of 0.6m (within errors) with greatest losses of -2.5m. The central and western sections of the bay show MHWS has accreted (advanced seawards) an average of 7.9m at the Fuel tank (Section H), an average of 2.2m at the Helipad (Section I) and 4m west of the Helipad (Section J). However, it should be noted that the limit of wave thrown debris has not moved seawards.

e. The vegetation edge shows more modest changes than MHWS, which is unsurprising given its altitude above a substantial storm beach and partial burial of vegetation in the central sections H and I. Whilst little change is evident between 2011 and 2021 alongside coastal defences, modest retreat is significant / perceptible at Dyke (east) (Section F) where the veg edge has retreated landwards an average 1.4 m (2011-2021). The greatest local retreat is 7.1m adjacent to the Fuel Tanks and 3.6m towards the Helipad.

f. Table 2 also notes the maximum altitude of wave thrown sediment and the minimum altitude of built assets. This provides an impression of the relative risk of assets being effected by wave thrown debris, or undermined by wave action. The limit of wave thrown sediments is typically between 7 to 8mOD, which is approximately 5 to 6m above MHWS. When future relative sea level rise is considered, mean sea level is expected to be 35cm and

1.0m higher by 2050 and 2100 (based on high emissions scenario (UKCP18 RCP8.5 95%) using Stornoway as a proxy for St Kilda).

Table 2 Coastal change results

Section		J	I	H	G	F	E	D	C2	C	B	A
		West	Heli-pad	Fuel tanks	Dyke (west)	Dyke (cent)	Dyke (east)	Gab'n	Pier front		Feat'r Store	East
MHWS	Max.1968-2021 (m)	+7.1	+5.1	+10.2	+3.8	-2.6	-1.0	-2.2	+4.2	+0.6	-	-
MHWS	**Ave. 1968-2021 (m)**	**+4**	**+2.2**	**+7.9**	**+0.5**	**-4.3**	**-4.0**	**-5.2**	**-0.7**	**-0.6**	**-**	**-**
MHWS	Min. 1968-2021 (m)	+0.1	-1.0	+5.8	-3.4	-5.2	-6.3	-9.8	-5.4	-2.5	-	-
Veg edge	Max. 2011-2021 (m)	+1.6	+0.1	+0.1	+0.1	-0.6	+0.1	-	-	+0.2	-0.3	+0.3
Veg edge	**Ave. 2011-2021 (m)**	**0.3**	**-1.3**	**-1.4**	**-1.2**	**-1.4**	**-0.5**	**-**	**-**	**-0.3**	**-0.5**	**-0.1**
Veg edge	Min. 2011-2021 (m)	-0.7	-3.6	-7.1	-4.3	-2.3	-1.3	-	-	-0.7	-0.6	-0.3
Ave altitude of wave thrown sediment (mOD)		7.2	7.6	8.1	8.3	8.2	7.4	5.1	5.9	8.1	7.3	7.4
Min altitude of asset (mOD)		Wall 5.5	Road 6.5	Road 13.0	Wall 10.0	Wall 10.5	Wall 10.5	Gabion 5.0	Seaw'l 3.9	Gabion base 8.0	Gabion base 7.1	Gun 13.4

g. The vegetation edge analysis has been extended at the Feather Store back to 1886, using the images shown in Hansom (2003 – original source unknown). The width of vegetation to the west of the store is 1.24 times the width of the store (estimated on 2011 aerial imagery of ca 5.7m). Thus in 1886 there was ca 7.2m of vegetated land before the cliff. Dennis' 2006 report depicts the vegetation edge retreating towards the door of the Store (See Dennis 2006, Fig 7, p8) which also shows a comparable photo from 2002. Gabion baskets were installed (and repaired) in 2006. Thus, almost 9m of land has been lost in the 120 years between 1886 and 2006, with an average rate of ca 8cm/yr. Whilst not a substantial rate, given the time periods involved in managing historic sites, this shows the importance of monitoring and timely interventions.

h. Foreshore changes at the foot of the gabion sea wall – waves are a clear risk to this structure and highly likely that waves were involved in the failure of the structure. Repeat three-dimensional beach monitoring is necessary to identify topographic variations in front of coastal defences.

i. Are there very large storm wave features visible – see NW of heli-pad. There may be some very large processes etched within this landscape.

6. Discussions

a. **Comparison with earlier reports.** Whilst the 1999 GUARD and 2002 Bain reports made observation of coastal change with reference to cultural assets, Hansom (2003) was the first geomorphological assessment that explored the coastal changes in more process detail. It noted that the erosion within the eastern parts of the bay were feeding sediment towards the central sections, the pier and outfalls were also acting as groynes temporarily retaining sediment on the upper beach and protecting it. Although repeat survey (via LiDAR or photogrammetry) is necessary to inform volumetric change, his interpretation appears justified by the analysis here.

b. **Coastal risk map.** Climate change will have impacts on a wide range of natural processes and consequential feedbacks. Whilst the CVI aims to explore these, this report concentrates on coastal processes within Village Bay, as summarized on Figure 1. Given the anticipated increases in relative sea level rise over and beyond the next century, the beach will become increasingly mobile (orange hatching in Figure 1) with associated risks to adjacent defences & structure. The wave thrown debris field is also expected to extend further inland (blue hatching in Figure 1) and landslips may increasingly occur in response to over-steepening (pink hatching in Figure 1).

c. Most of the coastal erosion reports (Table 1) identify qualitative changes within the bay. Hansom (2003) noted that the absence of qualitative data increased the uncertainty and hindered decision-making. Whilst the 2014 topo survey captured primary data, little comparisons were (perhaps able to be) made. The surveyed data on the areas of the Dyke which have total and partial collapse are interesting.
d. The Dynamic Coast project has acted as a catalyst for the updating of coastal change data since 2015, but the paucity of data remains problematic. Demonstrating this, some of the current MHWS and MLWS lines shown on modern day maps, was actually surveyed in 1968.
e. Given that Village Bay is perhaps one of the most extreme process environment of any beach in the UK, the continued threat to existing defences, and the proximity of coastal assets to current wave processes, effective robust and ongoing monitoring is essential. NTS should be credited for the surveys undertaken, as should HES for the LiDAR survey, but it is now essential that these data are compiled and interpreted together. The management burden and risks to cultural and built assets are set to increase. As such and in line with (forthcoming) Scottish Government Guidance, a Coastal Change Adaptation Plan should be undertaken, which would provide the monitoring baseline to track change, early definition of trigger points for action and to allow management approaches to flexibly respond to the anticipated future increase in risk.

7. Recommendations

The management burden and risks to cultural and built assets are set to increase. As such, and in line with (forthcoming) Scottish Government Guidance, a Coastal Change Adaptation Plan should be undertaken (together with updated in-field geomorphological assessments) to provide the monitoring baseline to track change, to define trigger points for early management action, and to allow management strategy to flexibly respond to the anticipated future increase in risk.

8. References

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9. Acknowledgements

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End.