COASTAL CLIFF MONITORING - COWBAR NAB, STAITHES, N. YORKSHIRE

Monitoring period: January 2023 – January 2024

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Prepared for and on behalf of:
Scarborough Borough Council
c/o Robin Siddle

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4. EXECUTIVE SUMMARY

- This report summarizes results from monitoring coastal erosion and cliff retreat at Cowbar Nab, Staithes, over two timescales:
    - Monthly analysis over the period since our last report to Redcar and Cleveland Borough Council (RCBC) which reported data up to January 2023.
    - Annual data since start of our monitoring at this site in January 2011.
- This report describes the rate of erosion and highlights features of the changes observed that are pertinent to the management of erosion risk at this site.
- The monitoring program is being undertaken for and on behalf of Scarborough Borough Council and Redcar and Cleveland Borough Council.
- Data have been collected in 3 phases at Cowbar Nab:
    - Between the start of surveys in 2011 and 2017 data was collected at monthly intervals using surveys from the foreshore accessed at low tide.
    - Between 2017 and August 2023 data was collected using a permanently installed terrestrial laser scanning system, developed specifically for this project. This system scanned the cliff each hour, with the data streamed and erosion calculated on a rolling basis.
    - Thereafter surveys have again been undertaken from the foreshore at monthly intervals coincident with low tides due to constraints on access to the permanent monitoring equipment, which has been mothballed. The regular sequence of surveys commenced in January 2024 due to instrument servicing, repairs and inclement weather between August and December 2023.
- We make recommendations based upon the changes that we have observed to date, and the outcomes from our wider program of coastal erosion monitoring along this coastline.

5. MONITORING OVERVIEW January 2023 to January 2024

- Data is reported for the months including and between January 2023 to January 2024, totalling 12 months. This period allows future reports to be presented on an annual basis, with interim reports as and where required.
- The background to the monitoring approach using the permanent laser scanner installation is described in full in our report dated August 2018, available from the following website:

  https://www.northeastcoastalobservatory.org.uk/data/reports/21_local_monitoring_reports/40_Redcar_&_Cleveland_Borough_Council/
- During this monitoring period the system functioned well (to August 2023), with continuous monitoring during 98.5% of the period covered in this report.
- The permanent monitoring installation was mothballed after loss of access to the site in August 2023. At this point the scanner was returned to the manufacturer for servicing and recalibration in Austria. The motherboard in the scanner required replacement which delayed its return to the UK, and combined with inclement weather and poor tides, monthly surveys were only able to the restarted from January 2024 onwards. The sum of erosion over this period is included within the data in this report.
- We note that during this period we are combining data from the permanent scanner and from the foreshore surveys, which introduces different view angles onto the cliff. This is reflected in the change data particularly at the margins of the surveyed cliff section.
- In this report, we document the calculation of the erosion rate for the seaward facing cliff at Cowbar Nab as a whole which includes an area of the cliff face immediately below Cowbar Lane, termed our 'focus area' from hereon.

6. MONITORING RESULTS

I. Results: January 2023 – January 2024

- We present the erosion rates between January 2023 and January 2024, which are presented in detail in Table 1, and Figures 1 to 5. The resultant erosion data is summarised on a monthly basis for comparability:
- A total volume loss of 166.18 m^3 in 5,241 discrete rockfall events occurred during this 12-month period.

- The area-averaged rate of retreat observed in the period January 2023 to January 2024 for the whole site was 0.023 x 10^{-3} myr^{-1}.
- The modeled rate of retreat in the period January 2023 to January 2024, which takes into account the probability of the largest events whether they occur or not, for the whole site was 0.0248 x 10^{-3} myr^{-1}.
- The area-averaged rate of retreat observed in the period January 2023 to January 2024 for the focus zone was 0.059 x 10^{-3} myr^{-1}.
- The lowest monthly volume of rockfall was observed in February (9.09 m^3). The highest monthly volume of rockfall occurred in May (30.38 m^3) (see: Table 1). The maximum depth (relative to the plane of the cliff face) of any single rockfall observed into the cliff face during this period was 0.68 m which occurred in July (Figure 1).
- We observe several sequences of events, whereby rockfall in successive months and years appear spatially connected. During this monitoring period, due to the relatively low levels of activity, whilst these processes continue, they hold a minimal impact on the overall cliff face topography. In summary, the main forms of behaviour observed in this period include the following, which have also been observed previously:
    - Upward propagation of rockfall, apparently initiated by wave quarrying of the cliff toe and subsequent failure of the overhanging cliff mass above to leave a more near-planar, near-vertical cliff face remaining. These sections tend in the immediately months that follow then experience less erosion.
    - Failure of small-scale convex sections (protusions) of the cliff face, to leave a more near vertical cliff face remaining. These size and shape of these failures are commonly defined by the pre-existing joint structure in the cliff face.
    - Lateral across-cliff failure migration, whereby rockfall scars coalesce into cross-cliff arch structures, which are inherently more stable, and are commonly bounded above by more massive rock beds. We note this behavior within the focus zone described above, most notably immediately above the rock armour. In this period we continue to see a large arch span develop across the Cowbar cliff frontage.
    - We observe that compared to preceding years, data collected with the fixed monitoring system since October 2017 and including the period of this report, has indicated that that the erosion rates and magnitude of rock failures have been low. Small failures compared to previous monitoring periods have occurred, but these have tended to be isolated, rather than contiguous

or connection upon the cliff face. None of these failures has significantly influenced the cliff top and within themselves indicate no pattern of wider instability.

- As observed previously, quarrying of the cliff toe immediately to the east and west of the rock armour continues (right in Figures 1 and 2), which has led to the undercutting off the cliff face above. The area to the west of the rock armour appears to be destabilizing with numerous moderate sized rockfalls in this area in this period, but a full larger-scale failure has not occurred. These rockfalls do not current threaten the cliff top.
- We see no further development in this period of the erosion which has previously led to undermine the road bed of Cowbar Lane. As observed previously, this is a section of coastline where the fence line is set further back inland, so if this failure were to develop, it would be unlikely to threaten any assets on the cliff top such as the road bed in the short term.
- We note no significant loss of cliff top / edge material during this monitoring period.
- The spatial pattern of erosion continues to be commensurate with marine driven erosion at the toe of the cliff, in addition to the continued failure of previously active sections of the cliff face above.

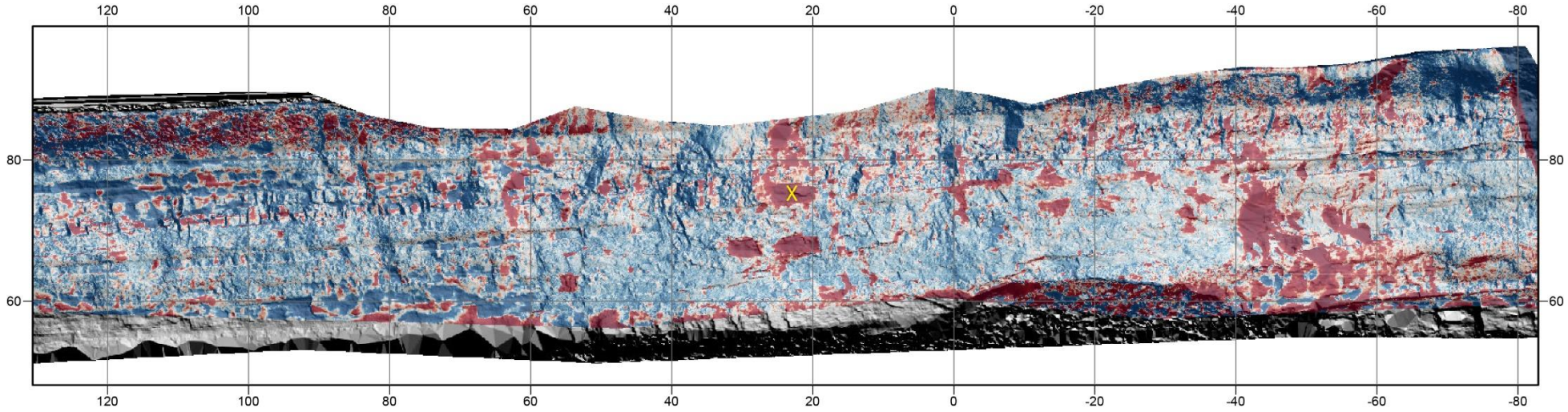

Figure 1: Digital elevation model of difference for the report period at Cowbar Nab, showing erosion (red) and negligible change (white to blue). Depth range of erosion on the free rockface is 0 to 0.68 m, at the point shown by the yellow 'X'.

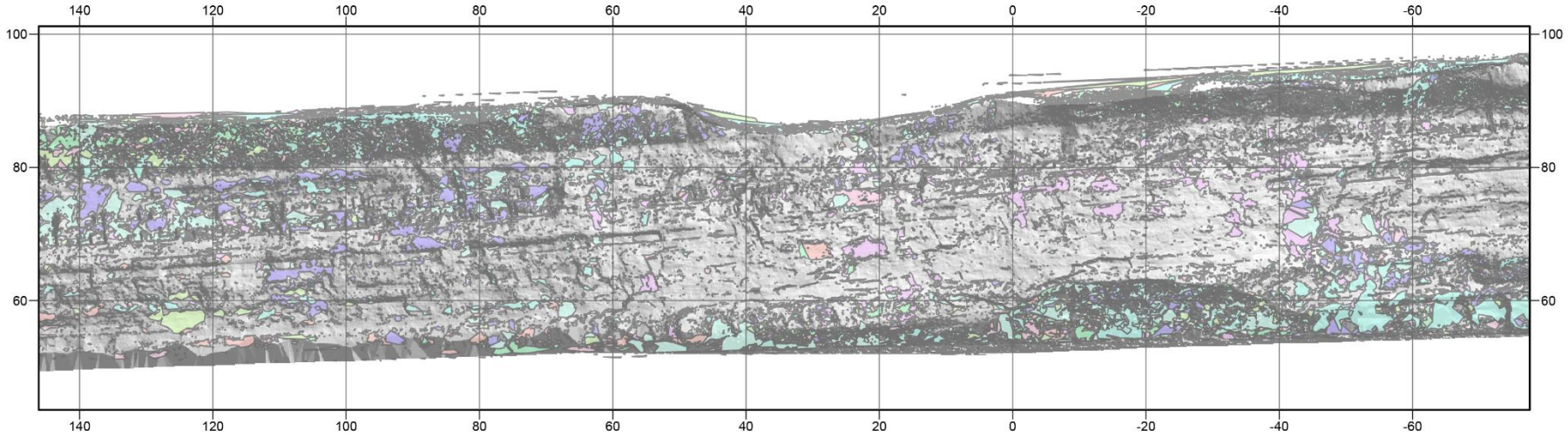

Figure 2: Monthly change for the monitoring period January 2023 to January 2024. Changes are shown monthly as polygons over the rockfall area, with a hillshade image of the cliff surface topography for context behind. Note that only areas of change that fall on the free rockface are included in the erosion calculation, and not those on the glacial till, the rock armour or in areas of vegetation.

II. Results: January 2011 – January 2024

- The long-term (January 2011 to January 2024) annualized erosion rates are as follows for the 158 months (4,728 days) of monitoring at this site to date:
    - 158-month area-averaged erosion rate for the whole site is 0.421 x 10^{-3} myr^{-1} (Table 1). This is based on observed rockfall alone.
    - 158-month modeled erosion rate for the whole site is 0.362 x 10^{-3} myr^{-1}. This rate considers the full range of possible rockfall sizes at this site, and is observed to stabilize over time as a more complete range of event sizes is recorded. It is also expected that this rates will converge with the observed area-averaged erosion rate over time. Using a modeled measure of erosion overcomes the limitations of monitoring only a small area / nonrepresentative sample, during a limited time period (see: Barlow *et al.*, (2012) for methodology, and Williams et al. (2019) for a wider justification).
    - 158-month area averaged erosion rate for the focus zone is 0.040 x 10^{-3} myr^{-1}. This rate is based purely on the rockfalls observed at the site using the laser monitoring, and shows a slightly higher rates of retreat in the central section of the monitoring cliff.
    - 158-month modeled erosion rate for the focus zone is 0.066 x 10^{-3} myr^{-1}. This rate considers the full range of possible rockfall sizes at this site, and will stabilize over time as a more complete range of event sizes is recorded. This is lower than the observed rate given the previous occurrence of relatively large rockfalls from this cliff section.
- Since the start of monitoring in 2011 a total of 5,636.08 m^3 of rockfall has occurred, sourced from 212,182 detectable discrete rockfall events identified from monthly monitoring (Table 1). This total volume of rockfall is equivalent to a cube with dimensions of 17.8 m. Rockfalls at this site adhere to a power law volume frequency distribution. This means that the majority of rockfalls are small (ca. 2.5 x 10^{-4} m^3 smaller) with a decreasing frequency of increasingly large failure events. As such, whilst the numbers of rockfalls observed is high, their individual volume and the erosion that the majority accrue remains very small, and importantly larger events that are more likely to result in a change to the cliff line are comparatively infrequent.
- On average over 158 months 1,434 discrete rockfall events occur at this site monthly, in rockfall volumes > 2.5 x 10^{-4} m^3, down from 1,544 reported in the last report, reflecting a relatively low level of recent activity in this monitoring period.

- Over 158 months, the average monthly volume of rockfall is 35.67 m^3, equating to 0.145 m^3 per month per metre of coastline, and equivalent to a cube of dimensions 0.525 m from each metre of coastline in each month.
- These data imply a continued return of the cliff towards rates comparable to the long term average, with limited occurrence and impact from individual storms which have not had comparable erosion / cliff collapse effects as those seen in, for example, 2015.
- The modeled erosion rate for the whole site, and for the 'focus section', continues to converge to a stable longer-term average (Table 1). This reflects the tendency to capture a more complete rockfall volume-frequency distribution of all possible rockfall volumes within a longer period of monitoring. This gives more confidence in the annualized erosion rates as a function of the convergence of these two methods.
- The rates of erosion observed at this site within each month remain heavily influenced by a low number (commonly < 3 in any given month) of larger (> 1 to 10 m^3) rockfall events possible at this site. This period of monitoring has again witnessed a lower number of events of this size, and so rates between months remain both consistent and relatively low.
- The potential for retreat at any point on the coast remains best predicted with a detailed structural assessment of the rock mass and change experience at that specific location, rather than wider-area, long-term erosion rates.
- Over the c.14 years of monitoring reported here, the development of rockfall scars that evolve from one year to the next is observed. In this period this process continues, albeit at a more reduced rate as compared to previous periods. This process is initiated by wave action at the cliff toe, which destabilises the cliff face above, tending to result in the failure of convex sections of the cliff.
- The monthly volume of rockfall for this section of cliff continues to be slightly lower than that observed elsewhere along this coastline (see: Benjamin, 2018), most likely due to the relatively low (< 30 m) cliff height – and hence area of cliff from which rockfalls can fall - as compared to the coastline both east and west of this site. Differences in retreat rates per unit area between this site and other sites monitored elsewhere on this coastline remain comparable and broadly in proportion to the cliff height / available rockfall source area.
- Based upon this data, there is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. This period of monitoring shows behavior more akin to the long-term average retreat rates observed previously at this site. The variations in rates of erosion reported here represents variability widely observed on similar cliffs, and should not be taken to infer increasing or decreasing stability.

- Despite the results in this monitoring period, this relative quiescence does not preclude the future possibility of a large scale rockfall that may threaten Cowbar Lane. However, the data presented here does not indicate a deterioration of the condition of the cliff that currently raises concern.

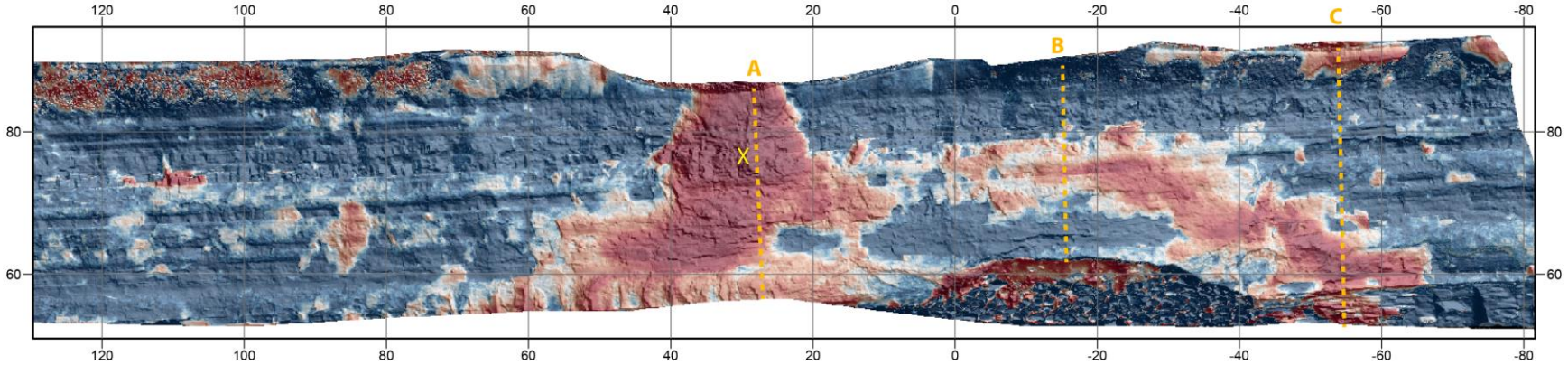

Figure 3: Digital elevation model of difference for the report period at Cowbar Nab, showing erosion (red) and negligible change (white to blue). Depth range of erosion on the free rockface is 0 to 1.92 m, at the point shown by the yellow 'X'. Profiles are shown in orange.

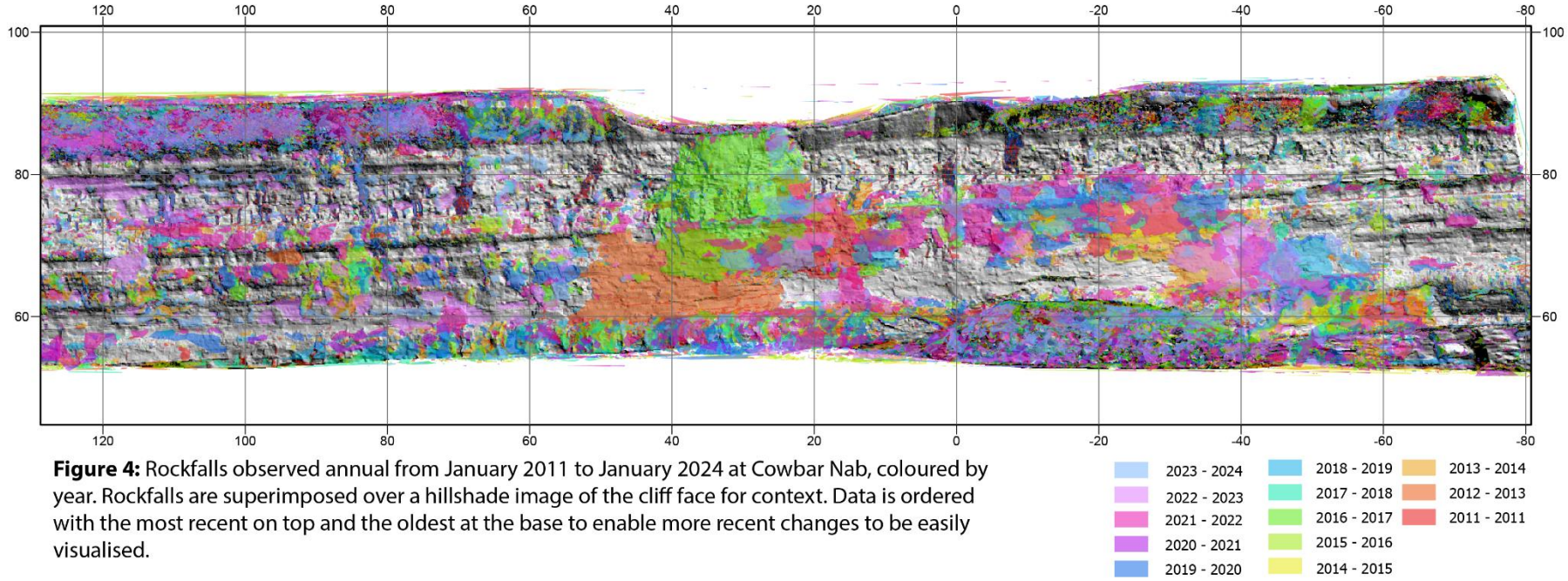

Figure 4: Rockfalls observed annual from January 2011 to January 2024 at Cowbar Nab, coloured by year. Rockfalls are superimposed over a hillshade image of the cliff face for context. Data is ordered with the most recent on top and the oldest at the base to enable more recent changes to be easily visualised.

III. Analysis of profile change

- Slope profiles have been extracted from the laser scan data through the cliff. Profile locations are provided in Figure 3, and profile change through time on an annual basis is provided in Figure 5.
- Note that the precise profile locations deviate slightly from report to report as the data is extracted from scratch for each reporting period.
- Profile A has remained relatively unchanged in form during this monitoring period, with only minor adjustments to small-scale convexities up profile. Some evidence of minor cliff toe quarrying is apparent, in line with typical changes observed on this cliff. This represents a minor additional oversteepening of the cliff, but is far from to a degree that would act to significantly destabilize the cliff mass above.
- Profile B has experienced a greater degree of back-wearing in the cliff toe area that is inundated by wave action, and some alteration around small scale convexities further up the cliff face profile. Again, this degree of back wearing (ca. 1 m max) around the bottom 10 m of the cliff face is small and reflects the coincidence of a single slab-like rockfall at this location, rather than a wider and more systematic alteration of the wider cliff form. Whilst this does contribute to undercutting at this location, the cliff toe remains seaward of the fence line, but the growth of the overhang continues (currently around 6 m at this location). As a result, whilst this profile has remained little changed in this monitoring period, it is anticipated that the rock above this section will fail in due course. The timing of this remains unknown, and our data to date shows no sign that this is imminent. Importantly, based on the style of previous failures of this type at this location, the rockfall will likely remove the overhang, rather than retreat the cliff edge back substantially, and so it is unlikely that the fence will be impacted.
- Profile C shows minimal loss of material from toe to crest. Continued development of the undercut at the toe of the cliff of a degree that raises concerns of wider-scale failure and collapse is not observed. Despite this, it is still anticipated that this area of failure will develop over time, over-steepening and collapsing the cliff face above, the rate of development of this failure in this area appears to have slowed. As previously, the cliff line at this point is some 5.5 m seaward of the fence line, and so based on the style of previous failures, this would be unlikely to impact upon assets at the cliff top.

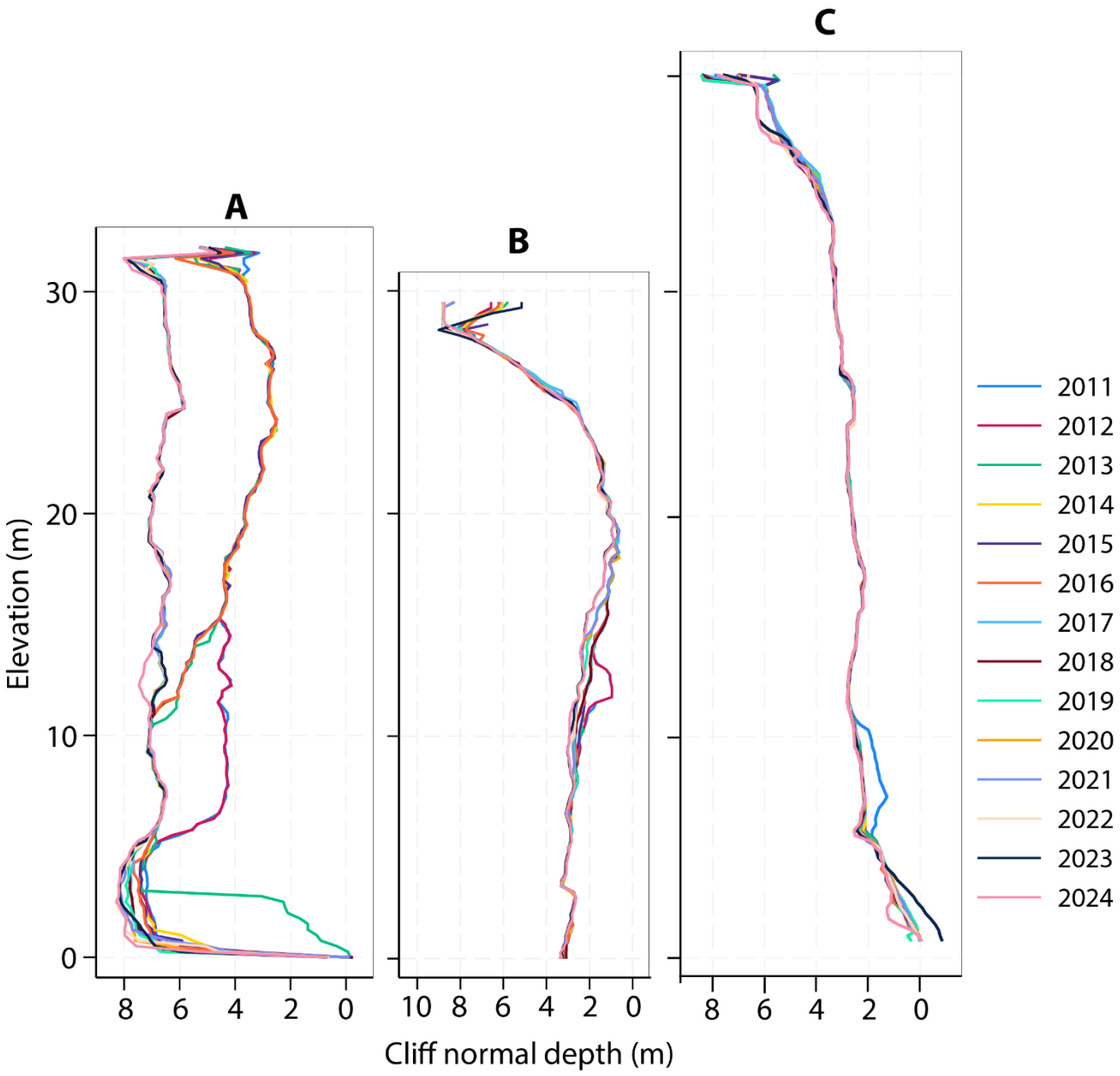

Figure 5. Cross profiles showing cliff-normal change by year between 2011 and Jan '24. Depths are provided in metres relative to an arbitrary vertical datum in front of the cliff. Profiles are stacked in chronological order, with the most recent on top. Profile locations are provided in Figure 1.

Table 1: Monthly rockfall and erosion data for Cowbar Nab, showing both observed and modelled rates for monthly and yearly periods. The period of this report is shaded in grey.

Incremental year	Incremental month	Month of year	Year	Survey date (Julian date)	Survey epoch length (days)	Running total of days	Number of rockfalls	Total volume of rockfalls (m3)	Area average erosion rate (x 10-3 myr-1)	m/f modelled erosion rate (x 10-3 myr-1)	Monthly average erosion rates - modelled (myr-1)	1 year average of monthly average erosion rates (myr-1)	Focus area erosion rate (myr-1)	Focus area erosion rate - modeled (myr-1)
	1	January	2011	40557	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2	February	2011	40592	35	35	990	31.69	2.77	0.023	0.0028			
	3	March	2011	40623	31	66	969	31	2.71	2.816	0.0027			
	4	April	2011	40661	38	104	1036	33.15	2.9	1.716	0.0029			
	5	May	2011	40683	22	126	4	0.13	0.01	0	0			
	6	June	2011	40711	28	154	21	0.68	0.06	0.022	0.0001			
	7	July	2011	40745	34	188	660	21.11	1.85	0.484	0.0019			
	8	August	2011	40780	35	223	560	17.93	1.57	2.684	0.0016			
	9	September	2011	40813	33	256	972	31.11	2.72	4.554	0.0027			
	10	October	2011	40837	24	280	802	25.66	2.24	4.642	0.0022			
	11	November	2011	40864	27	307	708	22.65	1.98	3.85	0.002			
	12	December	2011	40896	32	339	207	6.62	0.58	0.176	0.0006	0.0018	0.011	0.033
2	13	January	2012	40925	29	368	609	19.48	1.7	1.76	0.0017			
	14	February	2012	40962	37	405	1323	42.33	3.7	2.816	0.0037			
	15	March	2012	40994	32	437	1108	35.45	3.1	2.86	0.0031			
	16	April	2012	41017	23	460	2074	19.39	1.62	1.48	0.0016			
	17	May	2012	41038	21	481	1346	24.51	2.95	2.37	0.003			
	18	June	2012	41079	41	522	356	3.09	0.36	0.22	0.0004			
	19	July	2012	41104	25	547	101	2.91	0.33	0.21	0.0003			
	20	August	2012	41123	19	566	334	2.54	0.39	0.21	0.0004			
	21	September	2012	41160	37	603	598	7.79	0.88	0.17	0.0009			
	22	October	2012	41185	25	628	5312	11.15	0.57	0.35	0.0006			
	23	November	2012	41228	43	671	3231	7.32	0.63	0.36	0.0006			
	24	December	2012	41256	28	699	227	12.23	0.65	0.45	0.0007	0.0014	0.021	0.025
3	25	January	2013	41280	24	723	2891	2.85	0.51	0.14	0.0005			
	26	February	2013	41316	36	759	4379	20.24	5.29	1.09	0.0053			

	27	March	2013	41345	29	788	946	14.93	2.6	2.01	0.0026			
	28	April	2013	41389	44	832	160	366.76	4.979	1.5	0.005			
	29	May	2013	41417	28	860	559	1.03	0.014	2.459	0			
	30	June	2013	41450	33	893	251	7.23	0.098	0.234	0.0001			
	31	July	2013	41477	27	920	553	8.52	0.116	0.25	0.0001			
	32	August	2013	41506	29	949	349	6.83	0.093	0.229	0.0001			
	33	September	2013	41534	28	977	463	40.34	0.548	0.215	0.0005			
	34	October	2013	41568	34	1011	641	0.28	0.004	0.384	0			
	35	November	2013	41596	28	1039	409	7.38	0.1	0.418	0.0001			
	36	December	2013	41611	15	1054	349	6.86	0.093	0.534	0.0001	0.0013	0.012	0.074
4	37	January	2014	41656	45	1099	517	7.04	0.096	0.205	0.0001			
	38	February	2014	41688	32	1131	309	1.74	0.024	1.127	0			
	39	March	2014	41713	25	1156	255	4.6	0.062	2.096	0.0001			
	40	April	2014	41745	32	1188	2205	16.93	0.274	0.027	0.0003			
	41	May	2014	41773	28	1216	2245	103.93	1.683	1.265	0.0017			
	42	June	2014	41808	35	1251	1436	57.84	0.936	0.229	0.0009			
	43	July	2014	41834	26	1277	1449	10.94	0.177	0.169	0.0002			
	44	August	2014	41863	29	1306	1401	9.89	0.16	0.072	0.0002			
	45	September	2014	41892	29	1335	1470	7.65	0.124	0.074	0.0001			
	46	October	2014	41921	29	1364	3234	20.26	0.328	0.32	0.0003			
	47	November	2014	41949	28	1392	813	3.99	0.065	0.04	0.0001			
	48	December	2014	41978	29	1421	2427	14.55	0.236	0.096	0.0002	0.0004	0.024	0.038
5	49	January	2015	42025	47	1468	1944	9.65	0.156	0.103	0.0002			
	50	February	2015	42053	28	1496	983	4.88	0.079	0.067	0.0001			
	51	March	2015	42087	34	1530	727	4.24	0.069	0.031	0.0001			
	52	April	2015	42115	28	1558	3962	35.36	0.572	0.353	0.0006			
	53	May	2015	42143	28	1586	3802	19.11	0.309	0.014	0.0003			
	54	June	2015	42170	27	1613	1976	6.89	0.172	0.189	0.0002			
	55	July	2015	42195	25	1638	281	103.59	1.185	0.721	0.0012			
	56	August	2015	42227	32	1670	1411	21.97	0.363	0.004	0.0004			
	57	September	2015	42256	29	1699	758	1.91	0.017	0.068	0			
	58	October	2015	42282	26	1725	522	5.65	0.097	0.008	0.0001			
	59	November	2015	42313	31	1756	228	5.31	0.066	0.01	0.0001			
	60	December	2015	42344	31	1787	2069	15.16	0.261	0.046	0.0003	0.0003	0.026	0.034
6	61	January	2016	42373	29	1816	437	0.3	0.003	0.032	0			
	62	February	2016	42406	33	1849	506	0.47	0.013	0.001	0			
	63	March	2016	42437	31	1880	1873	7.53	0.05	0.072	0			
	64	April	2016	42471	34	1914	863	105.26	0.033	0.01	0			
	65	May	2016	42501	30	1944	364	702.23	0.042	0.013	0			
	66	June	2016	42533	32	1976	1747	7.18	0.481	0.076	0.0005			
	67	July	2016	42561	28	2004	1860	7.66	0.237	0.012	0.0002			
	68	August	2016	42597	36	2040	829	19.74	0.223	0.001	0.0002			
	69	September	2016	42599	2	2042	548	0.11	0.003	0.063	0			
	70	October	2016	42653	54	2096	83	0.81	0.056	0.007	0.0001			
	71	November	2016	42676	23	2119	194	0.44	0.009	0.001	0			
	72	December	2016	42707	31	2150	1309	4.56	0.172	0.035	0.0002	0.0001	0.007	0.13
7	73	January	2017	42740	33	2183	70	0.05	0.001	0.019	0			
	74	February	2017	42773	33	2216	231	0.44	0.012	0	0			

	75	March	2017	42802	29	2245	1190	4.83	0.048	0.071	0			
	76	April	2017	42834	32	2277	500	90.33	0.006	0.007	0			
	77	May	2017	42865	31	2308	175	614.22	0.3	0.007	0.0003			
	78	June	2017	42897	32	2340	358	1.15	0.356	0.035	0.0004			
	79	July	2017	42932	35	2375	1502	4.65	0.001	0	0			
	80	August	2017	42962	30	2405	319	10.54	0.183	0.001	0.0002			
	81	September	2017	42988	26	2431	239	0.05	0.002	0.001	0			
	82	October	2017	43009	21	2452	69	0.53	0.041	0.006	0			
	83	November	2017	43040	31	2483	3546	89.65	0.01	0.057	0			
	84	December	2017	43070	30	2513	4375	133.7	0.043	0.116	0	0.0001	0.231	0.148
8	85	January	2018	43101	31	2544	3668	141.32	0.027	0.071	0			
	86	February	2018	43132	31	2575	3813	107.46	0.017	0.176	0			
	87	March	2018	43160	28	2603	4619	62.8	0.007	0.093	0			
	88	April	2018	43191	31	2634	3649	110.92	0.006	0.027	0			
	89	May	2018	43221	30	2664	2169	184.71	0.062	0.142	0.0001			
	90	June	2018	43252	31	2695	2959	37.02	0.01	0.009	0			
	91	July	2018	43282	30	2725	2081	80.61	0.01	0.093	0			
	92	August	2018	43313	31	2756	2252	36.99	0.004	0.057	0	0	0.064	0.158
	93	September	2018	43344	31	2787	2929	17.47	0.03	0	0			
	94	October	2018	43374	30	2817	5694	49.83	0.08	0.036	0			
	95	November	2018	43405	31	2848	3116	36.64	0.06	0.003	0			
	96	December	2018	43435	30	2878	2052	29.07	0.05	0.002	0			
9	99	March	2019	43552	117	2995	959	11.46	0	0.004	0.0001			
	100	April	2019	43556	4	2999	1847	4.65	0.06	0	0.0002			
	101	May	2019	43586	30	3029	836	7.57	0.01	0	0			
	102	June	2019	43617	31	3060	4892	43.56	0.07	0.001	0			
	103	July	2019	43647	30	3090	1391	43.74	0.07	0.002	0			
	104	August	2019	43678	31	3121	1808	33.44	0.05	0.032	0			
	105	September	2019	43709	31	3152	1375	17.62	0.03	0.113	0			
	107	November	2019	43769	60	3212	3768	57.98	0.1	0.059	0			
	108	December	2019	43829	30	3242	2840	33.14	0.04	0.036	0	0.0211	0.002	0.029
10	111	February	2020	43892	12	2852	1724	15.22	0	0.002	0.0002			
	112	March	2020	43922	30	2882	1035	17.7	0	0.001	0.0002			
	113	April	2020	43952	30	2912	2521	28.92	0	0.003	0.0003			
	114	May	2020	43983	31	2943	3764	21.84	0	0.002	0.0003			
	115	June	2020	44013	30	2973	2986	14.66	0	0.002	0.0002			
	116	July	2020	44044	31	3004	1550	16.93	0	0	0.0002			
	117	August	2020	44075	31	3035	4742	33.93	0	0.005	0.0004			
	118	September	2020	44105	30	3065	1748	17.6	0	0.002	0.0002			
	119	October	2020	44136	31	3096	1555	15.95	0	0.002	0.0002			
	120	November	2020	44166	30	3126	2867	19.46	0	0.002	0.0002			
	121	December	2020	44197	31	3157	2020	13.19	0	0	0.0002			
11	122	January	2021	44228	31	3188	2583	75.29	0.01	0.008	0.0009			
	123	February	2021	44256	28	3216	2324	142.57	0.02	0.004	0.0017			
	124	March	2021	44287	31	3247	4847	52.02	0.01	0.003	0.0006			
	125	April	2021	44317	30	3730	834	22.33	0.02	0.03	0.03	0.00	0.00	0.00
	126	May	2021	44348	31	3761	631	19.07	0.02	0.02	0.02			
	127	June	2021	44378	30	3791	636	28.47	0.03	0.04	0.04			

	128	July	2021	44409	31	3822	864	38.54	0.04	0.05	0.05			
	129	August	2021	44440	31	3853	643	15.88	0.02	0.02	0.02			
	130	September	2021	44470	30	3883	665	16.13	0.02	0.02	0.02			
	131	October	2021	44501	31	3914	869	20.56	0.02	0.02	0.03			
	132	November	2021	44531	30	3944	856	22.93	0.03	0.03	0.03			
	133	December	2021	44562	31	3975	852	28.11	0.03	0.04	0.04			
12	134	January	2022	44593	31	4006	660	22.35	0.02	0.03	0.03	0.02	0.04	0.06
	135	February	2022	44621	28	4034	875	31.03	0.03	0.04	0.04			
	136	March	2022	44652	31	4065	958	27.48	0.03	0.03	0.04			
	137	April	2022	44682	30	4095	926	72.42	0.08	0.09	0.10			
	138	May	2022	44713	31	4126	940	45.56	0.05	0.06	0.06			
	139	June	2022	44743	30	4156	754	29.89	0.03	0.03	0.04			
	140	July	2022	44774	31	4187	528	28.84	0.03	0.03	0.04			
	141	August	2022	44805	31	4218	875	32.38	0.04	0.04	0.04			
	142	September	2022	44835	30	4248	1142	23.06	0.03	0.03	0.03			
	143	October	2022	44866	31	4279	708	31.85	0.03	0.04	0.04			
	144	November	2022	44896	30	4309	304	10.92	0.01	0.01	0.02			
	145	December	2022	44927	31	4340	545	19.81	0.02	0.02	0.03			
13	146	January	2023	44958	31	4371	784	56.33	0.06	0.07	0.07	0.04	0.06	0.10
	147	February	2023	44986	28	4399	495	9.09	0.01	0.01	0.01			
	148	March	2023	45017	31	4430	377	23.82	0.03	0.03	0.03			
	149	April	2023	45047	30	4460	460	20.50	0.02	0.02	0.03			
	150	May	2023	45078	31	4491	550	30.38	0.03	0.04	0.04			
	151	June	2023	45108	30	4521	435	13.68	0.02	0.02	0.02			
	152	July	2023	45139	31	4552	937	22.85	0.03	0.03	0.03			
	153	August	2023	45170	31	4583	942	27.21	0.03	0.03	0.04			
14	158	January	2024	45315	145	4728	1045	18.65	0.02	0.02	0.03	0.03	0.06	0.08

7. HIGH FREQUENCY MONITORING

- The fixed scanner at Cowbar Nab, used to collect the data presented in the period to August 2023 in this report enables more information on the size, location and timing of rockfall to be derived. The observations unique to this system include:
    - An increase in monitoring frequency to 1-hour intervals reveals a 10^3 increase in the number of rock blocks observed to fall from the cliff. This is because at 1-month intervals the rockfalls that are measured as single larger rockfall are actually a larger number of smaller neighbouring events. The absolute frequency of rockfall is therefore higher than monthly monitoring would suggest. This finding is now reported in Williams et al (2019).
    - A consequence of higher-frequency monitoring is that the average size of rockfalls observed is 10^2 smaller at 1-hour intervals as compared to 1-month intervals. This is again because over 1-month intervals multiple smaller rockfalls are observed as a single larger event. Whilst the mean size observed reduces, it remains the case that a rockfall of any size can occur.
    - On average, throughout the year, small rockfalls appear to occur at random, and there is importantly no period when rockfall frequency reduces to zero.
    - Large rockfalls have been observed to have a higher probability of occurrence during high tides, although can feasibly occur at any time.
    - The rate of rockfalls is steady through the Spring and Summer, but experiences a step-change increase at the start of Autumn, which is sustained throughout the Winter. This indicates the seasonality of cliff erosion.
    - Single large storms in the winter can account for > 15% of the total rockfall volumes experienced during the year. These are times when cliff failure is most probable.
    - On average, we observed a steady rise in rockfall rate (ca. 10%) through the day from dawn to dusk. A spike in rockfall frequency is also observed at sunrise, and but most notably at sunset. These findings are considered in greater detail in Williams et al., (2018) and Williams (2017).

8. RECOMMENDATIONS

- Monitoring since 2011 has demonstrated the continued failure of the cliff face at Cowbar Nab, Staithes. It is clear that surveys of the cliff line alone, either from visual inspection, stake measurements or from aerial imagery, would not have captured these changes.
- This period of monitoring shows a period of relatively low rates of erosion, and limited rockfall magnitude at Cowbar Nab. Where changes have been observed to occur, these have tended to be small in size and, based upon the analysis conducted, do not indicate a wider pattern of developing instability. The activity in the 'focus zone' – in which we calculate a separate set of erosion rate statistics for the section of cliff immediately underneath Cowbar Lane, that erosion rates in this period have tended to reflect longer-term rates.
- Some evidence of smaller rockfalls exaggerating overhanging sections of the cliff during this monitoring period, most probably driven by wave action at the cliff toe.
- These observations do **not** rule out the possibility of another future large rockfall that would change the position of the cliff line, and monitoring and planning for this eventuality should be continued.
- Any failure of the top of the cliff as a result of the loss of support from the erosion of the cliff face below is likely to be a rapid event. It is, however, likely that this will be preceded by either creep or rockfall from the failing cliff face area, over a period of months to days. Rockfalls from this cliff have however been shown to be rapid to evolve from a point of apparent stability, and so can occur with limited warning.

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