

## DEMONSTRATION AT SOUTHEND-ON-SEA PIER

### Why this location

Southend-on-Sea council were initially full partners in the SOCORRO project, and Southend-on-Sea pier was planned as a demonstration site. For the UK sites it offered a contrasting setting compared to the two south coast, estuarine, port and harbour sites, and a contrasting structure in terms a pleasure pier with heritage status. The site was included in the baseline environmental sampling program and the results of this are presented here.

### Baseline/starting situation

**Southend-on-Sea pier**, is a pleasure pier that now has heritage status as a grade II listed building (iron and steel construction dates to 1889) in the estuary of the River Thames, Essex, UK (Figure SE1). It is the longest pleasure pier in the world. The pier construction consists of hardwood decking on iron piles, extending 2.16km into the estuary. Sections of iron and steel construction include permanently submerged piles, intertidal piles and iron- and steelwork above high tide in the permanently sub-aerial zone. The latter is still affected by sea water spray. The bed sediment of the site is part of the estuary 'sea reach', dominated by bed load transport from the fully marine environment (Prentice, 1972). Sediment is of fine sand grade with siliclastic and bioclastic components and a lower clay content than the other 2 sites, although still with significant organic content. The Holocene deposits are relative thin (~15cm from coring as part of this study) compared to both Shoreham and Newhaven (several m) and subject to active scour (MALSF, 2009). The Holocene sediments are underlain by London Clay. There are potential nutrient contaminant inputs from storm and sewage sludge effluent (Baugh et al., 2013).

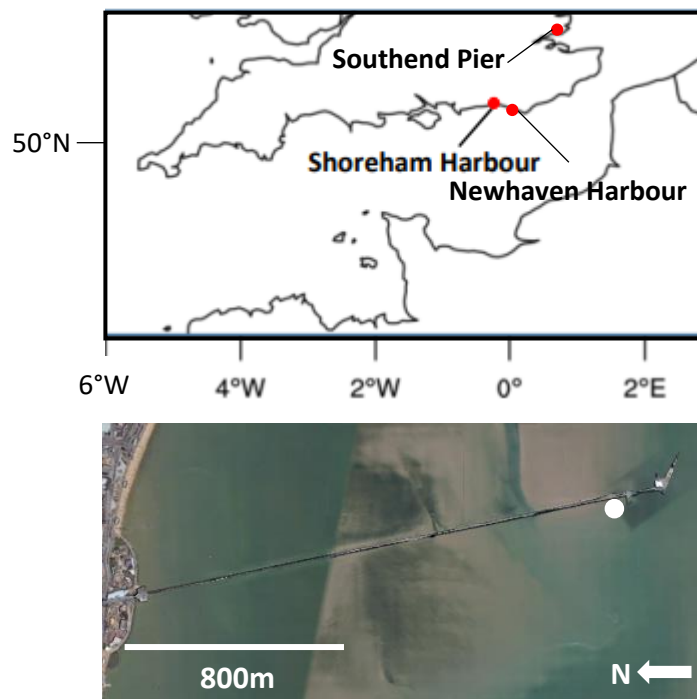


Figure SE1: Location map and Google Earth images of Southend on Sea pier.

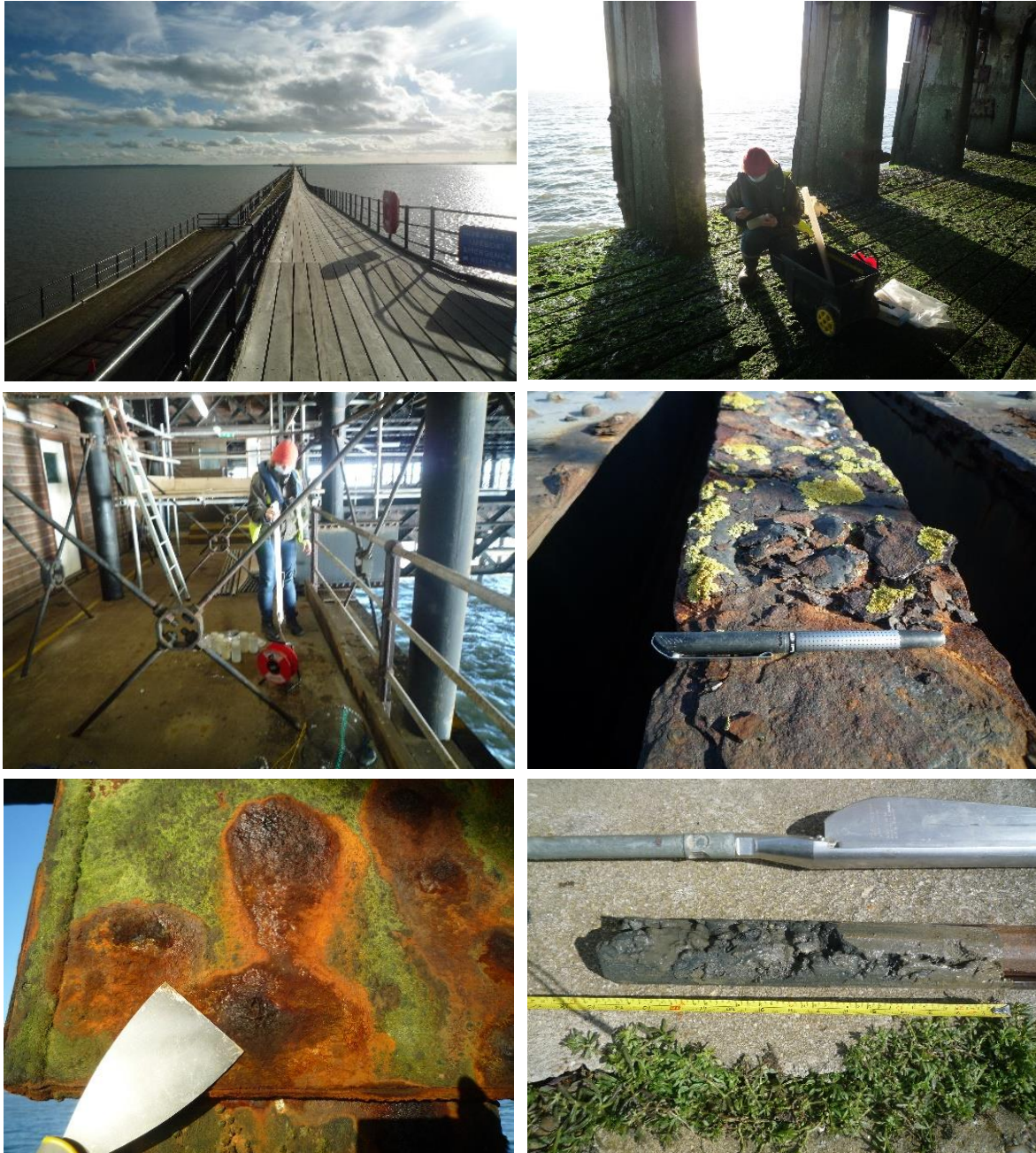


Figure SE2: Images of Southend on Sea Pier environment and corrosion. (A) View of the pier. (B) Water and corrosion sampling from end of pier service level. (C) Water sampling from pier office service level. (D) Sub-aerial corrosion. (E) Intertidal corrosion blisters. (F) Sediment core retrieved from below the pier at low tide.

The Southend site had a program of baseline environmental sampling from November 2020 to July 2021. The sampling included corrosion, water and sediment cores used for solid sediment analyses, and pore water analyses. Sub-samples of each sample type were taken for microbial analyses for comparison with the Shoreham and

Newhaven sites. Samples were collected from intertidal sites accessed at low tide either via exposed mudflats or the pier service levels. Samples were collected at high tide from the pier officer service level or from the pier itself. Images of steel corrosion, the sampling procedure and corrosion are given in Figure SH2.

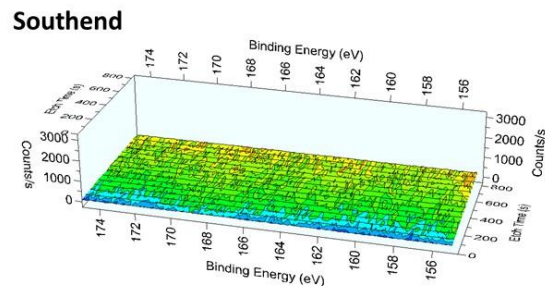
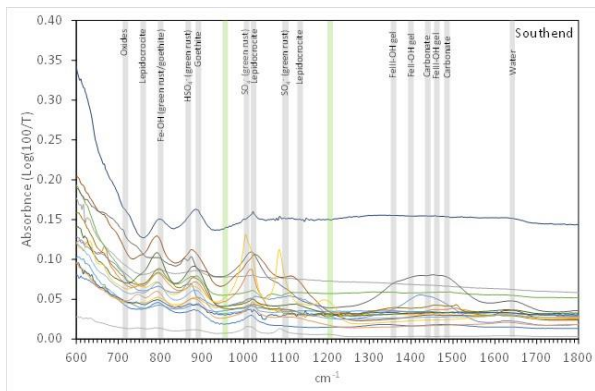


Figure SE3: Results of corrosion characterisation, Southend Pier. (A) Fourier transform infrared spectra of corrosion products. In this case dominated by iron oxides and oxyhydroxides. (b) X-ray photoelectron spectrum of intertidal corrosion products. No sulphur chemistry is detectable in this sample indicating no influence from sulphate reducing bacteria in corrosion.

The results of mineralogical and chemical analysis of corrosion samples are shown in Figure SE3. The FTIR spectra are characterised by a broad adsorption peak from 3000-3500 $\text{cm}^{-1}$  that can be attributed to O-H groups and  $\text{H}_2\text{O}$ , and multiple complex peaks in the range 600-1800 $\text{cm}^{-1}$ . Analysis of FTIR spectra was concentrated in the latter range as these absorption bands can be related to corrosion products on the steel surface. Two areas of the spectra were interpreted in detail using the PeakFit 4.12 software to deconvolute composite absorption peaks. Peaks were identified using gaussian amplitude deconvolution with a second derivative-based background fit, in separate windows from 750-1200 $\text{cm}^{-1}$  and from 1250-1750 $\text{cm}^{-1}$ . Deconvolution used a fixed full width at half maximum peak height of 18.1 $\text{cm}^{-1}$ , except for visibly narrower peaks at 861 $\text{cm}^{-1}$  and 874 $\text{cm}^{-1}$  where FWHM was reduced to fit the visible peaks. In sample SE3 (subaerial corrosion) a lower number of peaks was observable, with a close match to goethite peaks at 809 $\text{cm}^{-1}$  and 888 $\text{cm}^{-1}$ , and a minor component of lepidocrocite at 1012 $\text{cm}^{-1}$  (RRUFF database). Within the intertidal corrosion samples lepidocrocite absorbance peaks at 746 $\text{cm}^{-1}$  and 1023 $\text{cm}^{-1}$  were developed in all samples (RRUFF database). In contrast to Shoreham and Newhaven sulphur compound adsorption peaks are not well developed in the Southend samples implying a lack of sulphate reduction and sulphur oxidation as a process in corrosion. In X-ray photoelectron spectra the Southend Fe2p 3/2 binding energy spectra are dominated by magnetite, hematite and goethite/lepidocrocite. The only significant difference between sub-aerial and intertidal corrosion at this site is the presence of the Fe II satellite peak at 715.7eV resulting from a shake-up peak caused by excitation of the ion by the outgoing photoelectron. Sulphur compounds were not detected at Southend in subaerial or inter-tidal corrosion (Figure SE3).

The anion chemistry of seawater is shown in Figures SE4 and SE5. The bromide and chloride concentrations are strongly correlated in seawater and in sediment porewater. This is consistent with fully marine water diluted by river water in the port water column. This is typical of estuarine systems. Nitrate shows a slight negative correlation with chloride, but does not vary widely in seawater and is close to detection limits in most porewater. Some high nitrate values may be related to storm sewer releases in the local area. Sulphate is strongly correlated in seawater and most porewater samples. No evidence for sulphate reduction in bed sediment is visible. High sulphate in some pore water samples may relate to storm sewer releases in the local area.

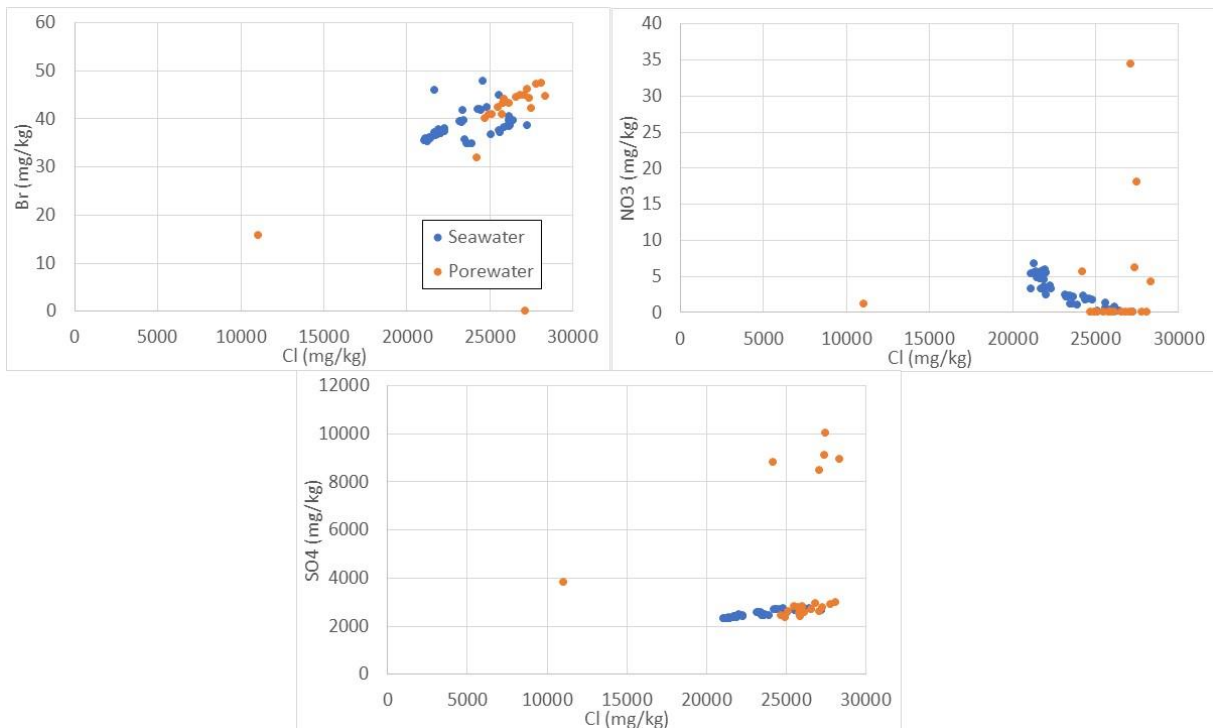


Figure SE4: Anion chemistry of sea/estuarine water and sediment porewater from Southend.

Figure SE5 shows summer and winter season depth profiles for the estuary water column anion concentration around the pier. All anions reflect the position in estuarine environment, in the sea-reach of Thames estuary where flow is dominated by seawater. There is some slight stratification of the water column caused by river water input at low tide.

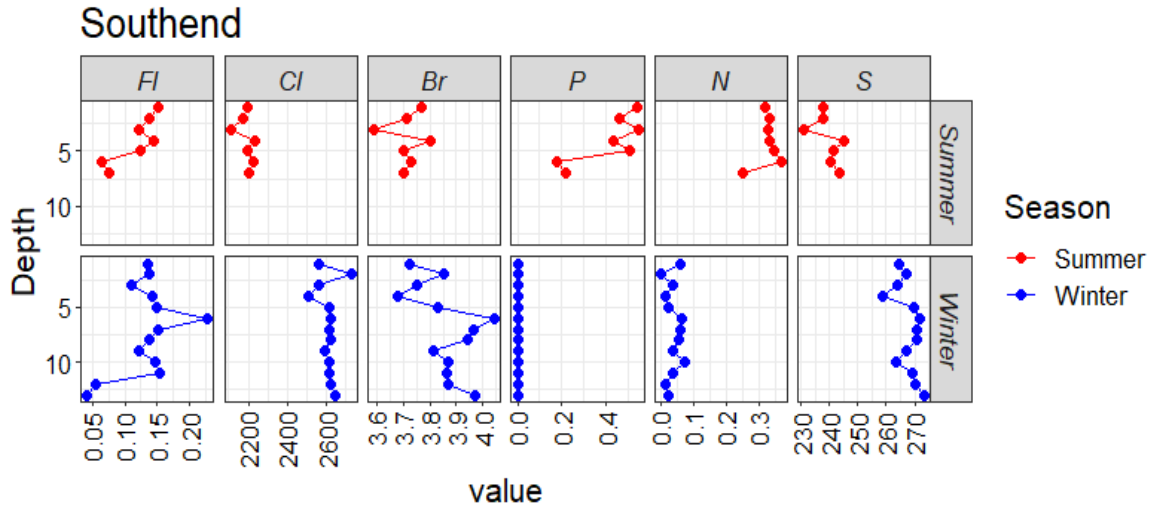
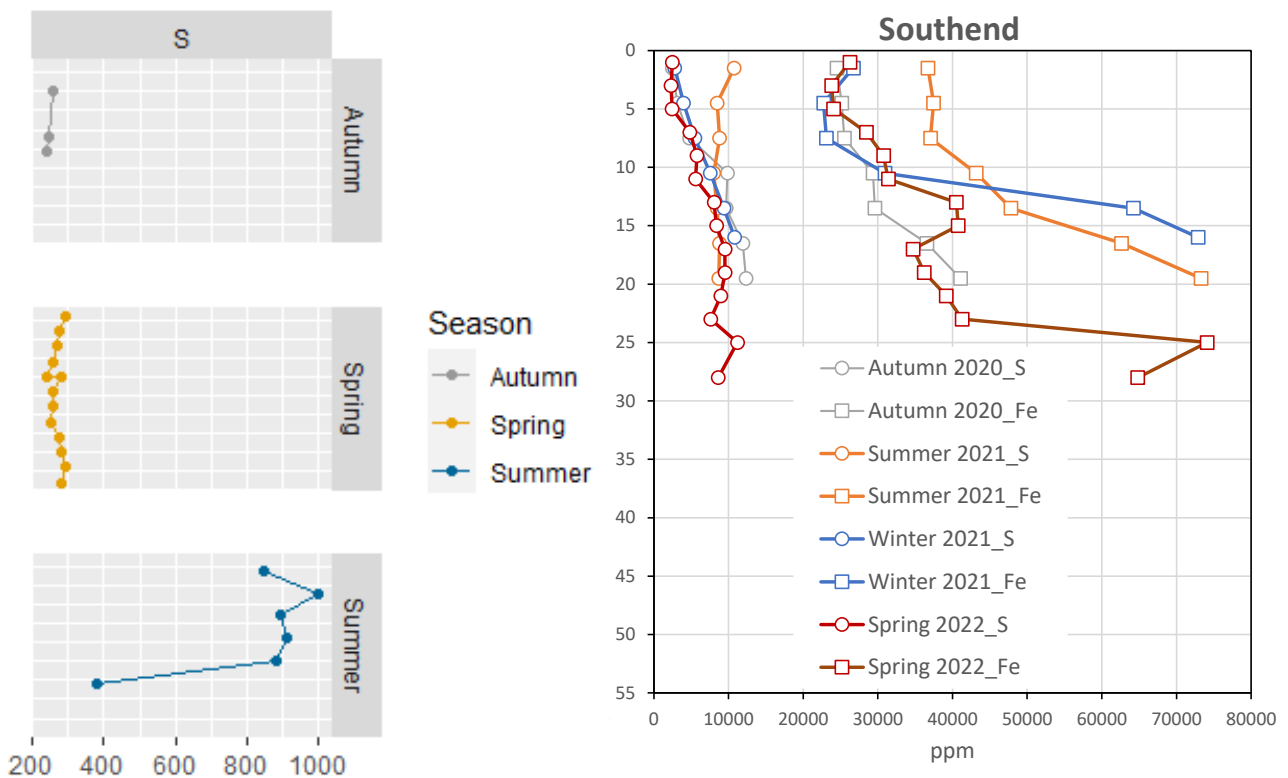


Figure SE5: Depth profiles in sediment cores for anion chemistry.

Analysis of sediment cores included solid phase iron and sulphur, and porewater iron and sulphur, sampled over 4 seasons. Results of these analyses are shown in Figure SE6. Sediment pore fluid sulphate concentrations do not vary significantly with depth at Southend. Solid phase iron and sulphur contents do increase with depth, but this is a sudden increase at the base of the sediment cores, and can be related to the cores extending into a stiff bedrock clay layer. This is identified as the London clay, and is a geologically old sediment, not related to current processes.



- correlations between these parameters (heatmap, PCA...)
- data analysis with SOCORRO data-app

Figure SE6: Depth profiles of pore fluid (left solid phase iron and sulphur content (right) from sediment cores at Southend.

Overall, environmental measurements at Southend show little evidence of anoxia and the development of sulphate reducing microbial populations in bed sediment. There is also little evidence for the involvement of sulphate reducing microbial species in sediment, with no sulphur compounds present in corrosion products. This information is important for the SOCORRO project (despite the lack of continuous monitoring data from Southend) as it provides a contrast to the other UK sites, Newhaven and Shoreham ports. Both of these have problems associated with Accelerate Low Water Corrosion (ALWC). This is a form of microbially influenced corrosion which can result in extremely rapid corrosion rates and is a major hazard for coastal and marine infrastructure. Utilising the environmental data and microbial analyses we can now confirm the mechanism of ALWC at Shoreham and Newhaven, and that this does not occur at Southend. The mechanism involves the colonisation of anoxic microenvironments on the steel surface by sulphate reducing bacteria derived from the local bed sediment. These generate hydrogen sulphide and iron sulphides on the steel surface which are subsequently oxidised to iron oxides and sulphate by iron and sulphur oxidising bacteria, generating very acid environments. The environmental data at Southend demonstrate that sulphate reduction is not a major sediment process there, and this correlates with the lack of ALWC on Southend Pier. We therefore propose that environmental evidence of bed sediment anoxia and sulphate reduction can be considered as risk factors for the development of MIC/ALWC in coastal and marine steel work, and detection methods for these risk factors and the diagnostic corrosion products can be used to target preventative and remedial action, which may ultimately reduce corrosion costs.

### Construction

Southend-on-Sea council withdrew from the project so no continuous monitoring was conducted at this site.

### Results:

Southend-on-Sea council withdrew from the project so no continuous monitoring was conducted at this site.

### Plans for further use?

Southend-on-Sea council withdrew from the project so no continuous monitoring was conducted at this site.

