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CENTRE FOR RESEARCH INTO ENVIRONMENT AND HEALTH

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Report to Anglian Water Services Ltd.

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A Report to
Anglian Water Services

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Executive Summary

1. This study investigated faecal indicator organism (FIO i.e. *E. coli*, presumptive intestinal enterococci (pEN) and confirmed intestinal enterococci (cEN)) concentrations in algal foam related to *Phaeocystis* spp. collected from intertidal areas associated with bathing waters at:
   - Hemsby
   - Caister Point
   - Great Yarmouth Pier

   Samples of detached, stranded (beach-cast) seaweed were also collected from the three bathing water locations to investigate faecal indicator organism concentrations associated with seaweed decaying in the intertidal zone.

2. The marine phytoplankton *Phaeocystis globosa* can form large nuisance blooms comprising of colonies of individual cells within a mucilaginous matrix of polysaccharides that are visible to the naked eye. When these colonies break-down the decomposition products can cause surface slicks and form a cream to brown foam, sometimes mistaken for sewage pollution, when agitated by wind and wave action. Anecdotal evidence has previously suggested that higher FIO concentrations in bathing water compliance samples have been present when such foams have been observed.

3. Samples of seawater, *Phaeocystis* foam, sediments and seaweed were collected from the intertidal areas close to, or at, the designated sample points (DSP) at Hemsby, Caister Point and Great Yarmouth North. Additional opportunistic samples of *Phaeocystis* foam and beach-cast seaweed collected from the Yorkshire coast is also reported to provide additional evidence.

4. The suspected *Phaeocystis* foams sampled at Hemsby and Caister Point, as well as in Yorkshire, were found to contain *E. coli* in the range 33,000 and 41,000 cfu $100ml^{-1}$ and cEN ranging between 46,000 and 250,000 cfu $100ml^{-1}$. Combined samples of seawater and foam displayed *E. coli* concentrations between 20 and 6700 cfu $100ml^{-1}$ and cEN concentrations between 1100 and 4600 cfu $100ml^{-1}$. Combined foam and sediment samples displayed concentrations of 1900 to 8500 cfu $100g^{-1}$ (wet weight) for *E. coli* and between 5900 and 19,000 cfu $100g^{-1}$ (wet weight) for cEN.

5. Samples collected at 1m depth at BWD DSPs when foam was present were generally above 100 cfu $100ml^{-1}$. The elevated concentrations at Hemsby, Caister Point and Great Yarmouth Pier DSPs on the same day as the foam was sampled, all which otherwise typically display low FIO concentrations, is suggestive of a link between the presence of the foam and poorer water quality.

6. The presence of the foam at Hemsby and Caister Point, but absent at Great Yarmouth, in conjunction with DSP sample concentrations above 100 cfu $100ml^{-1}$ at all three bathing waters, suggests that the impact of the *Phaeocystis* bloom decay is likely to cover a wider stretch of coastline and may not be predicated by visible foam at a DSP. Consequently non-compliance at bathing waters close to DSPs where foam has been observed could, perhaps, also be attributed to the decomposition of a regional bloom. Thus, the impacts of *Phaeocystis* algal bloom decay may not be dependent on the presence of the foam itself but merely the presence of the break-down products which may be manifest as an offshore slick not obvious to samplers at the beach.

7. Faecal indicator organism concentrations in beach-cast seaweed were highly variable, although some samples from all locations were found to contain high FIO concentrations in the washwater. At the three Anglian beaches sampled, the most extensive deposits and highest concentrations were observed at Hemsby. Here, *E. coli* concentrations ranged between <909 cfu $100ml^{-1}$ of wash water and 590,000 cfu $100ml^{-1}$ of washwater whilst cEN concentration ranged between <909 cfu $100ml^{-1}$ of washwater and 790,000 cfu $100ml^{-1}$ of washwater. There were similar, but smaller and less extensive beach-cast deposits at Caister Point with some fresher deposits also present in the intertidal area. However, FIO concentrations in these deposits were lower than those observed at Hemsby. Little seaweed was present at Great Yarmouth, and FIO concentrations were again lower than at Hemsby.

8. The temperatures recorded within the larger beach-cast seaweed deposits at Hemsby and Caister Point were generally greater than the air temperature, ranging between 20.3 and 36.7 ˚C. Cooler temperatures (c. 18˚C) were recorded in the wetter freshly deposited piles sampled from the intertidal area at Caister Point.

9. A range of different types of seaweed deposit were also sampled at Flamborough South Landing beach in Yorkshire. At spring tide high water mark, a significant deposit of mixed seaweed species had accumulated to depths of up to 20cm. This had been present for several days beyond the reach of subsequent tides. The deposit had developed a solid, matted crust of desiccated and sun-bleach seaweed above a wetter layer of decaying seaweed containing maggots and other invertebrates and generating significant odour. FIO concentrations in this deposit ranged up to 1182 cfu $100ml^{-1}$ of washwater for *E. coli* and 43,000 for $100ml^{-1}$ of washwater for cEN.

10. Residual water left in sample bags after the removal of the seaweed from the large Flamborough deposit contained FIO *E. coli* concentrations up to 58,599 cfu $100ml^{-1}$ and a cEN concentration of up to 2 million cfu $100ml^{-1}$. Squeezing some of the wet seaweed from below the crust resulted in an odorous, dark-grey to black liquid with *E. coli* and cEN concentrations of 25,455 cfu $100ml^{-1}$ and 100,000 cfu $100ml^{-1}$ respectively.

11. Temperature measurements made in the large Flamborough deposit ranged between 33.4˚C measured on the surface of the crust and 40˚C measured just below the crust. These were higher than the local air temperature of 24˚C (in a slight breeze) measured 1.5m above the seaweed deposit, and around ideal temperature for the growth of intestinal enterococci (37˚C).

12. Other types of seaweed deposit sampled from the intertidal area at Flamborough included apparently freshly deposited mix of seaweed, and an attached component of bladder wrack and small pieces of decomposing, leathery seaweed almost sedimentary in nature deposited both as a wet granular deposit on the sand and also at the base of pools within the sand. These displayed varying, but relatively low, concentrations of *E. coli* with the exception of the freshly deposited seaweed, which was similar to some samples from the larger strandline deposit, whilst cEN concentrations were generally lower than the strandline deposits. Concentrations in residual water from these samples were 100 cfu $100ml^{-1}$ or less.

13. Additional sampling at Flamborough over a spring high water period (i.e. before and after the deposits were washed for the first time after stranding suggests that the reservoirs of FIOs can be transferred back into the marine environment through wave action. It is possible the degree of transfer and impact will be related to the degree of

agitation and rougher conditions might result in greater transfer of organisms, perhaps to the point of re-suspending part or all of the deposits.

14. Both the presence of *Phaeocystis*-related foams or slicks and decaying seaweed appears to provide potential reservoirs of FIOs that could impact on bathing water quality. These impacts are likely to be ubiquitous and not specific to the beaches where samples were collected during this study. There are likely to be many factors that affect the degree of the impacts that such reservoirs might have, both in terms of the numbers of FIOs they might generate, and the degree to which these populations are transferred to the water column, and specifically, to the BWD designated sample point(s).

15. The presence of decaying seaweed or *Phaeocystis* foams should be considered a potential source of FIOs and also investigated as a reason for non-compliant samples. This may require that samplers record details of such occurrences and even take samples of foam and/or seaweed samples at the time compliance samples are collected, or the rapid-follow-up of non-compliant regulatory samples with sampling of the foam/seaweed, if still present, after regulatory results are reported.

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1. Introduction

1.1 Context

The bathing waters at Hemsby, Caister Point and Great Yarmouth Pier were classified as "Excellent" under the EU Bathing Water Directive (Anon, 2006) between 2016 and 2019, with compliance samples often displaying both *E. coli* and confirmed intestinal enterococci (cEN) concentrations below the limit of detection (<10 cfu $100ml^{-1}$). However, intermittent samples have displayed concentrations in excess of 100 cfu $100ml^{-1}$ in one or both faecal indicator organisms (FIOs) that were not associated with rainfall induced high flow events. With the absence of many of the typical potential sources of FIOs connected with elevated bathing water concentrations Anglian Water wished to investigate the potential impact of algal foam and deposits of seaweed that have anecdotally been linked to higher FIO concentrations is seawater.

A study conducted at Lowestoft by CREH for Anglian Water in 2019 (Stapleton *et al*., 2020) investigated FIO concentrations contained in seaweed growing in the intertidal zone due to the absence of large deposits of decaying seaweed. This concluded that it was difficult to assess the contribution of FIOs attached to the living seaweed have on the water quality of the area and the lack of similar studies mean it was not possible to contextualise the results. The upper end of observed concentrations on the seaweed samples was not reflected in the bathing water quality results from compliance monitoring data at the two bathing water locations or in samples collected at the mouth of the harbour. Nevertheless, it was recommended that further investigations into the impact of decomposing beach-cast seaweed were carried out at locations where high FIO concentrations are otherwise unexplained and accumulations had previously been observed.

CREH staff have experienced several reports of high FIO concentrations in seepages from piles of decaying seaweed (Wyer *et al*. (1997) Case Study E) and from decaying vegetation, such as surplus potato waste buried on farmland draining to bathing water beaches (Wyer *et al*. (1997) Case Study F), whilst studies elsewhere across the world have reported similar impacts of decaying seaweed (Anderson *et al*., 1997; Immamura *et al.,* 2011; Weiskel *et al*., 1996). Such organic piles often generate an exothermic reaction as the organics decay, resulting in an elevated temperature that, with associated DOC concentration, could support regrowth of FIOs. This has been replicated under experimental conditions by the Environment Agency (Dunhill *et al*., 2013).

The presence of a cream- to brown-coloured foam at the time of collection of bathing water samples that were later found to contain elevated FIO concentrations has periodically been reported by bathing water samplers or later reported to bathing water managers during follow-up investigations, However, this evidence is largely anecdotal and no peer-reviewed literature or grey-literature reports have been identified by CREH during the course of this study on this topic.

The reported foam is most likely the decomposition phase of *Phaeocystis* spp. blooms, most likely *Phaeocystis globosa* in temperate waters (Lancelot 1995; Alderkamp *et al*. 2007, Krompkamp, undated). The marine phytoplankton displays a polymorphic life cycle that alternates from free living cells of 3 – 9 μm to gelatinous spherical colonies of a few mm and visible to the naked eye. These colonies, contained within a mucilaginous matrix of polysaccharides, can develop into large and nuisance blooms which clog fishing nets. Lysis (break-down) of the cells can cause floating slicks, produce bad odour and large expanses of foam, particularly when agitated by wave action which can be blown onshore by prevailing

winds (Lancelot 1995). It is not known whether it is the presence of proteins, carbohydrates, lipids or a combination of these compounds that causes the foams (Hamm and Rousseau, 2003).

Phaeocystis blooms are included within the group of Harmful Algal Blooms (HABS) due to the nuisance impacts noted above, biomass accumulation that can smother the seabed and lead to shellfish mortality and production of dimethyl-sulphide precursors that promote acid rain (Blauw *et al.*, 2010; Krompkamp, undated). However, the foam is not considered to be toxic (Krompkamp, undated; Beachwise, undated). The Environment Agency (EA) includes a generalized statement on all bathing water profiles recognizing the potential presence of *Phaeocystis*, stating the following:

> *"A common marine algae found in UK coastal waters is Phaeocystis, which is often mistaken for sewage as it forms foam and a brown scum, but it is non-toxic."*

The majority of the research effort into *Phaeocystis* spp. blooms, however, has concentrated on its life-cycle, impacts of eutrophication or prediction and development of blooms. Blauw *et al*. (2010) reported whilst suitable conditions for foam events on the Dutch coast can be predicted from wind conditions and *Phaeocystis* bloom presence, foam was not always observed.

1.2 Aims of the project

The key aims of the study are summarised as follows:

- Deliver an assessment of faecal indicator organism concentrations in *Phaeocystis* associated foam through the collection of samples of foam and associated sea water and sediments from Hemsby, Caister and Great Yarmouth North bathing waters; and
- Provide an assessment of faecal indicator organism concentrations in accumulations of decaying beach-cast seaweed collected from Hemsby, Caister and Great Yarmouth North bathing waters.

Sampling was targeted during the period of late-August and September 2020, since anecdotal evidence suggested the algal foam and seaweed accumulations corresponding with elevated FIO concentrations were observed during this period of (G. Hall, AWS, *pers comm*). This report also describes results from additional opportunistic samples collected during the course of other CREH sampling undertaken during the mid-August to October 2020 period at other locations along the east coast of England.

2. Sampling and analysis techniques

2.1 Sample collection

Due to the sporadic occurrence of the *Phaeocystis* foam and accumulations of seaweed at Hemsby, Caister Point and Great Yarmouth Pier bathing waters, local observers (beach lifeguards, RNLI staff and volunteers, etc.) were asked to contact CREH when either foam or accumulations of seaweed were observed, and if possible, to supply photos. A CREH sampling team was subsequently dispatched to the bathing waters if the photographic evidence and descriptions of the observers provided a strong likelihood of either *Phaeocystis* foam or accumulations of seaweed would still be present when the samplers arrived. The presence of suspected *Phaeocystis* foam was reported at Hemsby on 28/08/20, triggering sampling at the three bathing waters. The *Phaeocystis* foam was observed at Hemsby and Caister Point, but was not visible at Great Yarmouth Pier. *Phaeocystis* foam, seawater and sediment, or combinations of these matrices, were collected.

Seaweed accumulations were sampled at all three beaches on 13/09/20 during a speculative visit by CREH staff, although there was not very much seaweed at Great Yarmouth Pier. Seaweed and seawater were collected in separate samples. Details of the different matrices present and tested for faecal indicator organisms (FIOs) at the three bathing waters, on each of the sampling days, are shown in Table 2.1.

Table 2.1: Details of sample types collected from Hemsby, Caister Point and Great Yarmouth Pier bathing waters.

Bathing Water	Sample Date	Samples Collected
Hemsby	28/08/20	*Phaeocystis* foam/seawater *Phaeocystis* foam on intertidal sand Seawater
	13/09/20	Beach-cast seaweed Seawater
Caister Point	28/08/20	*Phaeocystis* foam Seawater
	13/09/20	Beach-cast seaweed Seawater
Great Yarmouth Pier	28/08/20	Seawater
	13/09/20	Beach-cast seaweed Seawater

In addition to the targeted sampling described above, CREH field teams undertaking bathing water sampling in the Yorkshire region were asked to collect opportunistic samples of suspected *Phaeocystis* foam or accumulated and decomposing beach-cast seaweed, if encountered. Between the period mid-August to mid-October 2020, samples of foam were collected from Scarborough South bathing water. In addition, a large accumulation of beach-cast decomposing seaweed at Flamborough South Landing, East Yorkshire, enabled an opportunistic study of various different aspects relevant to the present investigation.

Seawater and *Phaeocystis* foam samples were collected directly into 150ml sterile bacterial sample pots (Media Disposables™), attached to an extendable sample pole where necessary. Samples of beach-cast seaweed were collected either directly into sterile plastic bags (Nasco Whirl-Pak™), or into sterile 150ml pots (e.g. for deposits of macerated seaweed). Any

leachates from seaweed deposits were collected into 150ml sterile sample pots. As soon as possible after collection, samples were placed inside a powered refrigeration unit within the sample vehicle (Dometic CFX-65™), maintained at a temperature of 5˚C ± 3˚C, and transported to the CREH *Analytical* Ltd. laboratory in Horsforth, Leeds. Prior to sampling, where possible, the temperature of the seaweed layer being sampled was measured using a Comark PDQ400™ digital probe thermometer.

2.2 Sample analysis

2.2.1 *Phaeocystis* foam sample preparation

Samples of *Phaeocystis* foam were subjected to vortexing for 30 seconds. This resulted in the foam forming into a small amount of liquid that was filtered using standard membrane filtration techniques for the isolation and identification of *Escherichia coli* and confirmed intestinal enterococci (cEN) using the methods described in Section 2.2.4. In some cases, particularly where the foam layer was on water and not very thick, seawater was also included within the samples. By the time the samples were delivered to the laboratory, in some cases the foam layer had disappeared. All samples described as foam, however, were subjected to vortexing even if foam did not appear to be present within the sample on delivery.

2.2.2 Seaweed sample preparation

Faecal indicator organisms were extracted from the seaweed samples by aseptically weighing 5 g of seaweed into a sterile 150 ml container and adding 100 ml of sterile Maximum Recovery Diluent (MRD). The samples were then shaken for 15 minutes at 600 rpm in a wrist shaker (Pall Corporation Model 4822). The resultant wash liquid was decanted into a separate, sterile, 150 ml container and filtered at 10 ml and 1 ml using standard membrane filtration techniques for the isolation and identification of *Escherichia coli* and confirmed intestinal enterococci using the methods described in Section 2.2.4.

Counts were obtained per 100 ml of washwater using the calculation:

$$\text{cfu } 100 \text{ ml}^{-1} \text{ of washwater} = \frac{\text{total number of colonies}}{\text{total volume of washwater filtered}} \times 100$$

2.2.3 Sediment sample preparation

Earlier work, reported in Watkins *et al.,* (2007), had evaluated four FIO extraction methods for UK inter-tidal estuarine sediments, namely stomaching, sonication, vortexing and shaking. The highest recoveries were achieved using a laboratory wrist shaker at 600 oscillations per minute for a period of five minutes and this approach was employed in this investigation for disassociation of FIOs from the intertidal sediments prior to enumeration.

Sediment samples were mixed using a sterile spatula and 3.0 g of each sample were weighed into sterile 50 ml centrifuge tubes. A volume of 27 ml of sterile maximum recovery diluent (MRD) was added to each tube and the tubes were shaken for 5 minutes on a wrist shaker (Pall Corporation Model 4822). Samples were diluted where appropriate in sterile MRD using serial ten-fold dilutions and aliquots were filtered through 0.45 µm sterile cellulose nitrate membranes (Sartorius). FIO concentrations were enumerated as described in Section 2.2.4. The spatula was sterilised between samples by wiping with a tissue impregnated with 70% iso-propanol.

2.2.4 Faecal indicator organism enumeration

Samples were tested for *E. coli* and confirmed intestinal enterococci. *E. coli* was enumerated using chromogenic membrane lactose glucoronide agar (MLGA) whilst presumptive enterococci concentrations (pEN) were enumerated using m-enterococcus (Slanetz and Bartley) agar and confirmed on kanamycin aesculin azide agar (KAAA).

Indicator organism enumerations (colony forming units (cfu) 100 ml^{-1}) followed Standing Committee of Analysts 'Blue Book' methods based on membrane filtration (SCA, 2015; 2016). Sample dilutions were performed at two or three sample dilutions. A complete duplicate analysis was carried out on at least one sample collected during each sampling run for quality control purposes. Samples were analysed as soon as possible after reception at the laboratory, but in all cases within 24 hours of collection.

In addition to microbiological analyses, liquid samples were also tested in the laboratory for specific conductance (µs cm^{-1}; mS cm^{-1}) and practical salinity using a Hanna Instruments EC215 conductivity meter, and turbidity (NTU) using a Hanna Instruments LP2000 turbidity meter. All meters were calibrated using standards of known concentration prior to analysis of each batch of samples. In some cases, the *Phaeocystis* foam did not produce sufficient liquid to allow determination of these parameters.

2.3 Statistical analysis

For the purposes of statistical analyses, samples where no organisms were detected were recorded as the lower detection limit value. This was <9 cfu $100ml^{-1}$ for seawater and *Phaeocystis* foam samples, <9 cfu g^{-1} for sediments and <9 cfu $100ml^{-1}$ of washwater for the seaweed samples. The distribution of microbial concentrations showed a closer approximation to normality when log_{10} transformed. All microbial concentration data were, therefore, log_{10} transformed prior to statistical analysis. The IBM SPSS Statistics software package (SPSS Inc.) was used for statistical analyses. Descriptive statistics were used to characterize the distributions of bacterial concentrations at each sampling location. These statistics include the geometric mean (GM), calculated as the antilog of the mean of log_{10} transformed concentrations.

3. Faecal indicator organism concentrations in *Phaeocystis* foam

3.1 Samples from Hemsby, Caister Point and Great Yarmouth Pier

A total of 27 samples were collected from the three bathing waters of Hemsby, Caister Point and Great Yarmouth Pier during the late afternoon of 26/08/20 after CREH were informed of suspected *Phaeocystis* foam at Hemsby by a local lifeguard. At this time, a relatively thick layer of foam had started to accumulate around high water (Figure 3.1). CREH samplers arrived at Hemsby approximately 2 hours after being informed of the presence of the foam, moving on to Caister Point and then Great Yarmouth Pier. Faecal indicator organism (FIO) concentrations (*E. coli*, presumptive enterococci (pEN) and confirmed enterococci (cEN)), turbidity, specific conductance, practical salinity and pH in the samples are summarised in Table 3.1 (Hemsby), Table 3.2 (Caister Point) and Table 3.3 (Great Yarmouth Pier).

At Hemsby bathing water, the foam had started to disperse by the time the CREH samplers arrived as the tide had ebbed away from high water mark. Most of the remaining foam was stranded around high water mark and within an area of seawater trapped behind a sand bar that was slowly draining into the sea (Figure 3.2). Fourteen samples were collected from Hemsby, with eight samples of the foam taken from the surface of the pool, three of combined foam and sediment collected from the edges of the pool, and three of seawater taken from the bathing water designated sample point (DSP) (Table 3.1). The three combined foam and sediment samples were necessary to be able to collect the thin layer of foam from the beach surface whilst the samples of foam from the pool also contained seawater from the pool.

E. coli concentrations in the foam samples collected at Hemsby bathing water ranged between 700 and 6,700 cfu $100ml^{-1}$, whilst cEN concentrations were between 1,100 and 4,600 cfu $100ml^{-1}$ (Table 3.1). The surface scrapes of intertidal sand that was covered by a thin layer of foam displayed *E. coli* concentrations between 19 and 85 cfu g^{-1} and cEN concentrations between 59 and 190 cfu g^{-1} (wet weight). Samples of the seawater collected at the DSP varied between 220 and 291 cfu $100ml^{-1}$ for *E. coli* and between 291 and 336 cfu $100ml^{-1}$ for cEN (Table 3.1).

On arrival at Caister Point bathing water, there were patches of foam stranded away from the waters edge on the upper intertidal area whilst there was an ‘oily’ film and a froth present on the water surface typical of *Phaeocystis* decomposition (Figure 3.3). The patches of foam on the beach were larger in size and appeared denser than at Hemsby, similar in nature to the foam observed earlier in the day at Hemsby shown in Figure 3.1. Ten samples were collected from around the DSP at Caister Point, four samples of foam from the beach, three seawater samples collected at the DSP, and three seawater samples collected approximately 15 to 20m to the south of the DSP, where the oily film that was present further offshore was closer to the shoreline (Table 3.2). However, it was not possible to collect samples of the surface slick itself due to the presence of a rip-tide, the rough nature of the waves and the depth of water. The majority of the presumptive enterococci were confirmed in samples from all matrices.

Both *E. coli* and cEN concentrations in the foam samples collected from Caister Point were greater than those observed at Hemsby by over an order of magnitude, with *E. coli* concentrations ranging between 33,000 and 41,000 cfu $100ml^{-1}$, whilst pEN ranged between 93,000 and 153,000 cfu $100ml^{-1}$ (Table 3.2). The majority or all of the presumptive enterococci in each sample confirmed, with cEN concentrations ranging between 88,000 and 150,000 cfu $100ml^{-1}$. Despite the much higher concentrations in the *Phaeocystis* foam at this site, concentrations of the seawater taken at the DSP and from locations further away from

the DSP were only slightly higher than those observed at Hemsby DSP, with *E. coli* ranging between 218 and 436 cfu $100ml^{-1}$ and cEN between 364 and 500 cfu $100ml^{-1}$ (Table 3.2).

Figure 3.1: Photos of the *Phaeocystis* foam at Hemsby bathing water on 26/08/20 at the time its presence was reported to CREH (approx. 13:45 BST).

Table 3.1: *E. coli*, presumptive and confirmed enterococci concentrations (cfu 100ml^{-1}/ cfu g^{-1}), pH, specific conductance, salinity and turbidity in suspected *Phaeocystis* foam and sea samples collected from Hemsby bathing water.

Code	Sample Time BST	Description	E. coli cfu 100 ml^{-1}*	Presumptive Enterococci cfu 100 ml^{-1}*	Confirmed enterococci cfu 100 ml^{-1}*	PH	Specific Conductance µS cm^{-1}	Practical Salinity	Turbidity NTU
H2	15:57	Foam/seawater (pool)	2,300	2,000	1,700	7.58	51,800	33.42	110.0
H3	15:59	Foam/seawater (pool)	791	1,600	1,400	7.63	52,500	33.85	62.0
H6	16:02	Foam/seawater (pool)	1,027	3,000	2,600	7.58	52,100	33.64	196.0
H6-A	16:04	Foam/seawater (pool)	700	1,300	1,100	7.64	52,300	33.75	131.0
H7	16:05	Foam/seawater (pool)	6,700	5,000	4,600	7.36	53,600	34.66	489.0
H8	16:08	Foam/seawater (pool)	955	1,100	1,100	7.33	52,200	33.78	348.0
H9	16:10	Foam/seawater (pool)	727	2,800	2,000	7.25	52,200	33.71	61.1
H10	16:10	Foam/seawater (pool)	755	1,700	1,700	7.27	52,000	33.64	109.0
HS1	16:30	Sea at DSP	291	309	291	7.62	53,300	34.42	69.6
HS2	16:32	Sea at DSP	220	355	327	7.67	52,600	33.79	45.2
HS3	16:34	Sea at DSP	264	373	336	7.66	52,000	33.50	59.4

Code	Sample Time BST	Description	E. coli cfu g^{-1}†	Presumptive Enterococci cfu g^{-1}†	Confirmed enterococci cfu g^{1}†	PH	Specific Conductance µS cm^{-1}	Practical Salinity	Turbidity NTU
H1	15:56	Foam/sediment	85	200	190	—	—	—	—
H4	16:00	Foam/sediment	19	65	59	—	—	—	—
H5	16:01	Foam/sediment	62	78	67	—	—	—	—

* FIO concentrations in foam and water are expressed as colony forming units per 100 millilitres (cfu 100ml^{-1}).

† FIO concentrations in foam/sediment samples are expressed as colony forming units per gram (cfu g^{-1}) wet weight.

Table 3.2: *E. coli*, presumptive and confirmed enterococci concentrations (cfu 100ml^{-1}), pH, specific conductance, salinity and turbidity in suspected *Phaeocystis* foam and sea samples collected from Caister Point bathing water.

Code	Sample Time BST	Description	E. coli cfu 100 ml^{-1}	Presumptive Enterococci cfu 100 ml^{-1}	Confirmed enterococci cfu 100 ml^{-1}	PH	Specific Conductance µS cm^{-1}	Practical Salinity	Turbidity NTU
C1	17:08	Foam	34,000	93,000	88,000	IS‡	IS‡	IS‡	IS‡
C2	17:10	Foam	39,000	153,000	150,000	IS‡	IS‡	IS‡	IS‡
C3	17:11	Foam	41,000	129,000	125,000	IS‡	IS‡	IS‡	IS‡
C4	17:13	Foam	33,000	107,000	107,000	IS‡	IS‡	IS‡	IS‡
CS1	17:00	Sea at DSP	336	536	500	7.74	51,300	32.74	27.0
CS2	17:03	Sea at DSP	436	545	464	7.74	50,300	32.05	25.3
CS3	17:06	Sea at DSP	336	518	473	7.75	51,300	32.79	75.7
CS4	17:15	Sea away from DSP	218	400	364	7.66	52,500	33.78	83.2
CS5	17:17	Sea away from DSP	309	491	427	7.66	52,400	33.69	99.0
CS6	17:20	Sea away from DSP	309	473	473	7.67	52,100	33.46	95.9

IS‡ Insufficient sample: Vortexing the suspected *Phaeocystis* foam samples yielded only a small volume of liquid sufficient only for FIO analysis.

Table 3.3: *E. coli*, presumptive and confirmed enterococci concentrations (cfu 100ml^{-1}), pH, specific conductance, salinity and turbidity in sea samples collected from Great Yarmouth Pier bathing water.

Code	Sample Time BST	Description	E. coli cfu 100 ml^{-1}	Presumptive Enterococci cfu 100 ml^{-1}	Confirmed enterococci cfu 100 ml^{-1}	PH	Specific Conductance µS cm^{-1}	Practical Salinity	Turbidity NTU
GS1	18:05	Sea at DSP	227	300	300	7.81	52,500	33.72	76.6
GS2	18:08	Sea at DSP	164	245	182	7.81	52,000	33.37	75.8
GS3	18:11	Sea at DSP	127	364	355	7.81	52,100	33.46	22.9

(a)

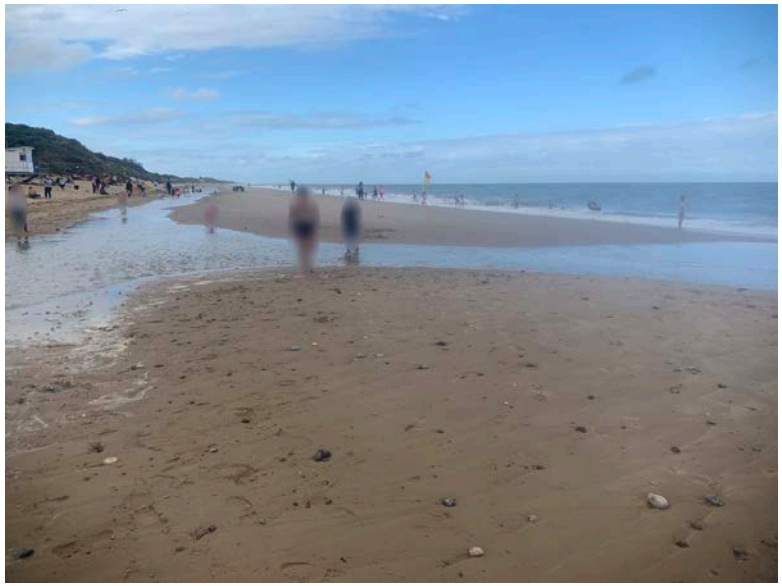
(b)

(c)

Figure 3.2: Photos of the *Phaeocystis* foam at Hemsby bathing water 26/08/20 at the time of sample collection (15:56 – 16:34 BST): (a – c) patches of foam at edge of pool trapped behind the sand bar.

(d)

(e)



(f)

Figure 3.2 (cont.): Photos of the *Phaeocystis* foam at Hemsby bathing water 26/08/20 at the time of sample collection (15:56 – 16:34 BST):
(d) pool trapped behind the sandbar, to the south of the DSP;
(e) point at which pool is draining into the sea, looking towards the DSP;
(f) evidence of foam at a point where the waves were washing over the sand bar into the pool.

(a)

(b)

(c)

Figure 3.3: Photos of the *Phaeocystis* foam at Caister Point bathing water 26/08/20 at the time of sample collection (15:56 – 16:34 BST):
(a & b) patches of foam on the intertidal area.
(c) the 'oily film' observed offshore beyond the breakers zone (in the middle-distance, beyond the white aerated water generated by wave action)

There was no evidence of *Phaeocystis*-type foam at Great Yarmouth Pier bathing water when the samplers arrived after taking samples from Hemsby at Caister Point. Consequently, just three samples were collected, of the seawater at the DSP. Despite the lack of evidence of *Phaeocystis* foam at Great Yarmouth Pier bathing water, the FIO concentrations at this site were similar to those observed at Hemsby and Caister Point, with *E. coli* ranging between 127 and 227 cfu $100ml^{-1}$ and cEN ranging between 182 cfu $100ml^{-1}$ and 355 cfu $100ml^{-1}$ (Table 3.3).

3.2 Opportunistic samples

Four opportunistic samples of suspected *Phaeocystis* foam were collected from Scarborough South Bay by CREH staff during the course of routine monitoring for another project sponsored by Yorkshire Water Services Ltd. These were tested for presumptive enterococci (pEN) and confirmed enterococci (cEN), with only one sample tested for *E. coli.* The results are shown in Table 3.4. Presumptive and confirmed enterococci concentrations at the Scarborough DSP on each of the sample days was available at half-hourly intervals from the routine monitoring project and is included here with the permission of Yorkshire Water. Scarborough South Beach is a wide, relatively flat urban beach contained within an embayment, backed by a road and businesses typical of a sea-side resort. During spring tides, the majority of the beach area is flooded at high water.

On two occasions, 17/08/20 and 30/09/20, a single sample of the suspected *Phaeocystis* foam was collected. On both days, a cream to yellow coloured foam was described forming on the sea surface close to the water edge. A photo of the foam taken at the time of the sample collected on 17/08/20 is shown in Figure 3.4 (unfortunately no photo was taken on 30/09/20).

Figure 3.4: Photo of the suspected *Phaeocystis* foam sampled opportunistically at Scarborough South Bay bathing water on 17/08/20.

On 17/08/20, the foam was observed at the start of the high water period when the tide was flooding over dry sand and, whilst present along much of the shoreline, this was only a relatively thin layer on the surface of the swash and backwash of the waves, accumulating in depressions in the sand, from which the foam was collected (Figure 3.4). This sample displayed pEN and cEN concentrations of 250,000 cfu 100 ml^{-1} (i.e. all presumptive organisms confirmed). Presumptive and confirmed enterococci concentrations at 1m depth at the DSP dropped from around 200-300 cfu 100ml^{-1} at 08:00 BST to around 30 cfu 100ml^{-1} at 13:30 (Figure 3.5a). Concentrations then gradually increased from before the foam sample was taken, exceeding the earlier high concentrations in the sample after the foam was collected and continuing until just after high water, when concentrations increased suddenly from a cEN concentration of 327 cfu 100ml^{-1} to over 2000 cfu 100ml^{-1}. Thereafter, concentrations began to fall again although pEN was still above 1000 cfu 100ml^{-1} and cEN above 500 cfu 100ml^{-1} in the last sample of the day at 20:00 BST (Figure 3.5a).

The suspected *Phaeocystis* foam sample collected on 30/09/20 was also described as a cream to yellow coloured foam forming on the sea surface close to the water's edge, although was collected at a lower tidal level than the sample collected on 17/08/20, around the middle of the flood tide. On this occasion, the sample was collected from the surface of the water and therefore contained both the foam and seawater. This sample displayed a pEN concentration of 1400 cfu 100ml^{-1} and a cEN concentration of 1300 cfu 100ml^{-1} (Table 3.4), although the *E. coli* concentration was much lower at 20 cfu 100ml^{-1}. Water quality at 1m depth at the DSP was decreasing around the time the foam sample was collected from 187 cfu 100ml^{-1} in the sample collected 30 minutes before the foam sample, to 6 cfu 100ml^{-1} 30 minutes after the foam was collected (Figure 3.5b) (both pEN and cEN were the same concentration in these samples). Whilst cEN remained within this range all day, there were periods where pEN was notably higher than the corresponding cEN concentration, most notably in samples collected just before high water, and again over the final hour of sampling (Figure 3.5b).

A relatively large expanse of quite dense foam was found to be present on Scarborough South beach on 04/10/20 concentrated around the high water strandline across the whole embayment (Figure 3.6a – b). Presumably deposited around high water (06:08 BST), this foam was still present over eight hours later when the photos in Figure 3.6 were taken and two samples of the foam were collected at around 14:15 BST. It was possible to collect just the foam without any underlying sand with the foam being described as having a reasonably solid mousse-like consistency (Figure 3.6c – d) with the circular impression of the sample pot being left in the foam when the pot and plug of foam contained within it was removed. The samplers also reported a foul odour in the sea not encountered during previous sample days. Presumptive enterococci concentrations within these samples were 134,000 cfu 100ml^{-1} and 170,000 cfu 100ml^{-1}, whilst approximately one third of the presumptive organisms confirmed with cEN concentrations of 46,000 cfu 100ml^{-1} and 56,000 cfu 100ml^{-1} respectively (Table 3.4). This is in contrast to all the suspected *Phaeocystis* foam samples described above at the East Anglian beaches as well as those samples from Scarborough South Bay on previous occasions, where the majority or all of the presumptive enterococci concentrations confirmed on KAAA (Table 3.1 to Table 3.4).

Table 3.4: Presumptive and confirmed enterococci concentrations (cfu 100ml^{-1}), pH, specific conductance, salinity and turbidity in samples collected from Scarborough South Bay bathing water.

Date	Sample Time BST	Description	*E. coli* cfu 100 ml^{-1}	Presumptive Enterococci cfu 100 ml^{-1}	Confirmed enterococci cfu 100 ml^{-1}	PH	Specific Conductance µS cm^{-1}	Practical Salinity	Turbidity NTU
17/08/20	15:25	Foam	—	250,000	250,000	7.63	53,800	34.49	111.00
03/09/20	13:00	Foam/seawater	20	1,400	1,300	7.90	54,000	35.25	36.00
04/10/20	15:15	Foam	—	170,000	56,000	IS‡	IS‡	IS‡	IS‡
04/10/20	15:18	Foam	—	134,000	46,000	IS‡	IS‡	IS‡	IS‡

IS‡ Insufficient sample: Vortexing the suspected *Phaeocystis* foam samples yielded only a small volume of liquid sufficient only for FIO analysis.

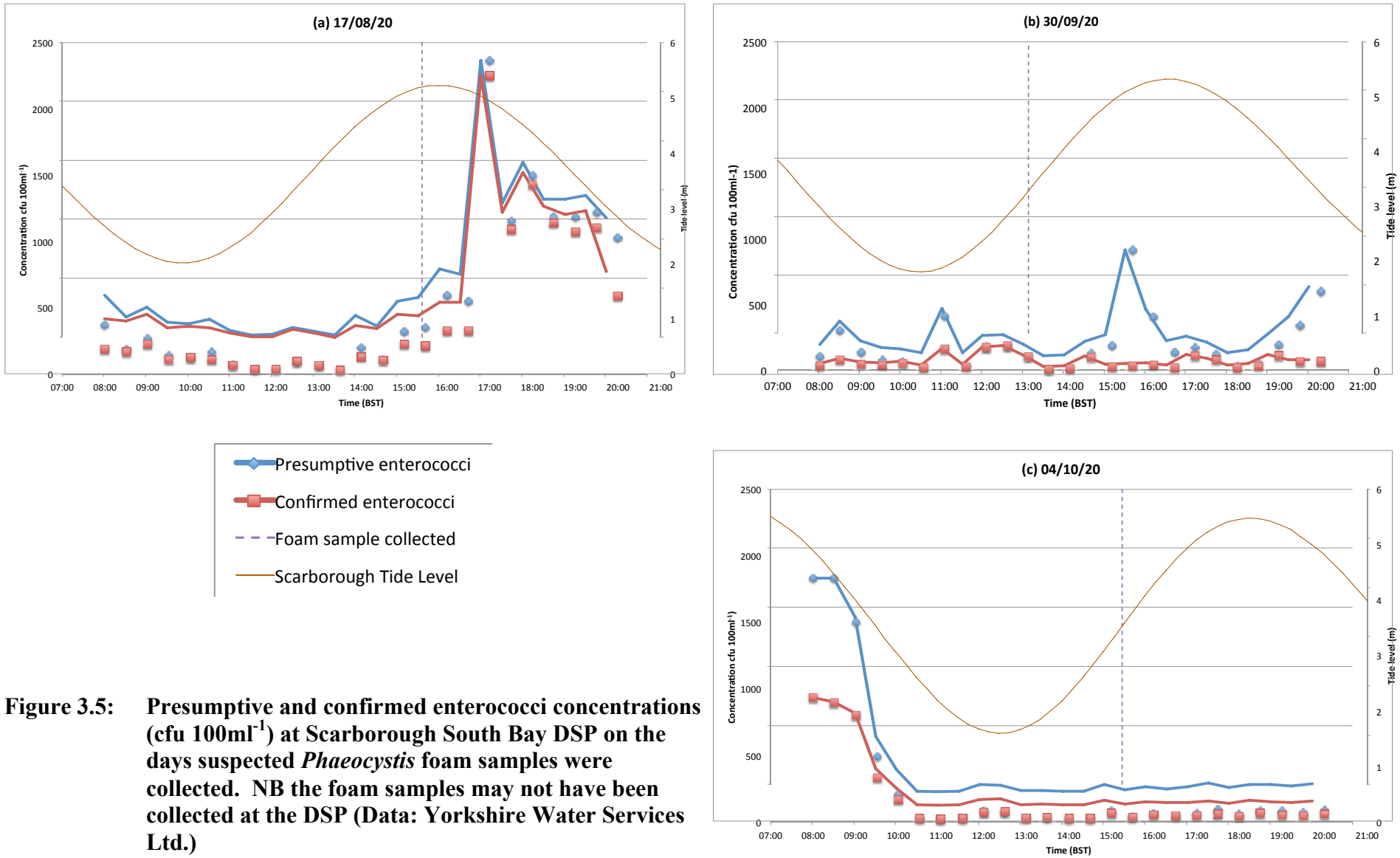


Figure 3.5: Presumptive and confirmed enterococci concentrations (cfu 100ml^{-1}) at Scarborough South Bay DSP on the days suspected *Phaeocystis* foam samples were collected. NB the foam samples may not have been collected at the DSP (Data: Yorkshire Water Services Ltd.)

(a)

(b)

(c)

(d)

Figure 3.6: Photos of the *Phaeocystis* foam at Scarborough South Bay bathing water on 04/10/20.

Presumptive and confirmed enterococci concentrations at the DSP on 04/10/20 were high in the first sample collected at 08:00 BST, 1833 cfu $100ml^{-1}$ and 933 cfu $100ml^{-1}$ respectively, showing a decrease in concentration over the next 2.5 hours to fall to 30 cfu $100ml^{-1}$ (pEN) and 27 cfu 100 ml^{-1} (cEN) (Figure 3.5c). Thereafter, concentrations remained below 100 cfu $100ml^{-1}$ for both pEN and cEN for the rest of the day. The first sample of the day was collected just under 2 hours after high water, not long after the tide would have ebbed away from the foam deposited at high water mark. In the evening, the incoming tide flooded the area where the foam was deposited (in fact the whole beach was flooded to the sea wall) but FIO concentrations in the samples collected at the DSP around this time remained low.

3.3 Discussion

Samples of *Phaeocystis* foam collected from the East Anglian beaches as well as from Scarborough displayed a range of FIO concentrations, although the relative concentrations appear to be related to the nature of the samples. The highest concentrations were largely found in the samples comprising just the foam itself, collected from Caister (4 samples) and Scarborough South Bay (3 samples tested for pEN and cEN only). Confirmed enterococci concentrations in these samples ranged between 46,000 and 250,000 cfu $100ml^{-1}$ with a geometric mean (GM) of 101,851 cfu $100ml^{-1}$. *E. coli* concentrations were lower, the four Caister samples displaying a range between 33,000 and 41,000 cfu $100ml^{-1}$ with a GM of 36,598 cfu $100ml^{-1}$.

Concentrations in samples of *Phaeocystis* foam collected from the water surface, and therefore including seawater within the samples, displayed *E. coli* concentrations between 20 and 6700 cfu $100ml^{-1}$ and cEN concentrations between 1100 and 4600 cfu $100ml^{-1}$. The GM values for the foam/seawater samples were 767 cfu $100ml^{-1}$ and 1748 cfu $100ml^{-1}$ for *E. coli* and cEN respectively.

Concentrations of the FIOs appear to be lower on the sediments when expressed as cfu g^{-1} wet weight, ranging between 19 and 85 cfu g^{-1} for *E. coli* and between 59 and 190 cfu g^{-1} for cEN. However, there is perhaps a mismatch between the units used to express the FIO concentrations in sediment and water, as 1ml water weighs 1g and perhaps sediment concentrations expressed per 100g may provide a more equitable comparison. Thus the equivalent concentrations to the foam/sediment samples could be 1900 to 8500 cfu $100g^{-1}$ for *E. coli* and between 5900 and 19,000 cfu $100g^{-1}$ (wet weight) for cEN. Since no sediment samples were collected away from the foam, it is difficult to be certain the FIOs found in these samples were due to the presence of the foam. However, away from readily identifiable sources of contamination (e.g. point sources, bird faeces, etc.) sandy sediments generally display very low FIO concentrations (e.g. such as the sandy sediments collected away from identifiable sources at Heacham, Hunstanton, Wells and West Mersea described in Stapleton *et al.* (2021), that were largely <9 cfu g^{-1}).

The mechanism for FIO accumulation within the foam is not clear, although it is possible that initial seeding is from the water column, perhaps through the trapping of fine sediment particles to which the bacteria may be attached. The foam may serve as a source of nutrients and organic carbon and also provide a protective environment from UV irradiation that might allow regrowth. The associated water surface film may also serve to trap and concentrate FIOs and fine sediments at the water surface seaward of the breaker zone that then contribute to the foam when it is agitated by wave action. Given the high concentrations observed in the foam it is possible that the lower concentrations in the seawater samples containing foam are the result of dilution of the high concentrations observed in the foam. However, the samples of foam taken soon after formation within the breaker zone mean that there is little time for regrowth to occur before samples were collected. It is also possible that the FIO

concentrations in the foam-only samples taken for this study are not directly comparable to the seawater concentrations, with the vortexing essentially concentrating a larger volume of foam (150ml of a full sample pot of foam was collected) to a few ml before analysis.

Despite the uncertainties about formation and comparability of concentrations in the different samples, the samples of combined seawater and foam, that were essentially analysed using the same method as bathing water compliance samples, displayed high concentrations well above the 100 cfu $100ml^{-1}$ threshold. Also, samples taken at the DSPs when the foam was present generally displayed FIO concentrations above 100 cfu ml^{-1} suggesting that the presence of *Phaeocystis* foams correspond to a deterioration on bacterial water quality.

4. Faecal indicator organism concentrations in beach-cast seaweed

4.1 Samples from Hemsby, Caister Point and Great Yarmouth Pier

Samples of beach-cast seaweed were collected from Hemsby, Caister Point and Great Yarmouth Pier bathing waters, together with seawater samples on 13/09/20. The amount of beach-cast seaweed varied at each beach, with the largest deposits at Hemsby, whilst very little seaweed was present at Great Yarmouth. In total, twenty-four samples of beach-cast seaweed were collected: 10 samples each from Hemsby (Table 4.1; Figure 4.1) and Caister Point (Table 4.2; Figure 4.2) and four from Great Yarmouth Pier (Table 4.3; Figure 4.3). A typical example of the seaweed sampled at each location is shown in detail in Figure 4.4.

Reasonably extensive patches of beach-cast seaweed were present at Hemsby around spring tide high water mark, approximately 15m higher up the beach from high water mark on the day of sampling. The deposits were not continuous along the beach, comprising patches of various length and breadth, with the depth of seaweed varying from a thin layer of individual fronds to depths of 10cm (Figure 4.1a & b). The patches comprised a dried- and sun-bleached surface layer that, where the depths of seaweed were greater, had formed a matted crust over damper seaweed that had retained its colour. This lower layer, although compacted to some extent, was 'looser' than the surface layer and individual fronds could be separated. Definitive identification of the seaweed was difficult due to its state although species present appeared to include two green seaweeds *Ulva intestinalis* (gut weed) and *Ulva latuca* (sea lettuce), a red seaweed, possibly *Coralliana officinalis* (coral weed), which made up most of the deposits, and some sparse amounts of *Fucus vesiculosus* (bladder wrack). Samples, mostly a mix of different species, were collected from the surface crust and from various depths beneath the crust. A description and results for samples collected from Hemsby are shown in Table 4.1, whilst photos of the samples are included in Figure 4.1c-e.

Table 4.1: Faecal indicator organism concentrations (cfu 100ml^{-1} of washwater) of beach-cast seaweed samples collected from Hemsby on 13/09/20.

ID	Description	Temp °C	*E. coli* (cfu 100 ml^{-1} of washwater)	Presumptive enterococci (cfu 100 ml^{-1} of washwater)	Confirmed enterococci (cfu 100 ml^{-1} of washwater)
1	Surface crust, mainly dry	34.7	<909	1,000	1,000
2	2.5cm below surface	24.5	2,000	1,000	1,000
3	4.0cm below surface	25.3	<909	<909	<909
4	Surface crust, mainly dry	30.4	1,000	1,000	1,000
5	2.0cm below surface	36.7	<909	4,000	4,000
6	5.5cm below surface	21.1	5,455	<909	<909
7	Surface crust, mainly dry	29.8	590,000	1,210,000	790,000
8	4.0cm below surface	25.2	<909	20,000	10,000
9	base – 7cm below surface	22.9	<909	14,545	13,636
10	base – 7cm below surface	22.6	<909	4,000	4,000

At Hemsby, sample 7 stands out with a high FIO concentrations of 590,000 cfu 100ml^{-1} of washwater for *E. coli* and 790,000 cfu 100ml^{-1} of washwater for cEN (Table 4.1). This sample was of the surface crust of the deposit and contrasts with the much lower values of the other samples collected from the surface crust. The sample collected 4cm below this surface displayed an elevated cEN concentration of 10,000 cfu 100ml^{-1} of washwater although the *E. coli* concentration was below the limit of detection (Table 4.1). The sample collected at the base of this deposit (sample 9) also displayed an elevated cEN concentration of 13,636 cfu 100ml^{-1} of washwater with the *E. coli* below the limit of detection.

(a)

(b)

(c)

Figure 4.1: Photos of the beach-cast seaweed deposits at Hemsby on 13/09/2020:
(a & b) general views of the patches of beach-cast on high water spring tide strandline.
(c) close-up of the base of the seaweed deposit (7cm depth) (sample 9)

(d) **(e)**

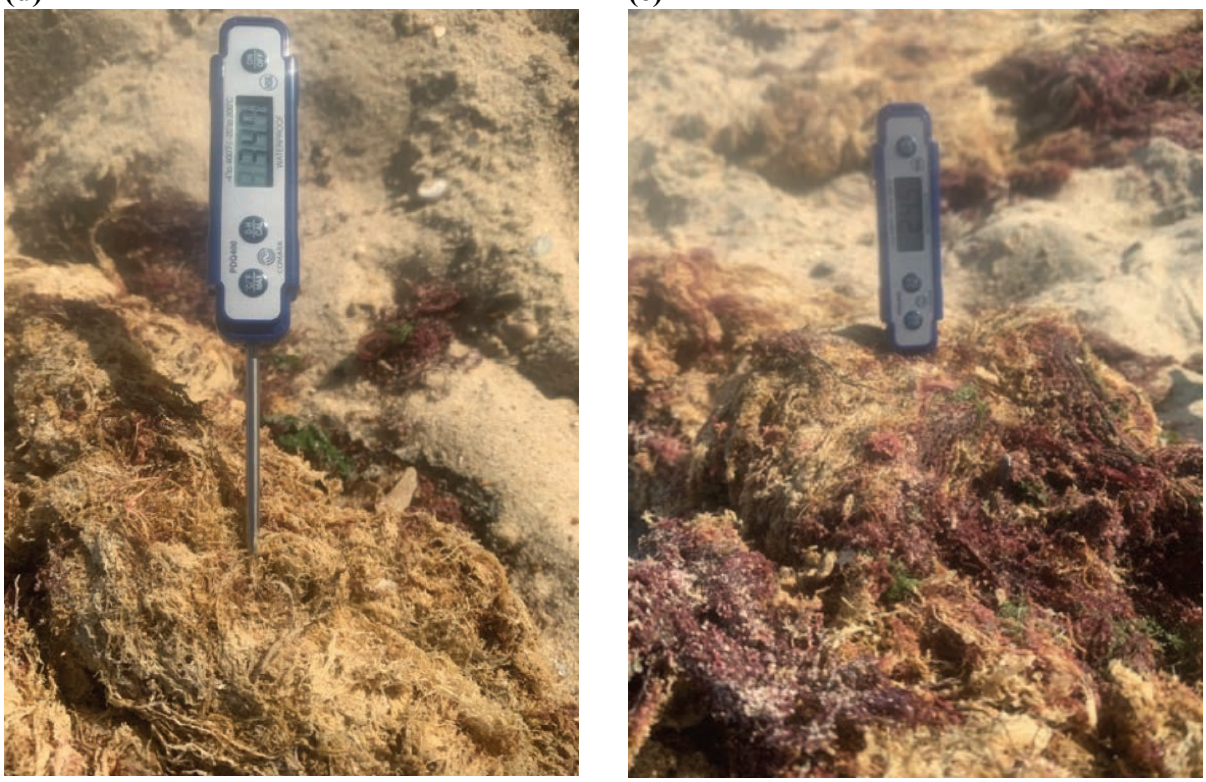


Figure 4.1 (cont.): Photos of the beach-cast seaweed deposits at Hemsby on 13/09/2020: (d) close-up of the surface crust of the seaweed deposits (sample 1); (e) close-up of the seaweed deposit with the section at 2cm depth revealed (sample 2).

Most other samples from Hemsby displayed *E. coli* and enterococci concentrations either in the low thousands cfu per 100ml of washwater or were below the limit of detection. Temperature in the piles of seaweed ranged between 22.6˚C and 36.7˚C, and tended to show a decrease with increased depth, although the highest temperature was measured just below the surface crust at a depth of 2cm.

The deposits of seaweed at Caister Point were similar to those at Hemsby, predominately red but with some green species, and somewhat dried and bleached by the sun on the surface of the deposits. However, the deposits at Caister were not as extensive and were generally smaller, rarely exceeding greater than 3cm in depth (Figure 4.2a). Unlike at Hemsby, there were also clumps of mixed species of seaweed present on the intertidal area (Figure 4.2b). Faecal indicator organism concentrations in all but one of the samples from Caister Point were below the limit of detection used for the Hemsby samples (i.e. <909 cfu $100ml^{-1}$ of washwater). *E. coli* concentrations in all samples were relatively low, not exceeding 100 cfu $100ml^{-1}$ in of washwater, with eight out of the ten samples displaying concentrations less than the limit of detection (<91 cfu $100ml^{-1}$ of washwater) (Table 4.2). However, most samples (7 out of the ten) displayed a cEN concentration above the limit of detection. The highest concentrations were observed in a sample of dry mixed seaweed collected from the strandline, displaying a cEN concentration of 1364 cfu $100ml^{-1}$ of washwater (Table 4.2). Other samples displayed cEN concentrations between 182 and 545 cfu $100ml^{-1}$ of washwater (Table 4.2). Temperature of the samples varied between 18.5˚C and 26.7˚C, with the coolest temperatures found in the wetter samples taken from the intertidal area. The temperature was highest in the deposit that contained the highest cEN concentration.

(a)

(b)

(c)

Figure 4.2: Photos of the beach-cast seaweed deposits at Caister Point on 13/09/2020:
(a) typical deposit of beach-cast seaweed at the strandline;
(b) typical deposits of beach-cast seaweed found on the intertidal area
(c) close-up of a collected sample from Caister Point.

Table 4.2: Faecal indicator organism concentrations (cfu 100ml^{-1} of washwater) of beach-cast seaweed samples collected from Caister on 13/09/20.

ID	Description	Temp °C	*E. coli* (cfu 100 ml^{-1} of washwater)	Presumptive enterococci (cfu 100 ml^{-1} of washwater)	Confirmed enterococci (cfu 100 ml^{-1} of washwater)
1	Dry mixed seaweed, 2cm deep	24.8	100	200	200
2	Small patch mixed wet seaweed	—	<91	545	545
3	Dry mixed seaweed, 2cm deep	20.3	<91	<91	<91
4	Small patch mixed wet seaweed	18.5	<91	300	300
5	Small patch mixed wet seaweed	18.5	<91	273	182
6	Dry mixed seaweed	27.6	<91	1455	1364
7	Surface crust, mainly dry	—	<91	200	200
8	4.0cm below surface	26.7	<91	<91	<91
9	base – 7cm below surface	21.1	<91	200	200
10	base – 7cm below surface	21.1	100	<91	<91

Very little beach-cast seaweed was present at Great Yarmouth, with the only deposits present generally only individual pieces or small piles of mixed species (Figure 4.3). Since there were no deposits of notable depth, fewer samples were collected and taking a representative temperature of the different layers was not possible. The highest concentrations were found in a sample of dry mixed species largely bleached by the sun (Figure 4.3a), displaying an *E. coli* concentration of 818 cfu 100ml^{-1} of washwater and a cEN concentration of 3273 cfu 100ml^{-1} (Table 4.3). This was the only sample from Great Yarmouth that displayed an *E. coli* concentration above the limit of detection (<91 cfu 100ml^{-1} of washwater). A 'wet 'sample of mostly *Ulva* spp. displayed a cEN concentration of 636 cfu 100ml^{-1} of washwater, whilst the other dried seaweed sample sampled displayed a concentration of 100 cfu 100ml^{-1} of washwater. The 'wet' sample of mostly red seaweed (Figure 4.3b), possibly purple laver (*Porphyra umbilicalis*), displayed both *E. coli* and cEN concentrations below the limit of detection (Table 4.3).

Table 4.3: Faecal indicator organism concentrations (cfu 100ml^{-1} of washwater) of beach-cast seaweed samples collected from Great Yarmouth Pier on 13/09/20.

ID	Description	*E. coli* (cfu 100 ml^{-1} of washwater)	Presumptive enterococci (cfu 100 ml^{-1} of washwater)	Confirmed enterococci (cfu 100 ml^{-1} of washwater)
1	Dry mixed seaweed	818	3364	3273
2	Dry mixed seaweed	<91	200	100
3	Wet, mostly red seaweed, possibly *Porphyra umbilicalis*	<91	<91	<91
4	Wet, mixed, mostly *Ulva* spp.	<91	636	636

NB: temperature was not measured as these samples were individual fronds

(a)

(b)

Figure 4.3: Photos of the beach-cast seaweed deposits at Yarmouth Pier on 13/09/2020: (a) dry seaweed deposit similar to Sample 1 –; (b) wet red seaweed making up the most part of Sample 3.

Figure 4.4: Examples of the contents of each seaweed sample at Hemsby, Caister Point and Great Yarmouth on 10/09/20. Note that the dry seaweed sampled at Caister Point was similar to the Hemsby example.

Concentrations of FIOs in the sea on 13/09/20 at the three bathing water DSPs was low, with concentrations at Hemsby and Great Yarmouth pier being below or close to the limit of detection, ranging between <9 and 10 cfu 100ml^{-1} (Table 4.4). However, the concentration of cEN was slightly higher at Caister Point, at 45 cfu 100ml^{-1}.

Table 4.4: Faecal indicator organism concentrations (cfu 100ml^{-1}) in seawater at Hemsby, Caister Point and Great Yarmouth Pier on 13/09/20.

Bathing Water	*E. coli* (cfu 100 ml^{-1})	Presumptive enterococci (cfu 100 ml^{-1})	Confirmed enterococci (cfu 100 ml^{-1})
Hemsby	10	<9	<9
Caister Point	<9	55	45
Great Yarmouth	<9	9	9

4.2 Samples from Flamborough South Landing, Yorkshire

During the planning stage for the current project, CREH became aware of a large accumulation of seaweed at Flamborough South Landing bathing water. This south-facing beach comprises chalk boulders overlying sand on the upper beach with a sandy intertidal area through which the rocky wave-cut platform protrudes in places. The beach is backed by steep chalk cliffs of Flamborough Head. Beach-cast seaweed had accumulated to a considerable thickness around the spring high water strandline. As the tide level moved away

from the spring highs, the deposits were likely to be progressively left dry by subsequent tides, perhaps except for the seaward face of the deposit, lower down the beach (Figure 4.5).

The accumulation of this seaweed coincided with particularly dry and warm antecedent conditions, leading to the surface of the deposit forming a solid, matted, sun-bleached surface layer overlying wetter decomposing seaweed, between 15 and 20 cm in depth (Figure 4.5). The accumulation comprised a mix of species, including the brown seaweeds *Fucus vesiculosus* (bladder wrack) and *Laminaria digitata* (oarweed, a kelp), the green seaweeds *Ulva intestinalis* (gut weed) and *Ulva latuca* (sea lettuce), and red seaweeds such as *Porphyra umbilicalis* (purple laver) and *Coralliana officinalis* (coral weed) (Figure 4.6). Samples were initially collected on 11/08/20, three days after the spring tides, although it is not clear whether at least some of the seaweed had been present for a longer duration. Also sampled on the intertidal area were areas of apparently freshly-cast seaweed with a similar mix of species as the accumulations stranded at high water mark, as well as patches of what appeared to be broken-down seaweed. Faecal indicator organism concentrations found on the various different seaweed deposits together with temperature measurements, where relevant, are shown in Table 4.5. Figure 4.6 shows photos of the locations and composition of the samples whilst Figure 4.7 shows typical contents of each sample in detail.

Samples of the large deposit at the spring high water strand line were taken at different depths, including the surface crust, just below the crust (approx. 2cm depth) and towards the bottom of the deposit (approx. 15cm depth) (Figure 4.6a & b). One sample, containing both the dry crust and some wet seaweed was deliberately left out of the fridge to allow decomposition to continue until arrival at the laboratory. Maggots and other invertebrates were observed in the deposits below the crust and there were considerable amounts of flies around the seaweed deposit. There was a notable foul odour once the crust was broken.

Faecal indicator organism concentrations in this deposit varied by over 3 orders of magnitude (i.e. 3 $\log_{10}$), ranging between <9 and 1182 cfu $100ml^{-1}$ of washwater for *E. coli* and between 243 and 43,000 cfu $100ml^{-1}$ of washwater for cEN (Table 4.5). The highest cEN concentration was observed in the sample left out of the fridge until arrival at the laboratory, although the *E. coli* concentration in this sample was lower than observed in some other samples (Table 4.5). There was no consistent pattern to the FIO concentrations taken from the different layers, with similar concentrations observed in one of the crust samples and wetter lower layers. One crust sample (sample 6) displayed a lower *E. coli* concentration, whilst the other crust sample (sample 3) displayed a pEN concentration an order of magnitude greater than the other samples transported to the laboratory in the fridge (although this was similar to the pEN concentration in the sample transported outside of the fridge).

There was some residual liquid present in the bags of samples 7 and 8, both samples collected from below the upper crust. The liquid derived from the sample collected from the base of the deposit (sample 8) displayed FIO concentrations greater than those observed in any of the seaweed samples[1], with an *E. coli* concentration of 58,599 cfu $100ml^{-1}$ and a cEN concentration of 2 million cfu $100ml^{-1}$ (Table 4.5). Concentrations in the other residual liquid sample, from the upper layer of wet seaweed displayed an *E. coli* concentration of 6000 cfu $100ml^{-1}$ and a cEN concentration of 17,000 cfu $100ml^{-1}$. Squeezing some of the wet seaweed from below the crust resulted in an odorous, dark-grey to black liquid (Figure 4.6c) with *E. coli* and cEN concentrations of 25,455 cfu $100ml^{-1}$ and 100,000 cfu $100ml^{-1}$ respectively.

[1] Note: concentrations for the seaweed and those for the residual water are not necessarily directly comparable.

(a)

(b)

(c)

Figure 4.5: (a – c) Beach-cast seaweed deposits at Flamborough South Landing on 11/08/20:

Table 4.5: Faecal indicator organism concentrations (cfu 100ml^{-1} of washwater) of beach-cast seaweed samples and from residual liquid from within sample bags/bottles (cfu 100ml^{-1}) collected from Flamborough South Landing on 11/08/20. Photos of some samples are shown in Figure 4.6

ID	Description	Temp	Seaweed			Residual liquid†		
			E. coli	Presumptive enterococci	Confirmed enterococci	*E. coli*	Presumptive enterococci	Confirmed enterococci
		˚C	(cfu 100 ml^{-1} of washwater)	(cfu 100 ml^{-1} of washwater)	(cfu 100 ml^{-1} of washwater)	(cfu 100 ml^{-1})	(cfu 100 ml^{-1})	(cfu 100 ml^{-1})
1	Water in rock pool	—	—	—	—	<9†	<9†	<9†
2	Water & bits of seaweed in rock pool	—	10	24,000	364	20	36	18
3	Dry surface of main HW deposit	—	1,273	43,000	6,000	—	—	—
4	Wet sample from below dry crust of main HW deposit	40.0	<9	514	243	—	—	—
5	Dry and wet from main HW deposit. Left out of fridge until arrival at lab.	—	800	38,182	38,182	—	—	—
6	Dry surface of main HW deposit	33.4	200	6,486	1,622	—	—	—
7	Wet sample from 2cm below dry crust of main HW deposit. Lab noted maggots in the sample.	40.3 (34.9)	1,622	5,045	4,144	6,000	17,000	17,000
8	Wet sample from 15cm below dry crust of main HW deposit	28.0	1,182	8,018	8,018	58,559	2,300,000	2,000,000
9	Liquid from squeezed wet seaweed taken from below dry crust of main HW deposit	—	—	—	—	25,455†	104,950†	100,000†
10	Macerated/small fragments of seaweed collected from intertidal area	—	<90	364	273	100	<90	<90
11	Macerated/ small fragments of seaweed and water collected from small pool in the sand of intertidal area	—	<90	270	270	<90	<90	<90
12	Growing attached bladder wrack (*Fucus* spp.) from intertidal area	23.9	<90	<90	<90	<90	<90	<90
13	Wet beach-cast seaweed from intertidal area - U*lva* spp. and *Porphyra*, etc.	—	1,455	545	455	<90	<90	<90

NB: Air temperature at the time of sampling measure 1.5m above the seaweed deposit using the probe thermometer was 24˚C in a slight breeze

† Residual liquid was the liquid remaining in the sample bag or pot after the seaweed had been removed. The exceptions to this are sample 1, which was the water from a rockpool that contained beach-cast seaweed and sample 9, which was the liquid squeezed from decomposing seaweed taken from below the crust of the main HW deposit

Sample 1

Sample 2

Samples 1 (l) & 2 (r)

Sample 3

Sample 4

Figure 4.6a: Photos of samples at Flamborough South Landing on 11/08/20.

Sample 6 **Sample 7** **Sample 8**

Sample 6

Sample 7 (sample 8 from lower in the deposit)

Figure 4.6b: (cont.) Photos of samples at Flamborough South Landing on 11/08/20.

Sample 9

Samples 10 (left) & 11 (right)

Sample 10

Sample 11

Figure 4.6c: (cont.) Photos of samples at Flamborough South Landing on 11/08/20.

Sample 12

Sample 12

Sample 13

Figure 4.6d: (cont.) Photos of samples at Flamborough South Landing on 11/08/20:

Figure 4.7: Examples of the contents of each seaweed sample at Flamborough South Landing on 11/08/20.

The temperature measurements made in the large deposit are also notable, with a temperature of 40˚C measured just below the crust and a temperature of 33.4˚C measured on the surface of the crust (Table 4.5). These are higher than the local air temperature of 24˚C (in a slight breeze) measured 1.5m above the seaweed deposit, and close to ideal temperatures for the growth of intestinal enterococci (37˚C). Once exposed by breaking open the dry crust of seaweed the temperature of the layer just below the crust decreased to 34.9˚C with an even lower temperature at the base of the deposit (28˚C) (Table 4.5). Therefore, the crust appears to be playing a role in trapping heat and maintaining high temperatures within the deposit. These relatively high temperatures within the deposit are likely to be the result of solar irradiation and exothermic decomposition processes within the nutrient- and carbon-rich environment.

The various other seaweed samples collected from Flamborough South Landing on 11/08/20 generally displayed FIO concentrations lower than those observed in the HW strandline deposits (Table 4.5). The highest concentrations were observed in the beach-cast mix of mainly *Ulva* and *Porphyra* species sampled from the intertidal area (sample 13; Figure 4.6d), which displayed an *E. coli* concentration of 1455 cfu $100ml^{-1}$ of washwater and a cEN concentration of 455 cfu $100ml^{-1}$ of washwater (Table 4.5). Two samples, of what looked like macerated seaweed (samples 10 and 11; Figure 4.6d; Figure 4.7), both displayed *E. coli* concentrations of below the limit of detection (<90 cfu $100ml^{-1}$ of washwater) and similar cEN concentrations around 270 cfu $100ml^{-1}$ of washwater (Table 4.5). The growing bladder wrack (*Fucus vesiculosus*) sample displayed *E. coli* and enterococci concentrations below the limit of detection, (<90 cfu $100ml^{-1}$ of washwater) (Table 4.5). The residual liquid from all

of these samples were also below the limit of detection (<90 cfu 100ml^{-1}) with the exception of *E. coli* in sample 10, which was 100 cfu 100ml^{-1}).

The FIO concentrations in the two samples of seawater collected from rock pools containing seaweed were low, with the one containing growing seaweed (sample 1; Figure 4.6a) yielding concentrations below the limit of detection (in this case, <9 cfu 100ml^{-1}), whilst the pool containing decomposing fragments (sample 2; Figure 4.6a) displayed concentrations of 20 cfu 100ml^{-1} for *E. coli* and 18 cfu 100ml^{-1} for cEN (Table 4.5). However, the seaweed fragments from this sample displayed a pEN concentration of 24,000 cfu 100ml^{-1} of washwater although a low proportion confirmed, yielding a cEN concentration of 364 cfu 100 ml^{-1} of washwater. The *E. coli* concentration in the seaweed from the rockpool, was 10 cfu 100ml^{-1} of washwater (Table 4.5).

The FIO concentrations in the two samples of seawater collected from rock pools containing seaweed were low, with the one containing growing seaweed (sample 1; Figure 4.6a) yielding concentrations below the limit of detection (in this case, <9 cfu 100ml^{-1}), whilst the pool containing decomposing fragments (sample 2; Figure 4.6a) displayed concentrations of 20 cfu 100ml^{-1} for *E. coli* and 18 cfu 100ml^{-1} for cEN (Table 4.5). However, the seaweed fragments from this sample displayed a pEN concentration of 24,000 cfu 100ml^{-1} of washwater although a low proportion confirmed, yielding a cEN concentration of 364 cfu 100 ml^{-1} of washwater. The *E. coli* concentration in the seaweed from the rockpool, was 10 cfu 100ml^{-1} of washwater (Table 4.5).

The sampling on 11/08/20 was followed-up with three samples collected on 17/08/20 at the bathing water DSP to investigate the impact of the high spring tide interacting with the decaying beach-cast deposit. Shortly before the incoming tide reached the seaward edge of the deposit, the first sample of seawater was collected at the DSP. When the waves were washing in and out of the deposit, a sample of the runoff from the deposit during the backwash of a wave was collected. Finally, another sample of the seawater at the DSP was collected once the tide no longer interacted with the deposit. There was a period of 1 hour 35 minutes between the first and second samples, with the final sample taken 1 hour 15 minutes after the second sample. Only presumptive and confirmed enterococci were enumerated in these samples.

Table 4.6: Faecal indicator organism concentrations (cfu 100ml^{-1}) in seawater at Flamborough South Landing on 17/08/20.

Bathing Water	Presumptive enterococci (cfu 100 ml^{-1})	Confirmed enterococci (cfu 100 ml^{-1})
Flooding tide before reaching seaweed	32	30
Runoff from seaweed as waves wash into/out of deposit	6,600	6,600
Ebbing tide after receding beyond seaweed	1,100	200

The results (Table 4.6) show that the lowest concentrations were observed in the sample collected during the flooding tide before the seawater reached the decaying seaweed deposit, with a cEN concentration of 30 cfu 100ml^{-1}. The runoff from the deposit during the backwash of a wave displayed the highest concentration, with a pEN and cEN concentration of 6600 cfu 100ml^{-1}, whilst the sample from the DSP after contact with the beach-cast seaweed displayed pEN and cEN concentrations greater than in the first seawater sample, at 1100 cfu 100ml^{-1} and 200 cfu 100ml^{-1} respectively (Table 4.6). This pattern, albeit from a very limited number of samples, suggests that there was the potential for transfer of FIOs from seaweed to the bathing water after contact with the large high water deposit.

4.3 Discussion

The sampling of beach-cast seaweed at the Anglian region beaches as well as at Flamborough South Landing display a wide range of concentrations that appear to vary with factors such as state of composition, nature and position of the deposit, and species. The transient nature of such deposits and opportunistic sampling taken during this project mean that the length of decomposition of the sampled deposits were subject to before they were sampled is not known, although in the case of deposits at the strand-line at high water spring tide level, this can be approximated from tide tables. However, this relies on the assumption that the deposits were made during the spring tide immediately before the sampling took place, and it is possible that some seaweed may have been deposited during previous spring tide cycles. Most deposits stranded away from interaction with the seawater are likely to have been subject to other factors, such as disturbance and contamination by beach users and wildlife. The seed population for the bacterial growth could either be from that present within the water column, biofilms already present on growing seaweed or from the faeces of birds and other species scavenging within the strandline deposits. There may also be an element of contamination by litter left behind by beach users.

Nevertheless, the range of FIO concentrations observed in the various seaweed deposits suggests that high concentrations can be present and that growth of the organisms in the environment is possible. Measurements within the deposits have shown that temperatures of up to 40˚C, suitable for enteric bacterial growth, can be present, perhaps generated by decomposition processes and the formation of a crust of desiccated seaweed creating a sealed, protective layer. As well as serving to produce a micro-climate within the piles, the outer crust will serve to protect the bacteria from the biocidal effects of irradiation, particularly ultra-violet wavelengths. Within these sealed deposits, the abundance of nutrients and organic carbon combine with the temperature to provide an almost-ideal environment for FIO growth. This notion of regrowth within deposits and subsequent transfer to the marine environment is supported by experiments carried out by Dunhill *et al*. (2013), who observed an increase in *E. coli* and intestinal enterococci concentrations over time when periodically flushing seaweed piles stored in water butts with sterile saline solution. During these experiments, the peak and subsequent decline of *E. coli* concentrations in the washwater occurred earlier than the intestinal enterococci, attributed by the authors to a stronger affinity for seaweed attachment and longer survival times of enterococci. This may explain the variability in the patterns of *E. coli* and the enterococci organisms in the samples collected from Hemsby, Caister Point and Great Yarmouth. Note that whilst Dunhill *et al*. (2013) did not report absolute temperatures within their seaweed piles, they plotted changes in the temperature differential between ambient air temperature and that within the piles of up to 7˚C. The temperature differential measured at Flamborough, when using the highest observed temperature of 40˚C within the high water deposit, was 16˚C.

The limited sampling undertaken at Flamborough South Landing on 17/08/20 appears to show that the FIO populations within the seaweed deposits at high water can be transferred to the water column through the washing/rewetting/agitation action of the waves as high tides reach the deposits during subsequent spring tides. This sampling showed an increase in cEN concentration from a compliant value of 30 cfu $100ml^{-1}$ as the tide approached the deposit to what might be considered a 'non-compliant' concentration above 100 cfu $100ml^{-1}$ after the high water period and interaction with the deposit. The elevated concentration in the runoff from the deposit after initial wetting by the incoming tide, an order of magnitude greater than observed in the seawater after interaction with the deposit, suggests that there is a degree of dilution present that might be variable depending on factors such as the level to which the

tide reaches, the length of time water is in contact with the deposit, the degree of agitation by wave action and/or the level of decomposition and bacterial population. However, it does appear that the process of release of the organisms back into the water may not require much agitation as wave action was quite gentle on the day of sampling. A greater degree of turbulence could result in a greater transfer of organisms. Dunhill *et al.* (2013) demonstrated that vigorous agitation of samples yielded additional FIOs in washwater after the seaweed samples had already been gently 'swirled' in a separate volume of recovery solution. They also suggested that intestinal enterococci had a greater affinity to attach to seaweed.

Some of the variability seen between the different seaweed deposits may be due to the species of seaweed present. Some species of seaweed encourage the sloughing of biofilms from their surfaces before they develop significantly (Quilliam *et al*. 2014) or produce compounds that discourage the formation of biofilms (Hellio *et al*., 2000; 2004). However, these anti-fouling substances appear to impact organisms differently, being ineffective against *E. coli (K12)* but effective against Gram-positive bacteria[2] (Hellio 2000), whilst other species, such as *Ulva* spp. and *Cladophora* spp. do not produce these substances (Burgess *et al.*, 2003) and therefore could provide suitable habitats for bacteria (Dunhill *et al.,* 2013). This might explain the differences in FIO concentrations observed in the various named species of seaweed sampled from the intertidal areas at Great Yarmouth and Flamborough South Landing, where in both cases the *Ulva* spp. samples displayed higher FIO concentrations than other species. Therefore, the species composition of beach-cast deposits may be a further determining factor of the extent to which seaweed deposits impact on bathing water quality. Given the different lifecycles of the various species of seaweed found in the UK, there may also be a seasonal element to the timing and extent of deposits and their impacts. The antecedent weather will also have an influence, with conditions suitable to encourage seaweed growth, detachment and accumulation, and then be suitable or otherwise for regrowth of the FIOs, all likely to result in impacts being intermittent throughout the bathing season.

Despite the potentially numerous factors impacting FIO concentrations in seaweed deposits, the presence of high concentrations of FIOs within some of the seaweed sampled above and described elsewhere (e.g. Dunhill *et al.,* 2013) show that piles of beach-cast seaweed is a likely source of FIO contamination of bathing waters. Consequently, it would be prudent to record a description of beach-cast seaweed deposits (species types, condition (freshly deposited or decaying), size, extent, etc.) at the time of the collection of bathing water samples where these might be suspected to be having an impact on water quality to enable a robust interpretation of subsequent results.

[2] Intestinal enterococci are Gram-positive although the study of Hellio *et al.*, 2000 did not include this organism within their tests. *E. coli* is a Gram-negative bacteria.

5. Conclusions

The opportunistic collection of *Phaeocystis* foam and decomposing beach-cast seaweed from Hemsby, Caister and Great Yarmouth as well as from beaches in Yorkshire has shown that both types of deposit can be reservoirs of FIOs. The presence of these deposits appears to have an impact on concentrations at the bathing water DSPs.

Very high concentrations of FIOs were found in the samples comprising solely of the *Phaeocystis* foam, with *E. coli* ranging between 33,000 and 41,000 cfu $100ml^{-1}$ and cEN ranging between 46,000 and 250,000 cfu $100ml^{-1}$. Whilst it is not clear whether such high concentrations are the result of regrowth, protection from predation and bactericidal irradiation, the accumulation through the trapping of sediments or bacteria, or a result of the analytical procedure concentrating FIOs within a larger volume of foam to a small volume of sample, it is apparent that the foam is contributing to elevated FIOs at the bathing waters. Samples of combined seawater and foam displayed concentrations above 1000 cfu $100ml^{-1}$, the lower concentrations perhaps due to dilution of concentrations present within the foam. Samples collected at 1m depth at BWD DSPs when foam was present were generally above 100 cfu $100ml^{-1}$. The elevated concentrations at Hemsby, Caister Point and Great Yarmouth Pier DSPs on the same day as the foam was sampled, all which otherwise typically display low FIO concentrations, is suggestive of causation. The presence of the foam at Hemsby and Caister Point, but not at Great Yarmouth, whilst DSP samples exceeded 100 cfu $100ml^{-1}$ at all three, suggests that the impact is likely to be regional and may not be predicated by visible foam at a DSP. Consequently, non-compliance at bathing waters close to DSPs where foam has been observed could, perhaps, also be attributed to the decomposition of a regional bloom. Thus, the impacts of *Phaeocystis* algal bloom decay may not be dependent on the presence of the foam itself, but merely the presence of the break-down products which may be manifest as an offshore slick not obvious to samplers at the beach.

Faecal indicator organism concentrations in beach-cast seaweed were highly variable, although some samples from all locations were found to contain high FIO concentrations in the washwater. Particularly high concentrations were notable and associated with deposits that have been subject to decay with desiccation and coalescence of the surface forming a protective layer or crust. The samples collected at Flamborough South Landing demonstrated that temperatures suitable for enteric bacterial growth were generated within 'sealed' deposits, providing an environment where high FIO concentrations can be present. The additional sampling at Flamborough over a spring high water period (i.e. before and after the deposits were washed potentially for the first time after stranding (following the neap tide period when the high tides did not reach the deposit) suggests that the reservoirs of FIOs can be transferred back into the marine environment through wave action. It is possible that the degree of transfer and impact will be related to the degree of agitation and rougher conditions might result in greater transfer of organisms, perhaps to the point of re-suspending part or all of the deposits.

Whilst high concentrations were observed in some beach-cast seaweed deposits, not all samples collected displayed high concentrations in the washwater (i.e. organisms dislodged from the surface of the seaweed) or in the residual water present in sample bags/pots after the seaweed was removed. Whilst some reasonably high FIO concentrations were found in a relatively fresh-looking deposit of *Ulva* and *Porphyra* species taken from the intertidal zone, the residual water from these samples all displayed concentrations of <90 cfu $100ml^{-1}$. Maybe of particular relevance to similar deposits previously noted at Felixstowe were the samples of small diameter, 'macerated', dark coloured pieces of 'leathery' seaweed, forming

deposits that appeared almost sedimentary in nature, collected at Flamborough. *E. coli* concentrations washed from these seaweed samples were below the limit of detection (<90 cfu $100ml^{-1}$ of washwater) whilst there was a reasonable concentration of presumptive and confirmed enterococci. However, concentrations in the residual water from these samples were 100 cfu $100ml^{-1}$ or below.

Overall, both the presence of *Phaeocystis*-related foams or slicks and decaying seaweed appears to provide potential reservoirs of FIOs that could impact on bathing water quality. These impacts are likely to be ubiquitous and not specific to the beaches where samples were collected during this study. The seaweed data supports the observations from experiments carried out by the EA, which similarly concluded that piles of seaweed can be reservoirs for FIOs (Dunhill *et al.,* 2003). There are likely to be many factors that affect the degree of the impacts that the reservoirs might have, both in terms of the numbers of FIOs they might generate, and the degree to which these populations are transferred to the water column, and specifically, to the BWD designated sample point(s). For example, large deposits stretching across a long length of strandline are more likely to have an impact than small pieces or individual fronds of seaweed, whilst such deposits may not impact at all despite potentially high concentrations present if there is not a hydrological connection between these and the sea (e.g. if subsequent tides do not interact with the deposits). However, it may not necessarily require subsequent tides to wash over the decomposing piles of seaweed, with the potential for rainfall percolating through deposits and running into the sea being another potential route. The impacts of decaying *Phaeocystis* blooms may be regional in extent although the visual manifestations of these (e.g. foams or slicks) may not be present.

Therefore, the presence of decaying seaweed or *Phaeocystis* foams should be considered as a potential source of FIOs and also investigated as a reason for non-compliant samples. This may require that samplers record details of such occurrences and even take samples of foam and/or seaweed samples at the time compliance samples are collected, or the rapid-follow-up of non-compliant samples with sampling of the foam/seaweed if still present after results are reported.

5.1 Recommendations

1. The research described herein has demonstrated that both *Phaeocystis* related foam and beach-cast seaweed can act as reservoirs of faecal indicator organisms and may also act as a mechanism to concentrate FIOs or potentially allow regrowth in the environment. However, the processes and mechanisms for generating these high concentrations are not well understood and further investigations, perhaps through both *in-situ* opportunistic study of deposits and through the use of microcosms, could lead to further understanding of the contribution decaying seaweed and/or decaying *Phaeocystis* blooms.

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