South Walney Lagoons: Species Composition Monitoring

Final Report

First published November 2021

Natural England Commissioned Report NECR398

Natural England Commissioned Report NECR398

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N. Bhatia & A. Franco

Published November 2021

ISBN: 978-1-78354-887-3

Project details

This report should be cited as: Bhatia, N. Franco, A. (2014). South Walney Lagoons: Species Composition Monitoring. A scientific report from the Institute of Estuarine and Coastal Studies, University of Hull to Natural England.

Natural England Project manager

Holly Latham

Contractor

Institute of Estuarine & Coastal Studies (IECS)

The University of Hull, Cottingham Road, Hull, HU6 7RX

iecs@hull.ac.uk

Author

N. Bhatia & A. Franco

Keywords

South Walney, coastal lagoons, biodiversity, communities, coasts, monitoring

Further information

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Acknowledgements

The Authors would like to thank **Mike Bailey** (IECS Estuarine Taxonomist & Benthic Survey Coordinator) and **Will Musk** (IECS Senior Marine Taxonomist) for their contribution in the fieldwork and laboratory phases of the project, and **Shona Thomson** (IECS GIS & Coastal Geographer) for undertaking the mapping requirements.

Thanks also to **Liz Hewitt** (Laboratory Manager at HEBOG Environmental) and the **National Laboratory Service** (Environment Agency) for undertaking the providing the data from the analysis of benthic, sediment and water samples collected at the study site.

the INSTITUTE of ESTUARINE and COASTAL STUDIES

South Walney lagoons: species composition monitoring.

Final Report

Report to Natural England

Institute of Estuarine and Coastal Studies
University of Hull

12th March 2014

Author(s): N. Bhatia & A. Franco

Report: YBB224-F1-2014

Institute of Estuarine & Coastal Studies (IECS)
The University of Hull
Cottingham Road
Hull
HU6 7RX
UK

Tel: +44 (0)1482 464120
Fax: +44 (0)1482 464130

E-mail: iecs@hull.ac.uk

Web site: http://www.hull.ac.uk/iecs

UNIVERSITY OF Hull
Institute of Estuarine and Coastal Studies

Document control

Title:	South Walney lagoons: species composition monitoring.
Report No.:	YBB224-F1-2014
Version:	F1
Status:	Final
Issue date:	12th March 2014
Client name:	Natural England
Client contact:	Margaret Street

Report QA	Name	Position	Signature	Date
Written by	Natasha Bhatia	Estuarine Ecologist		13/02/2014
Checked by	Anita Franco	Senior Estuarine and Coastal Fish Ecologist		21/02/201413/02/14
Approved by	Anita Franco	Senior Estuarine and Coastal Fish Ecologist & IECS Project Manager		21/02/2014

Version and approval history

Report date	Version	Status	Reviewed by	Organisation	Date
21/02/2014	D1	Draft Report	A Franco	IECS	21/02/2014
06/03/2014	F1	Final Report	Margaret Street Anita Franco	Natural England IECS	12/03/2014

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1. INTRODUCTION

1.1 Background

The Institute of Estuarine and Coastal Studies (IECS) was commissioned by Natural England to undertake a condition monitoring study to establish the current species composition of the South Walney lagoons near Morecambe Bay and, where possible, to comparatively analyse the condition of the communities against those identified in previous studies.

Morecambe Bay is the largest continuous intertidal area in Britain, covering an area of 310km^2 and comprising several areas of ecological interest, including intertidal mudflats and sandflats (Figure 1). It is designated as a Special Area of Conservation (SAC) under the Habitats Directive[1] (Natural England, 2012a), Special Protection Area (SPA) under the Birds Directive[2] (Natural England 2012b), Site of Special Scientific Interest (SSSI- along with South Walney and Piel Channel Flats), and Ramsar site (Figure 2). The intertidal and subtidal parts of these designations form the Morecambe Bay European Marine Site (EMS), and the Bay is recognised as an internationally important area supporting seabird and waterfowl populations (Morecambe Bay Partnership, 2012). As such, Natural England has a statutory duty to monitor and assess the condition of the intertidal features of the bay, such as the lagoon system at South Walney, in order to report on conservation status and assessment of condition.

Coastal saline lagoon ecosystems are of significant value to nature conservation due to the rarity in habitat and specialist species which they support, and are protected through a number of national and international wildlife designations (Bamber, 2010). The South Walney lagoons are located within the Morecambe Bay Special Area of Conservation (SAC), Morecambe Bay Special Protection Area (SPA) and Morecambe Bay Ramsar site; these comprise the Morecambe Bay European Marine Site (EMS) (Figure 2 and 3). The site is located within the South Walney and Piel Channel Flats Site of Special Scientific Interest (SSSI) and is also a Cumbria Wildlife Trust Nature Reserve.

The coastal lagoon communities are a key sub-feature of the SAC large shallow inlets and bays feature. Coastal lagoons are bodies of water, natural or artificial, partially separated from the adjacent sea. The coastal lagoon system at South Walney includes 11 pools, containing soft sediments which support the macrophyte *Potamogeton pectinatus* and a range of other plant and animal species. These communities are fragile and contribute to the diversity of Morecambe Bay European Marine Site (EMS).

The coastal lagoon system was formed through gravel extraction which occurred on site until around 10 years ago. Many of the pools are currently utilised as part of an aquaculture facility (Seasalter (Walney) oyster farm) on site and the water flow, water quality and micro-algal

[1] Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora (commonly referred to as the ‘Habitats Directive’).

[2] Council Directive 79/409/EEC of 2 April 1979 on the Conservation of Wild Birds (commonly referred to as the ‘Birds Directive’).

communities are managed for the culture of Pacific oysters (*Crassostrea gigas*). The pools are connected to the sea through an outfall pipe in the north western corner of the complex and many are interconnected through a series of sluice gates. The connection to the sea is controlled by the aquaculture operator to maintain favourable conditions for micro-algal growth and artificial addition of nutrients occurs in some pools. Sea water also enters the pools by percolation through the sand and gravel substrata.

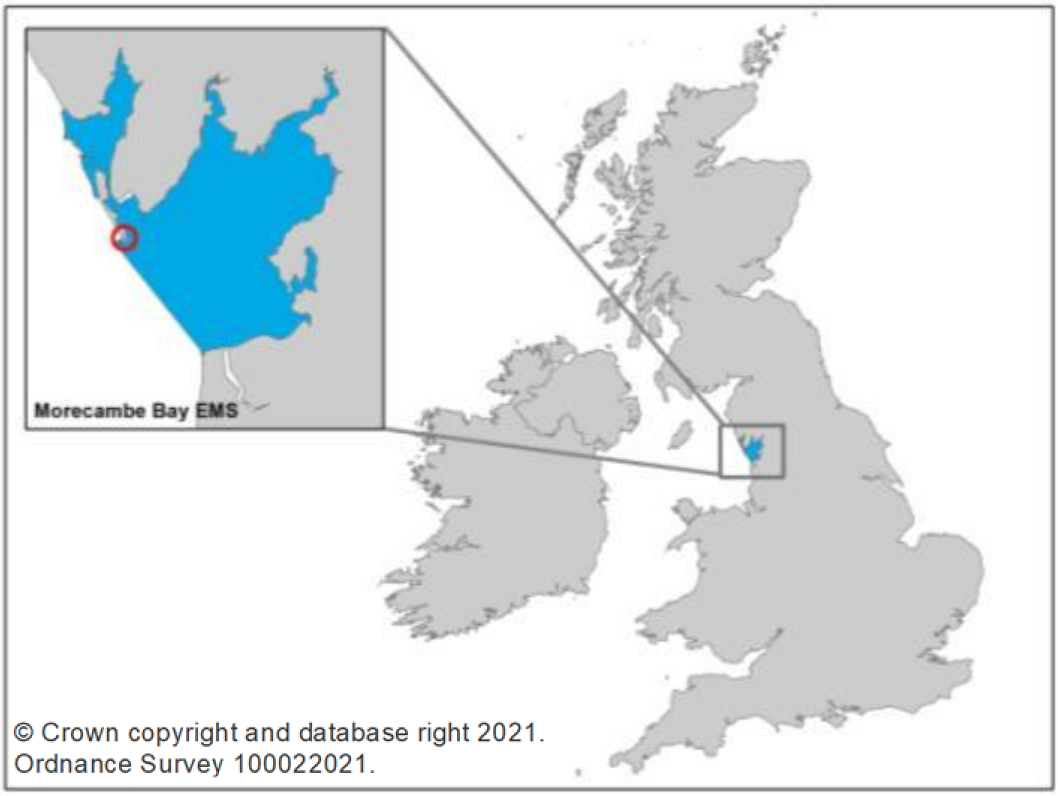

Figure 1. Location of Morecambe Bay European Marine Site within the UK. Red circle indicates the location of the South Walney lagoons system.

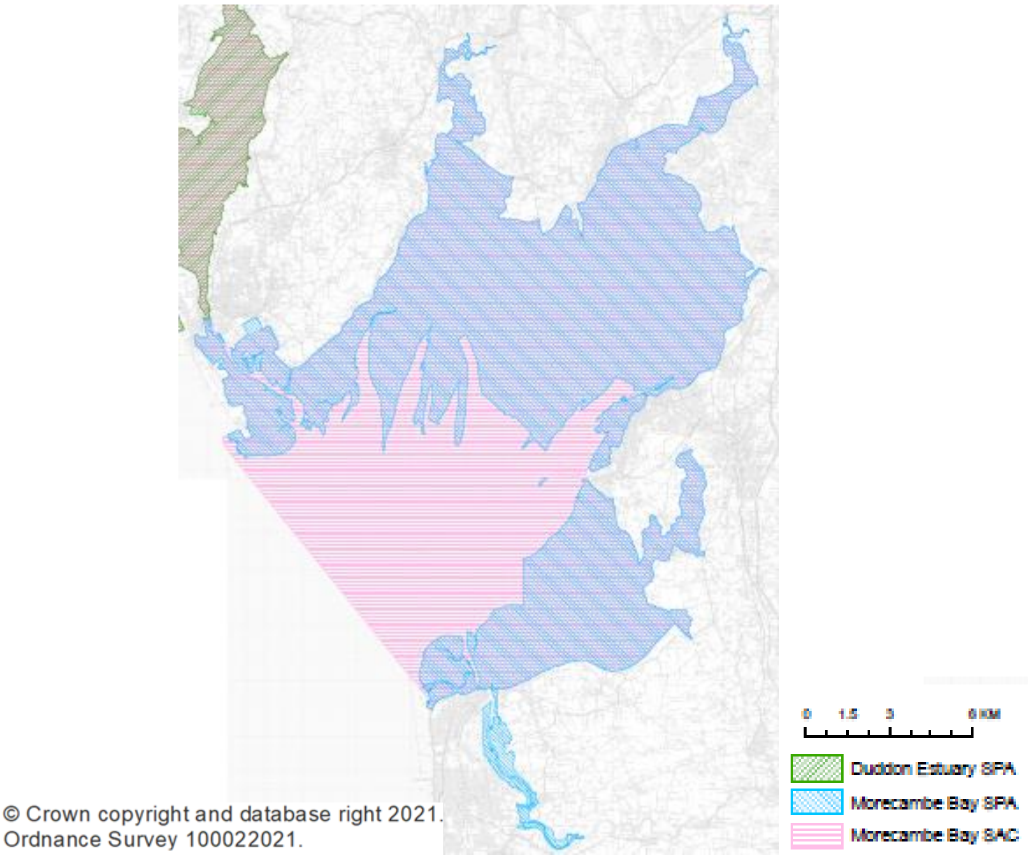

Figure 2. Map of Morecambe Bay including SAC and SPA boundaries.

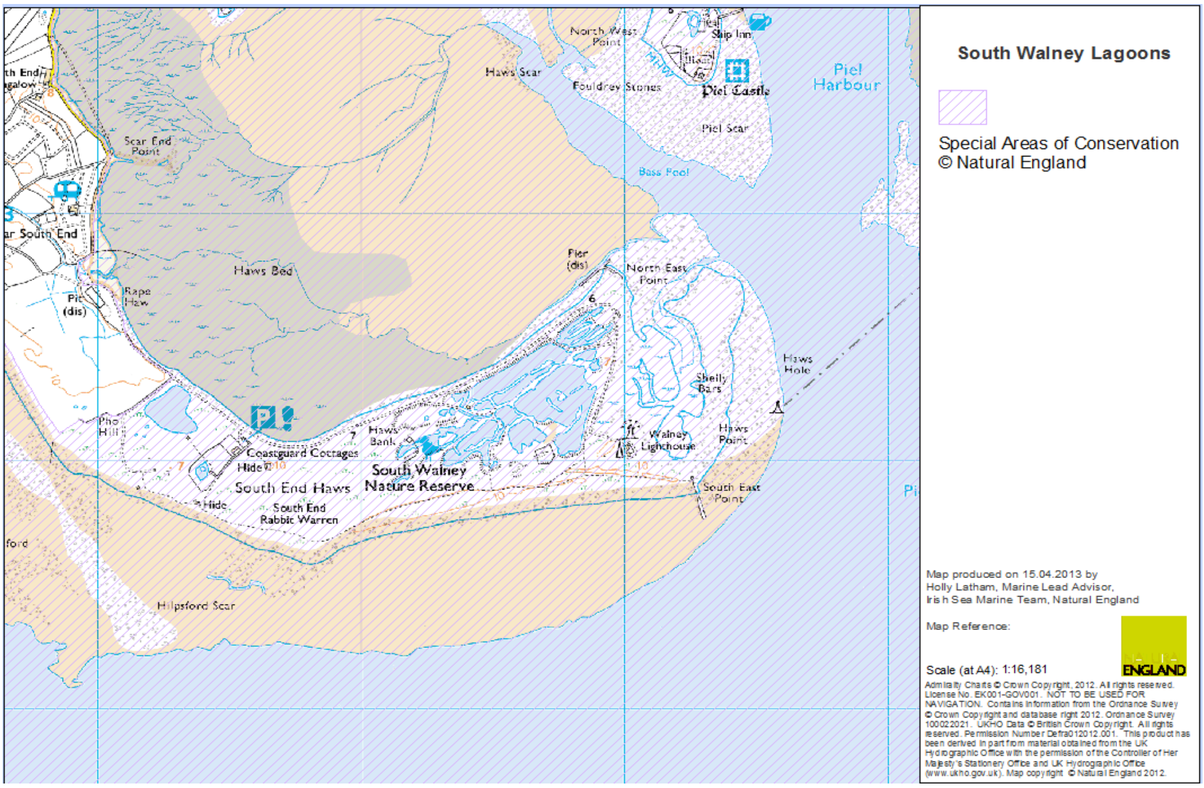

Figure 3. OS Map showing the location of the South Walney lagoons and the SAC designation boundary.

1.2 Previous surveys

The Nature Conservation Council (NCC) briefly surveyed the South Walney lagoons in the mid 1980s, as part of a nationwide assessment of the saline lagoon resource with salinity being recorded for most of pools (Hill et al., 1987). The NCC then conducted a comprehensive survey of the site in 1988 (Lumb, 1988), which concentrated on the central suite of lagoons surrounding the oyster farm (Pools 1 and 5 in Figure 4). Results showed Pool 1 to be the most saline of the five sampled, perhaps due to its proximity to the seawater inflow pipe. Species composition was identified as similar to those found in estuarine habitats, such as common shrimp *Crangon crangon* and the edible cockle *Cerastoderma edule*, which typically do not survive lagoonal conditions and were therefore considered as indicators of non-lagoonal habitat (Bamber *et al*., 2001). The remaining pools 2-5 had lower salinities, sometimes below the level ideal for sustaining lagoonal communities, as shown by the presence of the brackish macrophyte *Potamogeton pectinatus*. However, also present in the lower salinity pools were the lagoon specialists, amphipod *Monocorophium insidiosum* and bryozoan *Conopeum seurati*, suggesting that whilst Pool 1 was obtaining stochastic recruitment of estuarine species due to the inflow of seawater, the lower saline pools had the potential to develop typical lagoonal communities, if they were not suppressed by low salinities (Lumb, 1988; Bamber, 2001).

The South Walney lagoons were last comprehensively surveyed by the Natural History Museum in January 2001 in a report to English Nature, in which all 11 pools were surveyed for pool extent, salinity regime and water circulation, type of substratum and species composition (Bamber et al., 2001). Similarly to the results found in 1988, Pool 1 was found to have the highest salinity, due again to the saltwater flowing through the sluice, which resulted in the presence of echinoderms and tunicates such as *Ascidiella aspersa*, as well as sedimentary infaunal annelid worms such as *Tubificoides pseudogaster* in the samples. The presence of these species indicated a community more typical of estuarine rather than lagoonal environments, suggesting the movement of water from the inflow pipe was enough to prevent the development of a community more representative of lagoons. Of note in Pool 1 from this survey was the presence of amphipod *Gammarus chevreuxi*, as at the time the species had a restricted distribution, and this was the northernmost record. In contrast to Pool 1, Pools 2 to 7 were found to support communities characteristic of saline lagoons, including the specialist amphipod *M. insidiosum,* found commonly throughout Pools 2 to 8, the lagoonal isopod *Idotea chelipes* in Pool 7, and the lagoon cockle *Cerastoderma glaucum* in Pool 6.

Pool 8 differed slightly in species composition, although was still representative of a saline lagoon habitat. Species included a bed of the bryozoan *Conopeum seurati*, which in turn provided habitat for high densities of crustaceans such as *Palaemonetes varians* and *Jaera ischiosetosa*, and the lagoon specialist *I. chelipes*. Pools 9 and 11 had a lower salinity, and a species composition that reflected this, including the presence of insect larvae and Enchytraeidae annelid worms. Almost none of the species found in the other Pools were found in 9 or 11, and no lagoonal specialists were present.

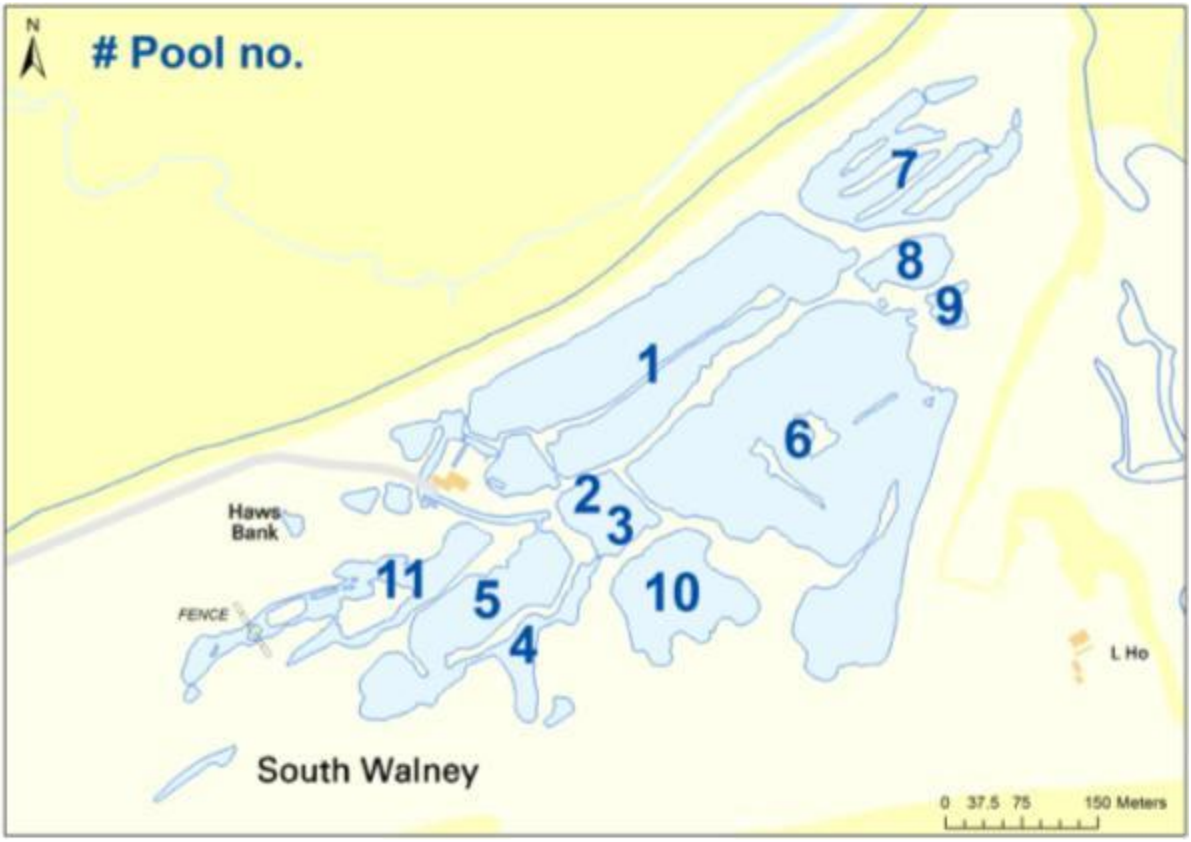

Figure 4. OS map of the South Walney lagoon system, with pools numbered following Lumb (1988) and Bamber et al. (2001). Note that in 2001 Pools 2 and 3 were partially separated by a spit.

1.3 Project aims and objectives

The main aim of this work is a condition monitoring study to establish the current species composition of the South Walney lagoons and, where possible, to comparatively analyse the condition of the communities against those identified in previous studies. The survey took into account attributes and techniques used by the previous surveys as well as those identified by Common Standards Monitoring (lagoons), Water Framework Directive (WFD) and National Marine Biological Analytical Control Scheme (NMBAQCS).

Regarding the methodology, it is important that a statistically rigorous monitoring programme is established, which can be used repeatedly in order to assess changes in lagoonal community composition and feature condition on a temporal scale; therefore providing a quantitative baseline data set which can be established for areas not previously surveyed, or not surveyed since 2001.

The objectives for the survey and report refer to the key attributes to be targeted by the survey methodology:

1. To provide baseline data for a series of attributes, including extent of basin and extent of water, condition of the isolating barrier, salinity regime, water depth, water inputs,

water quality, distribution of habitats[3], biotic composition (incl. species composition of representative or notable biotopes and, if possible, species population measures), human activities.

2. To establish the species composition of the lagoon communities within the South Walney lagoons through sampling:
   - Infaunal community;
   - Algal cover and associated epifauna;
   - Conspicuous nekton.
   -
3. To establish variation in physical and chemical factors which give context to the species composition within the lagoons:
   - Sediment granulometry;
   - Water depth;
   - Salinity;
   - Organic enrichment;
   - Nutrient enrichment;
   - Turbidity;
   - Contaminants.
   -

In order to meet these objectives, surveys were designed and conducted so that they:

- provided an assessment of the direction of ecological change by the integration of previously obtained relevant data;
- provided an ecological baseline for attribute condition (from which to assess future change);
- were suitably robust to enable the collection of compatible future data, permitting quantitative long term trend analysis;
- identified any anthropogenic influences that may influence the ability of the sub-feature to achieve Favourable Condition;
- attempted to collected data that were compatible (analytically) with historical survey data, or at least made reference to and utilised such historical data.

Considering the data available from the most comprehensive survey undertaken in 2001 (Bamber et al., 2001) (see Section 1.2), the data collected in 2013 were used either to assess changes compared to this existing baseline, or as a baseline for future comparison, as indicated in Table 1.

[3] As the distribution and extent of biotopes within the lagoon pools is likely to be difficult to determine, areas of different habitats (e.g. shallow sediment shelves) were to be identified as part of the detailed site descriptions wherever possible.

Table 1. Existing baseline monitoring data for attributes of the South Walney lagoons.

Attribute	Existing baseline
Extent	2001 (all pools, January; Bamber et al., 2001)
Isolating barrier	No previous assessement (2013 constitutes baseline)
Water inputs	2001 (all pools, January; Bamber et al., 2001)
Depth	2001 (all pools, January; Bamber et al., 2001)
Water circulation	2001 (all pools, January; Bamber et al., 2001)
Salinity regime	2001 (all pools, January; Bamber et al., 2001)
Substratum type	2001 (all pools, January; Bamber et al., 2001)
Nutrient enrichment	No previous assessement (2013 constitutes baseline)
Sediment contamination	No previous assessement (2013 constitutes baseline)
Species composition	2001 (all pools, January; Bamber et al., 2001)

2. SURVEY METHODOLOGY

Monitoring surveys at South Walney Lagoons were undertaken between the 6th and 10th of August 2013. Survey dates following periods of fine weather were targeted to maximise water clarity and enable the extent of submerged vegetation, features etc to be observed and recorded. The survey team was composed of 2 IECS staff (A. Franco, survey leader and project leader, and M. Bailey). On the third day of fieldwork, IECS staff was joined by one person from Natural England (L. Browning) who helped with the survey on that day.

Survey methods were as per survey plan (IECS, 2013). Where possible, similar techniques used in the 2001 survey were used in this survey, to aid comparison between the data sets[4]. However, minor modifications of sampling methodology/design were applied based on local constraints (details below). These modifications took into account the survey rationale in order to obtain high quality data and to allow fulfilment of the project's aims.

2.1 Survey design

In order to ensure thorough coverage of each pool, without excessive sampling, IECS used the sampling stations described in Bamber et al. (2001) as a guideline. Sampling stations were located based on the site map given in the 2001 monitoring report (Bamber et al. 2001) and pools were numbered accordingly for consistency (Figure 4). Location of sampling station, as per map, was initially targeted and final location was adjusted on site based on the actual observation of the habitats in adjacent areas (e.g., to match shallow water sandy stations with actual patches of sands along the margin).

This approach ensured each pool was sampled and samples were collected from representative habitats, with multiple stations surveyed in larger pools and single stations in smaller pools (Figure 5). Qualitative description of the habitat, physical parameters and biological samples were collected at the sampling stations (Table 2).

Twenty-seven stations overall were sampled in the pools for biological assemblages, with quantitative sampling of sediments collected by corer in shallow marginal stations (where the sediment type allowed coring) and grab in deeper stations. Nekton fauna was also sampled semi-quantitatively by means of a push net swept in marginal stations and, where aquatic vegetation was present, vegetation coverage was estimated by using 1m^2 quadrats and samples of epifauna were collected from the submerged vegetation (by washing 0.5L of seaweed). Further details on the methods are given in sections below.

Care was taken to minimise disturbance to waterbirds and wildlife associated with the site, and survey work was undertaken outside of the main breeding season for most bird species. Particular care and attention was taken to prevent disturbance to the breeding gull colony in

[4] It is of note however that the survey by the Natural History Museum (NHM) was conducted in January, whilst the survey by IECS was conducted in August, and therefore any differences between data sets could be due to the difference in season rather than changes that have occurred temporally. However, reasonable comparisons in community structure and physical-chemical characteristics between pools will be presented and described.

the vicinity of the lagoons. Therefore, if adult gulls with juveniles were observed in the direct path of the survey team, an alternative route to the proposed lagoon station was established, or alternatively the station was sampled later in the deployment.

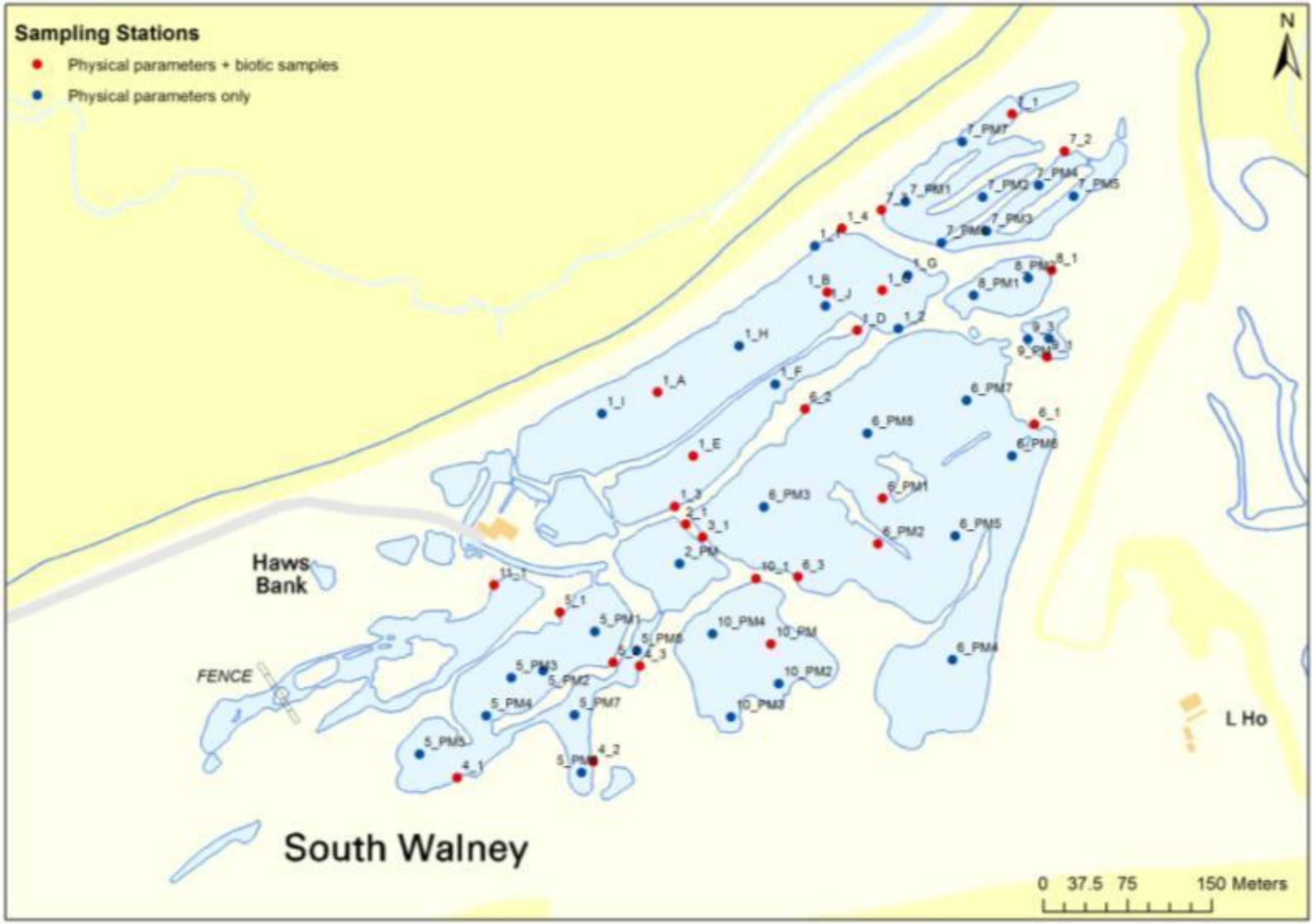

Figure 5. Location of sampling stations.

Table 2. Samples collected at each site (see Appendix I for additional details on sampling replication and habitat description).

	Samples collected					
Site	**Benthos**	**PSA**	**Contam-inant**	**Nekton**	**Vegetation**	**Epifauna**
1_3				x		
1_4					x	x
1_A	x	x				
1_B	x	x	x			
1_C	x	x				
1_D	x					
1_E	x	x				
2_1				x		
3_1			x	x		
4_1	x	x		x	x	x
4_2	x	x		x	x	x
4_3	x	x	x	x	x	
5_1	x	x		x	x	x
5_2	x	x	x	x	x	
6_1	x	x	x	x		
6_2				x		
6_3	x	x		x		
6_PM1	x	x				
6_PM2	x	x				
7_1	x	x	x	x		
7_2				x		
7_3				x		
8_1	x	x	x	x		
9_1	x	x	x	x	x	x
10_1				x		
10_PM	x	x	x			
11_1	x	x	x	x		

2.2 Sampling techniques

The survey was carried out in accordance with the technical specifications provided by NE, as directed by the Common Standards Monitoring and Water Framework Directive Guidance as well as the NMBAQC Scheme.

All sites were accessed on foot and samples collected from the edge of each lagoon or from shallow waters, as requested by Natural England, in order to reduce disturbance. Where deeper stations were to be surveyed, the sampling sites were accessed by using a small shore-launched canoe with paddles. This allowed safer access to sampling locations, while also reducing disturbance to the habitat due to wading and walking through the sediment and vegetation.

2.2.1 SITE DESCRIPTION

A detailed description of each pool including submerged vegetation (species, extent and condition), surface features, notable species and habitats was recorded with the aid of laminated maps and aerial photographs, which were annotated in the field. The main habitats and substrata of the pools were described as well as the fringing habitats.

Mapping boundaries, including the extent of the basin, were initially undertaken using aerial photographs, however, onsite monitoring was undertaken to confirm the extent of the basin and water level. Where access allowed, a dGPS (Magellan Professional CX ±1m accuracy) was used to mark spot positions along the basin and water margins (if different). These positions were superimposed onto the aerial photographs to enable the extent of the lagoon system to be determined, as well as the percentage covered by water and potential changes over time.

Relevant morphological attributes of the site at the time of the survey were noted in order to provide a detailed description of the management of water flow between the pools. These details included level of the water, presence of bare mud and direction of flow (if any), likely direction of seawater input, presence of freshwater inflow, built structures and nature of adjacent habitats. The evidence of any areas of disturbance/relevant pressure, human activities, status of the surrounding embankments and of the sluice and ditches was also recorded. Further information n water circulation and management and previous conditions of the pools were obtained from the oyster farm staff present on site.

Photographs of the site and each sampling location were taken and photograph numbers recorded simultaneously with position, site number and date. The photographs were relabelled immediately upon return to the laboratory to ensure they can readily be linked to a particular site or sample.

A full survey log was maintained throughout the survey detailing time of sampling, position (dGPS derived), station and station number (replicate), water depth, physical characteristics of the sample, texture and presence of surface features, RPD layer (cm), digital image number and/or time (cross referencing (QA)), climatic conditions and any other notable features.

2.2.2 BENTHIC INVERTEBRATES

Nineteen stations were sampled for benthic invertebrates in the lagoons (Figure 5, Table 2, Appendix I). A standard size corer (11 cm internal diameter, 0.01m^2 area) was used to take core samples[5] in shallow (marginal) areas. This size corer is commonly used in shallow and intertidal coastal and estuarine habitats, and could be efficiently used in stations with coarser sediments was used also in the other shallow stations for standardisation of methods. Five replicates per station were taken to achieve a total sampled area of 0.05m^2, as required by the survey specifications. Core samples for infaunal analysis and particle size analysis were taken to a depth of 10 cm in the sediment (where possible). At deeper sites a 0.025m^2 Ekman grab was used to collect 2 replicate samples at each site so that the total area sampled at

[5] The original methods stated a small corer (8cm internal diameter, 0.005m^2 area) was to be used, however due to lack of market availability one could not be obtained, and the samples were attempted using a pipe of the same diameter, as employed in other lagoon monitoring programmes (R. Bamber, pers. comm..). In the field, it became apparent the pipe was not suitable for sampling as it could not effectively penetrate the coarser substrata and could not take a full sample at each station. Therefore in order to standardise sample size, the decision was made to use a standard size corer. Five replicates instead of ten were then taken, so the required sample area of 0.05m^2 was still achieved, without increasing disturbance of the site.

shallow sites and deeper sites was comparable. All infaunal samples were sieved on site in close proximity to the sample location, therefore ensuring any specimens passing through the sieve were returned to the original collection site. The replicate samples were sieved separately through a 0.5mm mesh and sieve residual preserved in stained formalin (4% formaldehyde) solution, as per survey plan.

All samples were sent to HEBOG Environmental for analysis, including taxonomical identification (to the species level, where possible) and species abundance measurement. HEBOG Environmental's standard operating procedure followed the internal AQC procedures outlined in the NMBAQC scheme Guidelines for Processing Marine Macrobenthic Invertebrate Samples: a processing requirements protocol (2010) and conformed to EN ISO 16665:2005 and BS EN 14996:2006. The member of staff involved in laboratory management including overseeing the analysis of samples and designated quality controller was Liz Hewitt.

2.2.3 Nekton

Nineteen marginal stations were sampled semi-quantitatively for nekton in the lagoons (Figure 5, Table 2, Appendix I). A push net 0.25m wide, with mesh size 250um was swept 5 metres, with 3 replicate sweeps taken and a total swept area of 3.75m^2 per station[6]. The sampling area was standardised (1.25m^2) per sweep and the abundance was calculated as density to allow comparison with other data. This method allowed the characterisation of nektonic fauna, particularly on substrata unsuitable for coring (e.g., cobbles). Where possible, the catch was identified in situ, recorded, photographed and returned to the water body alive. Where in situ identification was not possible, samples were taken and preserved in stained formalin (4% formaldehyde) solution until identification was carried out at IECS laboratory.

2.2.4 Algal cover and associated epifauna

At stations where aquatic vegetation was present (Figure 5, Table 2, Appendix I), a 1m^2 quadrat was used to assess the submerged vegetation coverage (including algae) at the site. Vegetation was identified and percentage coverage recorded, along with an overall visual assessment.

The epifauna associated to submerged vegetation was assessed by collecting 3 replicate samples at stations where conspicuous vegetation was present. A fixed volume (0.5L[7]) of seaweed (*Enteromorpha* in most of cases) was washed gently on a 0.5mm sieve and the sieve

[6] A push net 0.5m wide, 0.5mm mesh size was used initially, however damage on pebbles/boulders in the field resulted in irreparable damage, and therefore a smaller replacement push net was used, rather than discontinuing the nekton sampling. To achieve total swept area of 7.5m^2 (as per original survey plan), 3 x 10m sweeps should have been undertaken, but this would have resulted in walking on the shallow habitat for longer transects and consequently causing higher disturbance

[7] It was observed that taking 1L bucket of seaweed for washing and sieving (as per original plan) would have caused a high defloration over a large area in several sampling stations with high potential disturbance, therefore sampling volume was standardised to 0.5L to avoid excessive disturbance at the sites.

residual preserved in formalin solution for identification in the IECS laboratory. When possible, identification was carried out on site, and some specimens for ID confirmation were kept; however, in some cases, numerous very small organisms were present that could not be identified in situ and the whole sample was kept for counting and identification. Abundance categories were defined and an adapted version of the SACFOR scale was applied based on density (numbers per volume of washed seaweed) to allow comparison with future data.

2.2.5 Physical and chemical factors

Depth and vertical profiles of salinity, water temperature, turbidity and dissolved oxygen were measured at deeper station, with additional measurements of salinity and depth taken at the marginal stations (Figure 5). A Hydrolab Quanta Water Quality Monitoring System (Salinity accuracy +/- 1% of reading +/- 1 count, Resolution 0.01 PSS) was used.

Water samples were collected from marginal and deeper stations at the studied pools samples for dissolved inorganic nutrient analysis. Two samples (one at surface and one at bottom) were obtained from deeper stations, whereas in shallow stations (where depth was usually <30cm), only one sample was obtained from the water column. The water samples were filtered on site and preserved following standard methodologies and guidelines provided by the National Laboratory Service (NLS, Environment Agency). Samples were subsequent analysed by the NLS.

One additional sediment sample was collected from each benthic station for Particle Size Analysis (PSA) and Total Organic Carbon (TOC) analysis. Sediment samples for contaminants analysis were also collected (one station per pool), as per survey plan. Samples for sediment contaminant analysis were collected on site by scraping the surface layer[8] of sediments in core and grab samples. Sample methodologies and handling guidelines were provided by the National Laboratory Service, who processed the samples.

[8] Due to the presence of anoxic conditions to the sediment surface in deeper areas, sediments were collected from shallow stations when both shallow and deep sampling stations were identified in a lagoon.

3. RESULTS

In contrast to what was reported during the previous monitoring survey (in January 2001), the pools where highly vegetated (some more than others), with *Enteromorpha* usually abundant in sheltered areas, and also *Chaetomorpha* observed in Pool 1. Filamentous algae of the family Cladophoraceae[9] were also present in some places (Appendix I). Mats of diatoms were observed covering sediment and boulders, particularly in lower salinity pools, e.g., 11, 8, 9, 7.

The lagoon shores were predominantly a mixture of pebbles and boulders, with localised patches of sand. Sediments were generally anoxic, particularly those taken in deeper stations. However, also in shallow core samples, RPD surface layer was never >1cm deep.

Information obtained from the oyster farm staff indicated that unusually high water temperatures were recorded at the pools during the summer months 2013 (up to 26 degrees Celsius), with associated algal blooms, oxygen depletion and consequent mortalities of oysters. Therefore, the lagoons were flushed more often by allowing intake of sea water from the outfall during high tides in order to deplete algal cover and increase oxygenation. Enquiries were made about records of salinity and nutrients at the pools during the previous year. No regular records are kept, and, from an examination of the log book, no recent records were found.

3.1 The Pools

There are 11 main pools that comprise the lagoon system at South Walney. At high tide, seawater enters a sluice pool controlled by the nearby oyster farm, via inflow pipes opened at low shore during high tide. From the sluice pool, seawater flows directly into Pool 1 and circulates through pools 2, 3, 4 and 5 as shown in Figure 6. An open drain is also present between Pool 1 and 6[10] (Figure 6). Although a narrow stream providing Pool 5 with low salinity water from Pool 11 was reported previously (Bamber et al. 2001), this could not be detected in 2013. Pools 7-11are isolated, with water exchanges occurring via groundwater percolation.

Features that were common to all pools in 2001 included: uniform salinity within each pool without stratification even with turbulence caused by wind, a lack of observed nekton, and a lack of submerged plants. In the 2013 survey as in 2001, in general salinity only differed slightly within pools, with greater differences observed between pools. However greater numbers of nekton and a much greater algal coverage (in particular *Enteromorpha*) were observed throughout the lagoonal system, as well as vertical stratification of water quality parameters in certain pools. These differences from conditions observed in 2011 are likely due to the difference in seasonality of the two surveys.

[9] A more detailed identification was not possible on site as microscopic examination would have been needed.

[10] An old intake (from Pool 6 to Pool 1) is present also near the western corner of Pool 6, but, according to information obtained from the oyster farm staff, this is not used anymore.

pH levels found throughout the lagoon system were higher than those expected of seawater, with the large majority being between 9 and 9.9, with seawater tending to average around 7.6.

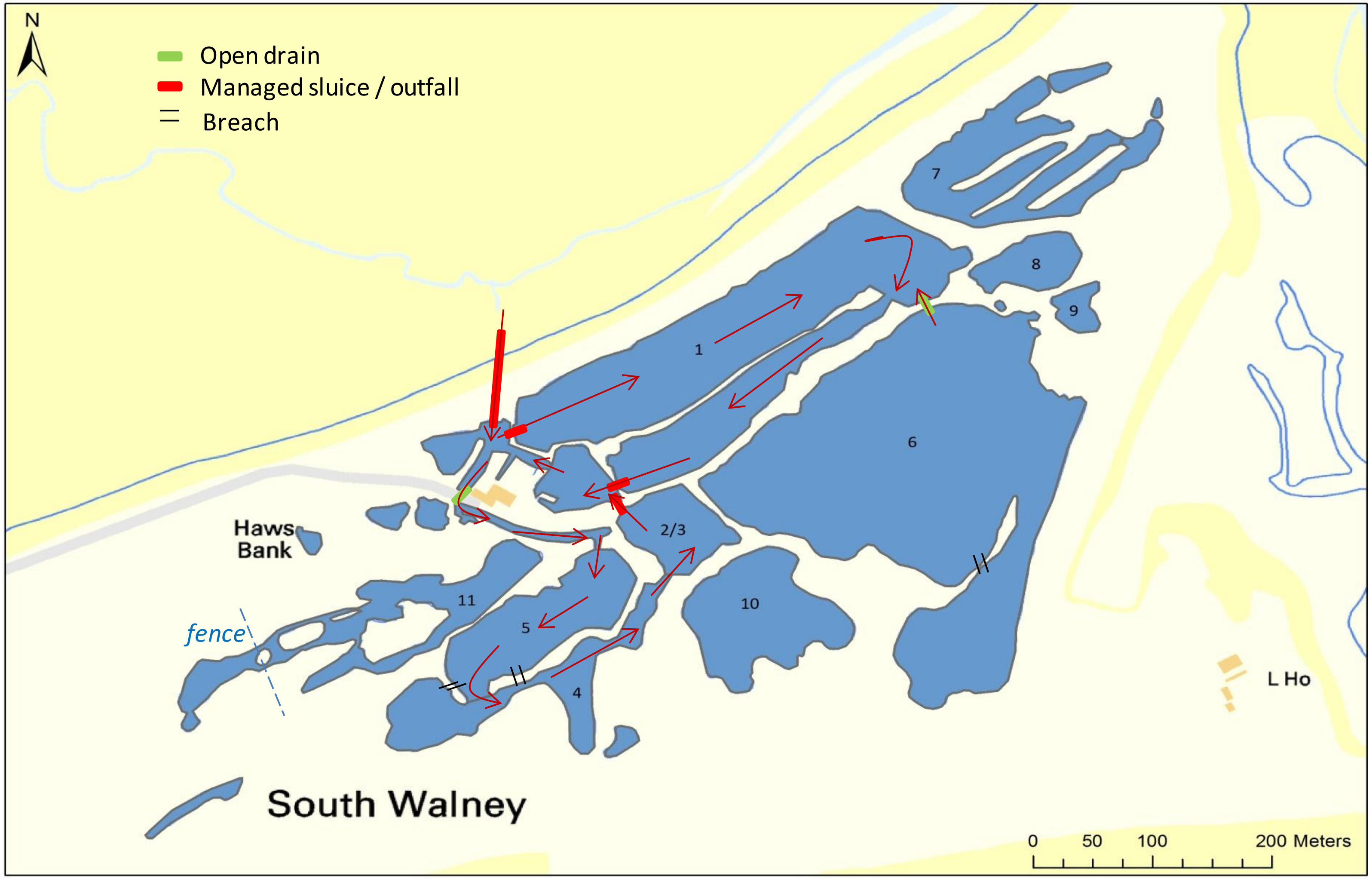

Figure 6. Water circulation and sluices/drains location in the pools. Lagoons numbered as referred to in text.

Here below a general description of the environment observed at each pool is given. Further details on results from sampling of biotic assemblages and abiotic attributes of the lagoons are given in sections 3.2 to 3.4.

3.1.1 POOL 1

Pool 1 is fed seawater from the sluice pool controlled by the oyster farm on the western side of the pool and water circulation is as shown in Figure 6. An open drain was observed connecting Pool 1 and 6 near the eastern corner of this latter pool, with an intake of less saline water from Pool 6[11] (Figure 6). Pool 1 is configured into two arms, divided throughout the majority of their length by a narrow embankment covered in vegetation. The shoreline around the Pool generally consisted of grassy vegetation with scattered rocks and pebbles, before transitioning into finer sediment with attached algal coverage, mostly represented by *Enteromorpha* and *Chaetomorpha* (Plate 1 and 2).

Plate 1. North (left) and South (right) arms of Pool 1 with dividing embankment.

Plate 2. Shoreline around Pool 1 showing vegetation, pebbles and algal coverage.

The surface area extent[12] of Pool 1 in 2013 is 4.13ha, in comparison to 4.17ha recorded in 2001 (Bamber *et al*., 2001). Depth was 4.5m at the deepest point (station 1.E, Figure 5) with depth increasing from few centimetres at the lagoon margins to values ranging 1.1 to 2.6m in the other non-marginal stations. Water temperature was 18.2°C on average, ranging between 16.4 and 19.6°C along the vertical profile (Appendix II-A). Throughout the pool, salinity increased with depth, with a mean surface value of 29.7 (ranging 24.8 to 31.9) and values at the bottom (in stations deeper than 1m) ranging from 30.8 to just under 33 at the deepest part of station 1-A (approx 2.5m) (Appendix II-B). This salinity stratification is likely the result of the

[11] Salinity measured right in front of the open drain in Pool 1 was 20.

[12] Where no further indication is given, basin and water extent were the same.

input of more saline waters from the Walney Channel (33.6)[13]. A general decrease in salinity at the surface is also observed between the northern arm of the Pool (stations 1-A, 1-B, 1-H, 1-I, with a mean salinity of 31.7) and its southern and eastern areas (stations 1-A, 1-B, 1-H, 1-I, with a mean salinity of 27.8) (Figure 5, Appendix II). This is most likely the result of the mixing with more fresh waters flowing into Pool 1 from Pool 6 through the open drain near the eastern corner of Pool 1 (Figure 6).

Dissolved oxygen (DO) content tended to decrease with depth, with mean saturation value at surface being approx. 100%, and values at the bottom (stations >1.5m deep) ranging 49.4 to 182.7%[14] (Appendix I-C). Average water turbidity was generally low in the lagoon (ranging 0.9 to 14.6 NTU, 5.35 NTU on average[15]) (Appendix I-D).

3.1.2 POOLS 2 & 3

In contrast to previous maps showing a partial separation between Pools 2 and 3, in 2013 these two pools were connected to essentially form one large pool (Figure 6). In 2001, the cumulative area of Pools 2 and 3 was recorded as 0.49ha (Bamber *et al*., 2001), with the extent increasing to 0.79ha in 2013 with the disappearance of the separating spit. The margins are mostly steep surrounding the pool, covered by rough grassland interspersed with *Atriplex spp*. and ragwort in places (Plate 3). Dense patches of boulders and pebbles line the shore, which on the north side are slightly encrusted with epiphytes (Plate 4). Small patches of sand covered the boulders in places on the east side of the pool, with *Enteromorpha spp.* attached to the substratum, but generally a thin layer of sediment (max 5cm deep) was present[16]. A sandy patch was present also on the western corner, near the sluice (Figure 6), where *Arenicola* casts were observed, but this area could not be accessed for sampling due to the steep margin.

The depth of Pool 2/3 was 3.9m at the deepest point recorded. Mean water temperature was 17.7°C, with only minor changes observed along the depth profile (0.7°C) and on the water surface (17.5 to 18.6 °C). Salinity ranged between 29.9 and 31.5 at the surface (mean 30.9), with a maximum value of 31.5 recorded at the bottom of the deeper station. A similar pattern

[13] Other water quality characteristics recorded from the Walney Channel were: water temperature 18.4°C, pH 9.0, oxygen saturation between 96 and 102%, turbidity 9-10NTU.

[14] It is of note that deepest readings showed higher values than the previous shallower reading in most cases. This anomaly is likely due to sampling technique, as the instrument was lowered from the side of a boat in the deeper sections of the pool until it reached the bottom. It is speculated that whilst care was taken to disturb the benthos bottom as little as possible, it is this slight disturbance that may have caused a fluctuation in the bottom dissolved oxygen readings. This seems confirmed by higher turbidity values that were generally recorded in bottom readings (Appendix II-D).

[15] These values do not take into account higher turbidity readings at the bottom, likely affected by sediment disturbance with the sonde (Appendix II-D).

[16] For this reason core samples could not be taken from stations 2-1 and 3-1.

was seen with regard to pH, which at the surface ranged between 9.13 and 9.23, and decreased gradually from 9.23 to 9.17 with depth (Appendix II).

At the surface, DO saturation was higher at station 3-1 (149.8%) than it was at stations 2-1 or 2-PM (111.7% and 93.6% respectively), with also higher mean turbidity values being recorded at 3-1 (2.2 NTU) compared to 2-1 and 2-PM (both 0.4 NTU) (Appendix II-D).

Plate 3. Pool 2/3, North margin from North corner. Steep sides with grasses, *Atriplex spp*. and ragwort.

Plate 4. Pool 2/3, Epiphytes attached to boulders. Small tufts of *Enteromorpha* are also visible.

3.1.3 Pools 4 & 5

Pool 4 and 5 are separated lengthways by a thin densely vegetated margin, connected on their western side (Figure 6). The dividing margin is commonly accessed by animals, as indicated by the cow and other mammal excrement, as well as crushed shells from birds feeding observed on site. Two breaches were noted between the pools, one connecting the southern edge of Pool 5 to the northern edge of Pool 4, and another which dissects an offshoot margin encroaching from the northern side (Figure 6). Pool 5 is connected to the sluiced pool where sea water inflow occurs through a channel, and a water flow from Pool 5 to Pool 4 and from this into Pool 2 (through a connection on the eastern margin) was observed during the survey. The margins surrounding Pools 4 and 5 tended to be steep and highly vegetated (Plate 5), with less boulder coverage than seen in Pools 1 to 3. Where pebbles did occur, they were abundantly covered in filamentous algae and epiphytes (Plate 6) and intermittently areas of sand and fine sediment were amongst smaller pebbles around the outside margins of both pools, with evidence of *Arenicola* casts and black anoxic sediment visible from the surface (Plate 7).

Pool 4 had an area of 0.93ha, similar to the extent recorded previously (Bamber et al., 2001). Depth increased from marginal areas (20-30cm) to a maximum of 2.3m recorded at station 5-PM7 and values between 1.2 and 1.8m measured at other deep stations in this pool. Pool 5 had an area of 0.97ha, with the deepest point (5.7m) measured at station 5-PM3 and values ranging 1.4 to 2.7m in the other non-marginal stations.

The mean water temperature of Pools 4 and 5 was 19.5°C, with surface values ranging overall between 18.2 and 20.9°C (mean surface values 19.4 and 20.3°C at Pool 4 and 5 respectively). At pool 5, where deeper areas occurred, a small but continuous temperature decrease with depth was observed, with bottom temperatures (at depth >1m) around 19°C (Appendix II-A). Salinity had a small variability at the surface, ranging between 31.1 and 31.8 across the two pools. As with temperature, salinity generally changed very little at the shallower stations, and increased slightly and gradually with depth, reaching approximately 33 at its deepest point (station 5-PM3) (Appendix II-B).

pH varied very little across the surface of Pool 4 and 5, ranging between 8.9 and 9.3. DO saturation levels ranged from 93.6 to 129.1% over the surface of Pool 4 and 5 (with mean surface values of 109 and 120% respectively). Where deeper stations were surveyed, DO saturation showed only minor changes with depth, with values always >100%. Only at the deepest station in Pool 5 (5-PM3, 5.7m) a noticeable decline in water oxygenation occurred between approximately 2 and 4 metres depth, with the lowest saturation value of 26.2% measured near the bottom[17] (Appendix II-C).

Plate 5. Pool 4 with vegetated margins. Looking SW from eastern corner.

Plate 6. Attached algae to pebbles below the margin, Pool 4 southern margin.

[17] An anomaly in the pattern seems to occur at the deepest reading from 5-PM3, where DO content rises steeply from 26.2 to 64.6%sat, which is mimicked in the turbidity readings, which also see a dramatic rise from penultimate reading to last reading (Appendix II-D). This again suggests the sediment at the bottom was disturbed and caused a fluctuation in the DO results. However, if this is the case, these fluctuations in turbidity also occur at the shallower stations in Pool 5, without having the same effect on their corresponding DO measurements. This could be caused by sediments at the shallower stations being disturbed more frequently than at the deeper stations, so any ‘trapped’ oxygen has already been released.

Plate 7. Small stones and fine sediment with visible anoxic layer. Sample 4.4, NE corner.

3.1.4 POOL 6

Pool 6 was once known as "Lighthouse Pond" and was reconfigured in 2000 with the aim of developing bird conservation habitat, with floating pontoons still present on the pool to provide areas for birds. It is the largest basin of the system, with an extent of 6ha measured in 2013. Previously, when the water in this pool had a lower salinity than presently, water was pumped from Pool 6 into Pool 1 in order to control salinity in Pool 1 (Bamber *et al*., 2001). However the salinity in Pool 6 has since increased and the old intake at the western corner is no longer active. It is of note however that an open drain was present near the eastern corner, with water flowing freely from Pool 6 to Pool 1 (Figure 6).

The margins around Pool 6 are all well vegetated with grasses, *Glaux maritima* and *Salicornia* spp., and where areas are more exposed, cobbles and pebbles are present below the water line where the margin banks are steep (Plate 8), and in a wide band along the water line where the margin banks are shallower (Plate 9). Where the margins are more sheltered, fewer cobbles and pebbles were seen, patches of fine sandy sediments were seen instead, with few scattered stones.

The depth at station 6-PM8 (4.5m), was the highest value recorded, with depth increasing from few centimetres at the lagoon margins to values ranging 1.5 to 3.3m in the other non-marginal stations. Mean water temperature in this pool was 18.8°C, with values across the surface ranging from 18°C to 21.3°C (20.4°C on average) and a steady decrease with depth (with bottom temperatures at stations deeper than 1m ranging 17.5 to 17.6°C) (Appendix II-A). Salinity was lower compared to the pools previously described, with an overall mean of 16.8, and very uniform values measured across the surface and through the water column, with all salinity readings between 16 and 17, apart from the surface reading at station 6-PM2, which was 15.7 (Appendix II-B). pH readings were also similar regardless of position within the pool, all ranged between 9.5 and 9.8 (Appendix II-E).

Plate 8. Submerged cobbles/pebbles where banks are steeper, with *G. maritima* and *Salicornia spp*., Pool 6 NW margin.

Plate 9. Cobble/ pebbles along water line where banks are shallower. Pool 6 NE margin.

Results from the DO and turbidity readings again appeared to be related, as in most cases, both showed a steady decrease with depth until the last reading, which again is thought to be as an unavoidable result of sampling technique. Oxygen saturation levels ranged 112 to 125.4% at the surface (with a mean of 127%), and a general decrease in water oxygenation was observed with depth, with the minimum value of 86.5 recorded near the bottom at the deepest station 6-PM8 (Appendix II-C).

3.1.5 Pool 7

Located in the North East corner of the lagoon system, Pool 7 is comprised of five thin basins separated by two steep vegetated margins, and two margins made from concrete bricks, enduring from a military construction which was abandoned before completion and dismantled (Plate 10). The basins are all connected on the western edge of the Pool (Figure 6), with an overall basin extent of 1.33ha (similar to the area of 1.35ha observed by Bamber et al., 2001). None of the shorelines below the margins were completely covered in water, and where margins were shallower, pebbles and cobbles were exposed for approximately 70cm from the margin. The density of algal and epiphytic coverage of the sediment was also much lighter than that seen in other pools, with submerged vegetation identified as *Suaeda maritima* (Annual seablite) found sparsely (Plate 11). The pool is isolated from the sea and other pools, hence any water exchange would occur by percolation through the margins.

The greatest depth recorded at Pool 7 was 2.8m at station 7-PM2, with depth values ranging from few centimetres at marginal stations and at some central stations (particularly at the western edge where the lagoon basins are connected) to values around 2m in other deeper stations. Temperature throughout the pool did not fluctuate greatly, with surface temperatures ranging from 18.3 to 19.9°C (mean 18.8°C). Temperatures did not differ largely throughout the water column for most of the stations, with values generally <20°C (Appendix II-A).

The mean salinity of Pool 7 was 17.7, with values between 16.9 and 17.8 at the surface and values ranging between 17.1 and 18.6 near the bottom at deeper stations (Appendix II-B). pH was recorded between 9.16 and 9.46 at the surface, decreasing slowly and gradually with depth in most cases, however at 7-PM5 the difference in pH decreased at a larger rate than seen in other stations, from 9.39 to 8.82 (Appendix II-E).

Plate 10. Northernmost basins, separated by concrete blocks. Pool 7.

Plate 11. *S. maritima* on Western margin. Pool 7.

Water oxygen saturation ranged between 87.2 and 115.4% at the surface. Through the water column, DO fluctuates somewhat, decreasing and then increasing again with depth (Appendix II-C). It is suggested these fluctuations are due to variable water mixing caused by the windy conditions.

4.1.6 Pool 8

Pool 8 was one of the smallest pools of the system, with an area of 0.33ha, similar to that recorded previously (Bamber et al., 2001). Greater turbidity was seen in Pool 8, thus leading to lower visibility below the surface of the water. In addition, access was inhibited along the northern margin, and therefore information was gathered from the margins that could be accessed, on the eastern, southern and western edges. The western margin formed a gentle slope, with good vegetation coverage including Sea milkwort (*Glaux maritima*) and a large pebble and boulder shore (Plate 12). The south margin was steeper in places, with larger boulders present to the water line (Plate 13). In contrast, no pebbles or cobbles were visible from the eastern margin, which transitioned from a steep, vegetated margin to fine sand with patches of Sea club-rush (*Scirpus maritimus*) on the shoreline (Plate 14 and 15). Due to the cobble and pebble density, core samples could only be taken at site 8.1 (Figure 5), where generally highly anoxic sediment (as were the other sites) with a high clay content was observed.

Plate 12. Large pebble shore with *G. maritima* in foreground, western margin Pool 8.

Plate 13. South margin looking West, Pool 8.


Plate 14. East margin, steep vegetation and fine sand sediment. Pool 8.


Plate 15. *Scirpus maritimus* (Sea club-rush) close to East margin. Pool 8.

Depth increased from few centimetres at the margins to 1.5-2.8m in deeper areas. Overall, the mean water temperature of this pool was 17.7°C, with values at the surface ranging between 17.6 and 18.4°C, and only a very minor decrease occurring with depth at the deeper station (from 17.8°C at the surface to 17.5°C near the bottom). Salinity was homogeneous, with values of 10.1 throughout the majority of Pool 8. Water oxygen saturation was 114.2% on average, with values at the surface ranging 106.0 to 114.3% and a decrease to values around 100% in deeper waters. Turbidity was high throughout the pool compared to the other lagoons of the system, with a mean of 40.3 NTU (from 37.5 to 52.6 NTU), and pH remained consistently between 9.78 and 9.93 regardless of position in the water column (Appendix II).

3.1.7 POOL 9

Situated to the south of Pool 8, Pool 9 is the smallest of the South Walney lagoons with an extent of 0.12ha estimated in 2013. It is also a generally shallow lagoon in comparison to the other larger pools, with the maximum depth reading of 2.4m taken from the centre of the pool (Figure 6). A significant shelf occurs in the northern half of the pool, approximately 30cm deep, whilst the southern half is deeper; this appears to be caused by water level rise for this pool, as aerial photographs taken in 2003 show only the southern half covered by water, with the northern shelf as dry land. The margins surrounding this pool are covered in grassy vegetation, with the northern sides quite steep whilst the southern side are quite shallow (Plate 16). On the northern margin, boulders and pebbles are seen below the shoreline for approximately 1m before transitioning into fine sandy sediments with *Agrostis stolonifera* identified. In the shallower North East corner, an extensive mat of green algae (*Enteromorpha*) stretched from the shoreline, covering approximately 10% of the water basin (Plate 16). Significant algal coverage was observed also in the South East corner of the pool, as well as areas inhabited by the fennel pondweed *Potamogeton pectinatus* (Plate 17 and 18). On the western margin (site 9-3), also the invasive alien swamp stonecrop *Crassula helmsii* was observed on the margin, together with *Enteromorpha*.

Temperature throughout the pool ranged between 16.9 and 18.8°C, with generally higher values at the surface (mean 18.3°C). Salinity was consistently low, with values <6.6, whereas a marked decrease in water oxygen saturation was observed with depth, with values recorded at the surface being always >84% (93% on average) and the lowest value of 17.9% being recorded nearer the bottom at the deeper station (9-PM)[18]. Turbidity was generally low (between 1.9 and 2.5 NTU), with a peak of 69.6 NTU at the bottom of the pool likely ascribed to sediment disturbance during the measurement. pH seems to be unaffected by the change in turbidity, as levels are 10.1 at the surface, decreasing gradually through the water column to 8.51 at the deepest point measured (Appendix II).

Plate 16. Pool 9 from the North corner showing algal mat coverage.

Plate 17. Pool 9, Algal mat in the South East corner. Fennel pondweed *P. pectinatus* is also evident covering the eastern and southern marginal areas of the pool.

Plate 18. Pool 9, Fennel pondweed *P. pectinatus* covering the South-eastern areas of the pool.

3.1.8 Pool 10

Situated to the south of Pool 2/3 (Figure 6), Pool 10 has an extent of 1.09ha, and is one of the deeper pools, with 5.5m recorded at the deepest measurement (station 10-PM). Margins

[18] Similarly to what was observed in other pools, outlier values characterised the bottom reading for several water quality parameters (compared with the general pattern of these variables along the depth profile), these values being likely ascribed to the interference of disturbed sediment at the bottom while deploying the sonde.

surrounding the East and West sides of Pool 10 were observed as steeper, with larger pebbles present at the water edge (Plate 19 and 20), whilst the northern and southern margins were shallower with smaller pebbles, and fine sandy sediments with attached *Enteromorpha* (Plate 21).

The pH levels in Pool 10 remain consistently between 9.4 and 9.7 throughout the water column, decreasing slightly to 8.5 at approximately 4m depth. Similar consistency was observed with water temperature, with values mostly 17.3 and 17.7°C. Lower values (14.7°C) were only observed at the deepest areas (approx 5-5.5m deep), these conditions suggesting a general well mixing of the water column. This was confirmed by the homogeneity in salinity readings (12.3-12.4), with higher values (around 14) being observed only in deeper waters. DO content follows the expected pattern of gradually declining with depth, although a relative homogeneity was observed in the first 2-2.5m below the surface, with saturation levels being 81.7% on average (mostly between 80 and 88%), and a decrease to values <45% in deeper strata. Intermediate turbidity levels (with values mostly around 20 NTU) were recorded in this pool compared to the others (Appendix II).

Plate 19. East margin looking South, Pool 10.

Plate 20. West margin with larger pebble section looking South, Pool 10.

Plate 21. South margin showing fine sandy sediments with attached *Enteromorpha*.

3.1.9 Pool 11

Pool 11 is positioned to the north of Pool 5, separated by a thin and shallow margin (Figure 6). At the time of the survey, much of the area on the north-western arm of the pool did not contain any water, but was covered with dense and tall riparian vegetation more commonly seen in wetland habitats. Relevant wetland species were observed in this area such as the reed *Phragmites australis* and species of Bracken (Plate 22). The westernmost part of this area could not be accessed due to the presence of a fence (Figure 6); however observations from an elevated point confirmed the presence the riparian vegetation coverage west of the fence (Plate 22). This vegetation covered also the area between the northern margin of the pool and the two small islands present to the east of the fence (Figure 6).

The margins surrounding Pool 11 are generally shallow, transitioning into black anoxic mud sometimes covered with a thin layer of yellow clay (Plate 23). The presence of cracks in the clay suggests exposure to air, indicating that the lagoon is subject to drying. Cattle tracks were also observed along the margins but also crossing the lagoon (Plate 22), suggesting that disturbance of the bottom by cattle passage is a common condition.

The estimation of the pool basin extent was difficult, due to the inaccessibility of part of the pool and the presence of dense and tall vegetation in sites, therefore an approximate estimate was derived by comparing OS maps with the sketch maps drawn during the survey. Approximately 25% of the area of the pool (as from OS maps) was covered by riparian vegetation, hence the lagoon basin extent (excluding this area) was estimated as 0.76ha at the time of the survey.

Pool 11 was generally shallow, with depth being around 15cm throughout the basin. Temperature was 14.7°C, salinity was 2.64, pH was 10.5, DO saturation was 100.4%, and turbidity was 6 NTU (Appendix II).

Plate 22. View of the western arm of Pool 11, covered in riparian vegetation including *Phragmites australis*.

Plate 23. Anoxic fine sediment, with evidence of cattle tracks.

3.2 Water quality (nutrients)

The nutrient content in the water of the lagoon system was assessed in order to provide an overview of the current status of water quality, as well as provide baseline data from which future studies can compare results, and predict trends in nutrient concentration. At least one sample from all 11 pools (26 samples in total) was taken, and concentrations of ammoniacal nitrogen, nitrite, nitrogen, orthophosphate and silicate were measured (Appendix III). In general, concentrations for each nutrient were homogenous between pools, regardless of sample depth.

Ammoniacal nitrogen ranged from 0.026 (Pool 11) to 0.071mg l^{-1} (Pool 5) with the highest concentrations found in pools 4 and 5. Measurements taken from 1B, and pools 2, 6, 7 8 and 10 were below detection limits (<0.02mg l^{-1}).

Nitrite and Total Oxidised Nitrogen concentrations were largely homogenous across all pools and sites sampled. Nitrite concentrations ranged from <0.004 to 0.01mg l^{-1}, however concentrations from 70% of the sample stations were below detection limit (<0.004mg l^{-1}). Those that were high enough to report were from pools 2, 3, 4 and 5, and ranged between 0.009 and 0.014mg l^{-1}. Similarly, concentrations of Total Oxidised Nitrogen from 25 out of the 26 samples were below detection limit (<0.1mg l^{-1}), and therefore only one reading of 0.1mg l^{-1} is reported, from Pool 4, station 4.2.

Concentrations of Orthophosphate were not high enough to be detected in Pools 7, 8, 10 or 11 (<0.01mg l^{-1}) and ranged from 0.044mg l^{-1} (Pool 6) to 0.48mg l^{-1} (Pool 9) in other pools. In general, concentrations were low in Pool 6, slightly higher in pools 1-5, and notably higher in Pool 9 (Appendix III).

Contrary to values for Orthophosphate, Silicate concentrations in Pool 9 were below detection limit, and highest values were measured in Pool 10 (1.8mgl^{-1}). Concentrations that could be measured were lower at pools 7 and 11 (0.22 and 0.26mg l^{-1} respectively) increased slightly in Pool 6 to around 0.5mg l^{-1}, and ranged between 0.7- 0.9mg l^{-1} in pools 1, 2, 3, 4 and 5.

Ideally, these data could be compared with Environmental Quality Standards (EQS) (as described in the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD)), or Environmental Assessment Levels (EAL) (Environment Agency Standards), to indicate whether the lagoon pools were within stated guideline concentrations, or whether hypernutrification had occurred. However many of the guidelines for the data available have not been fully developed at the time of study, or exist exclusively for freshwater environments winter survey times, of which neither are appropriate to use as a comparison tool. In this instance, comparison with future water quality data from the site will provide much insight into its environmental status.

3.3 Sediment characteristics

3.3.1 BULK SEDIMENT PROPERTIES

Across the lagoon system as a whole, in general the sediments varied from medium sand to fine silt, with occasional larger particle sizes present where stones or shell fragment were found in the sediment (Figure 7) (Appendix IV). It is important to note that the samples used for Particle Size Analysis (PSA) were taken at the margin of the pool with a corer, or at the deeper station with a grab, and therefore the results are representative of the habitats from which they were taken. This accounts for the lack of boulders and cobbles found in the PSA sample even though they were present at most pools (as described in Section 3.1) and therefore contribute to the overall habitat composition of the lagoon system.

Particle size ranged from -4 ϕ (gravel) to 10 ϕ (clay)[19], with percentage content of particles 2 to 3 ϕ (fine sand) being the highest over all the stations (Figure 7). The finest sediments were found at the deep station 10-PM (0.021mm grain size on average) and the largest at marginal station 6.1 (0.4mm on average). The mean sorting coefficient (1.7) implies that the sediments are relatively homogenous (being composed of a small range of particle size classes) across all sample sites.

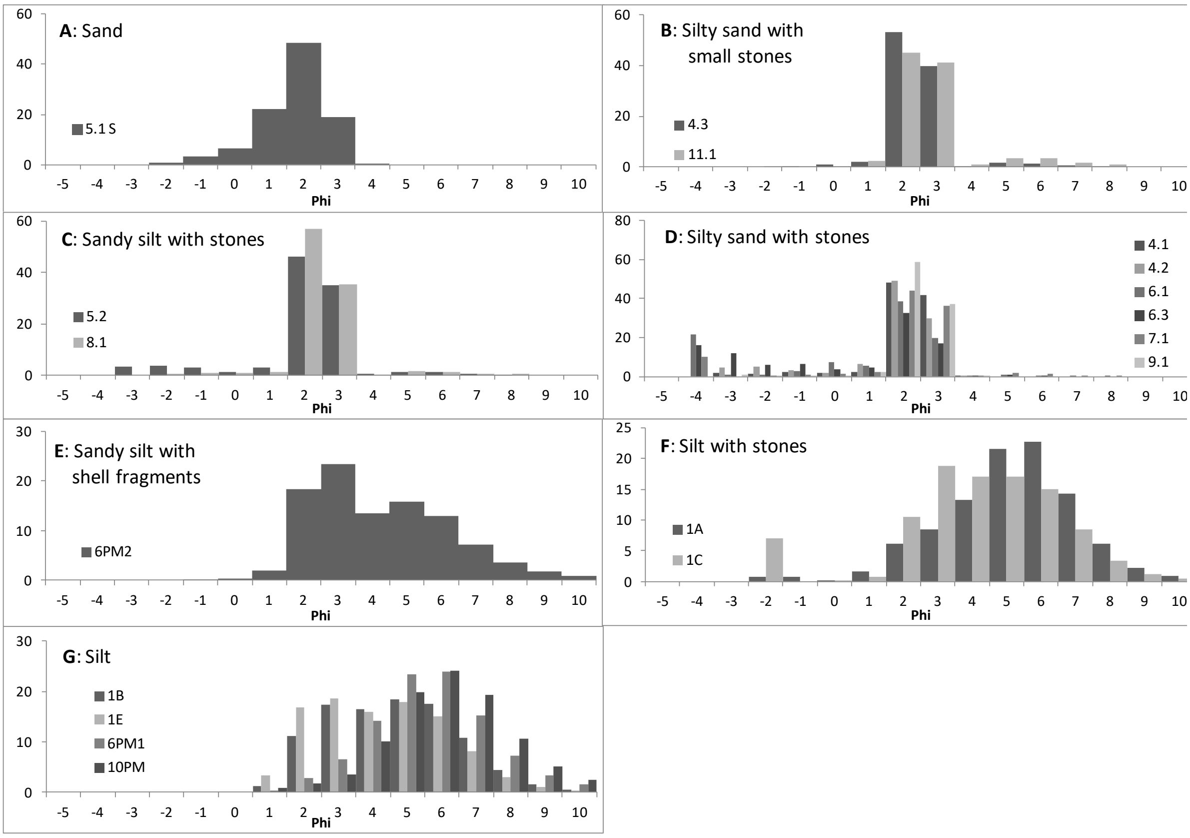

Figure 7. A-G. Phi histograms grouped according to particle description.

There was no notable difference in particle size between pools. However, particle size tended to differ according to whether the sample had been taken at a shallow station (<1m) in comparison to when they were taken from a deeper station (>1m). This relationship is evident in Figure 7, with higher percentages of larger grain sizes (mostly fine sand between 2-3 ϕ)

19 Particle sizes are presented as phi values, according to the Wentworth Scale (Bale & Kenny, 2005). An increasing value of phi indicates a decrease in particle size. Sediment types are identified based on phi range as follows: gravel, phi <-1; sand, phi -1 to 4; silt, phi 4 to 8; clay, phi >8.

found at shallower stations (graphs A, B, C, D), compared to deeper stations (graphs E, F and G) where sediments with particle sizes mainly between 5-6 ϕ (silt) were found.

3.3.2 SEDIMENT CONTAMINATION

Ten sediment samples were taken from separate pools (2 from grab samples (deep stations) and 8 from core samples (marginal stations)) and analysed for the contaminant content. The results were compared against Interim Sediment Quality Guidelines (ISQGs) (CCME, 2001). The ISQG represent the concentration below which adverse effects are expected to occur rarely. Probable effects levels (PELs) were also used to represent the concentration above which adverse biological effects are expected to occur frequently (CCME, 2001).

Results from the contaminant analysis are presented in Table 3, along with the relevant compound ISQG and PEL levels for ease of comparison. In terms of the metallic compounds (Mercury to Zinc), in general concentrations were notably higher at pools 1, 10 and 11 than they were for pools 3 to 9, with concentrations of Mercury and Arsenic exceeding ISQG levels at pools 1 and 11; Chromium and Copper higher than ISQG at pools 1, 10 and 11; and concentrations of Lead and Zinc higher than the guidelines at Pool 1.

Table 3. Results from the sediment contaminants analysis. Highlighted cells are those above ISQG level, indicating a moderate likelyhood of toxic effects on sediment-dwelling organisms. None are above probably effects level (PEL).

Compound	Unit	Station									
		1B	3.1	4.3	5.2	6.1	7.1	8.1	9.1	10PM	11.1
Mercury : Dry Wt ISQG: 0.13 ,PEL: 0.7	mg/kg	**0.372**	<0.002	<0.002	0.004	<0.002	0.003	0.002	0.003	0.04	**0.283**
Aluminium, HF Digest : Dry Wt N/A	mg/kg	42400	14800	17200	14200	25800	18300	15300	15700	15500	9230
Iron, HF Digest : Dry Wt N/A	mg/kg	32300	9230	6840	7040	15600	9540	8490	6770	14000	8560
Arsenic, HF Digest : Dry Wt ISQG: 7.24, PEL: 41.6	mg/kg	**18.7**	3.71	4.27	4.98	3.01	3.22	2.61	1.37	4.6	**10.8**
Cadmium, HF Digest : Dry Wt ISQG: 124, PEL: 271	mg/kg	1.01	<0.03	<0.03	<0.03	<0.03	0.043	0.05	<0.03	0.503	0.411
Chromium, HF Digest : Dry Wt ISQG: 52.3 ,PEL: 160	mg/kg	**120**	20.7	6.86	7.9	26.3	31.8	10.8	13.1	**195**	**91.3**
Copper, HF Digest : Dry Wt ISQG: 18.7, PEL: 108	mg/kg	**46.8**	2.53	2.52	2.68	3.14	4.97	8.2	2.87	**34.1**	**40.5**
Lead, HF Digest : Dry Wt ISQG: 30.2, PEL: 112	mg/kg	**65.2**	6.05	5.97	6.98	5.15	10.2	8.1	5.93	16.6	25.2
Lithium, HF Digest : Dry Wt N/A	mg/kg	43	11	11.2	11.2	16	16.5	11.7	12.1	13.8	6.64
Manganese, HF Digest : Dry Wt N/A	mg/kg	538	175	243	127	241	168	148	118	523	239
Nickel, HF Digest : Dry Wt N/A	mg/kg	66.5	4.71	3.9	4.44	6.38	11.7	6.27	4.73	123	52.1
Zinc : HF Digest : Dry Wt ISQG: 124, PEL: 271	mg/kg	**252**	15.6	16.9	17.8	21.4	29.3	35.5	15.9	73.1	76.1
Hexachlorobenzene : Dry Wt N/A	ug/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Hexachlorobutadiene : Dry Wt N/A	ug/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Anthracene : Dry Wt ISQG: 46.9, PEL: 245	ug/kg	**85.5**	<2	<2	<2	<2	5.7	<2	<2	<2	<2
Benz(a)anthracene : Dry Wt ISQG: 74.8, PEL: 693	ug/kg	**574**	<2	<2	<2	<2	41.6	<2	<2	5.5	<2
Benzo(a)pyrene : Dry Wt ISQG: 88.8, PEL: 763	ug/kg	**663**	<2	<2	<2	<2	36	<2	<2	9	2.28
Benzo(ghi)perylene : Dry Wt N/A	ug/kg	335	<10	<10	<10	<10	16.3	<10	<10	12.8	<10
Chrysene+Triphenylene : Dry Wt ISQG: 108, PEL: 846	ug/kg	**601**	<3	<3	<3	<3	41.5	<3	<3	<3	<3
Fluoranthene : Dry Wt ISQG: 113, PEL: 1,494	ug/kg	**1020**	<2	<2	<2	<2	86.7	<2	<2	4.8	<2
Indeno(1,2,3-c,d)pyrene : Dry Wt N/A	ug/kg	384	<10	<10	<10	<10	17.2	<10	<10	<10	<10
Naphthalene : Dry Wt ISQG: 34.6, PEL: 391	ug/kg	**95.7**	<30	<30	**95.4**	**83.8**	<30	<30	<30	**52.8**	<30
Phenanthrene : Dry Wt ISQG: 86.7, PEL: 544	ug/kg	**497**	<10	<10	<10	<10	69.5	<10	<10	<10	<10
Pyrene : Dry Wt ISQG: 153, PEL: 1,398	ug/kg	**889**	<3	<3	<3	<3	80.2	<3	<3	20.6	<3
Tributyl Tin : Dry Wt as Cation	ug/kg	<10	<4	<4	<4	<4	<5	<4	<4	<7	<6
Dry Solids @ 30°C	%	23.1	76	72	74.4	75.6	65.2	69	73.4	43.6	51.7
Accreditation Assessment	No.	2	2	2	2	2	2	2	2	2	2

Concentrations of the organic compounds Polycyclic Aromatic Hydrocarbons (PAHs) in Pool 1 were above ISQG (whenever an ISQG was available), suggesting contamination of sediments from organic compounds in this pool. There were also notably high concentrations of Naphthalene in Pool 5, 6 and 10.

Although there are several examples of contaminant concentrations above the ISQG, particularly in Pool 1, none of the contaminants within the sediments in the lagoon system had concentrations above PEL level.

3.4 Species composition

Twenty-seven stations overall were sampled in the pools, with quantitative sampling of sediments collected by corer in shallow marginal stations (where the sediment type allowed coring) and grab in deeper stations. Nekton fauna was also sampled semi-quantitatively by means of a push net swept in marginal stations and, where aquatic vegetation was present, vegetation coverage was estimated by using $1m^2$ quadrats and samples of epifauna were collected from the submerged vegetation (by washing 0.5L of seaweed). A list of the sampled stations, with indication of the method used, number of replicates collected and a description of the observed habitat is given in Appendix I.

3.4.1 Marsh and aquatic vegetation

Vegetation cover around the lagoon system and in more developed boundaries between the pools generally comprised of well established common grasses including Couch grass (*Elymus repens*), Cocksfoot (*Dactylis glomerata*) and Yorkshire fog (*Holcus lanatus*). This was interspersed sporadically with terrestrial species such as Ragwort (*Senecio spp.*) thistle species such as *Cirsium spp*. and Burr dock (*Arctium minus*) (Plate 24). The rougher grassland was generally fronted by more euryhaline species, common to mid and lower marsh habitats, such as Sea milkwort (*Glaux maritima*) and Spear-leaved Orache (*Atriplex spp.*). Communities in this area were ruderal in resemblance, similar to those which may colonise disturbed or uncultivated rough ground. At the lagoon shoreline, *Salicornia spp*., *Scirpus maritimus* (Sea Club-rush) and *Sueda maritima* (Annual seablite) were present at some pools, in particular Pool 6, Pool 8 and Pool 7 respectively.

Plate 24. Typical vegetation found on the outskirts of lagoon system, including *Senecio spp*. *Cirsium spp*. and various grasses.

Plate 25. Quadrant 1, Site 1.4, Pool 1.

Table 4. Coverage (%) of aquatic vegetation in sample quadrats taken at Pools 1, 4 and 9.

			Species % coverage					
Pool	**Site**	**Quadrat**	*E. lactuca*	*C. linum*	*Rhizoclomium spp.*	*P. pectinatus*	*A. stolonifera*	*C. helmsii*
1	1.4	Q1		100	25			
1	1.4	Q2		95	5			
1	1.4	Q3		99	25			
4	4.1	Q1	15		5			
4	4.1	Q2	3		7			
4	4.1	Q3	10		88			
4	4.2	Q1	20		2			
4	4.2	Q2	60		20			
4	4.2	Q3	30		15			
4	4.3	Q1	10	40	60			
4	4.3	Q2	20	30	50			
4	4.3	Q3	20	30	50			
5	5.1	Q1	5		90			
5	5.1	Q2	35		5			
5	5.1	Q3	10		10			
5	5.2	Q1	6		4			
5	5.2	Q2	4		20			
5	5.2	Q3	4		6			
9	9.1	Q1	15				35	
9	9.1	Q2	60			1	50	
9	9.1	Q3	15			20	5	
9	9.3	Q3	70				55	2

Along and below the water line, algal species were abundant rather than diverse, occurring at most of pools with few exceptions. *Enteromorpha lactuca* was the most abundant and widespread species. Other algae included *Chaetomorpha linum,* filamentous algae of the family Cladophoraceae (possibly *Cladophora* and *Rizochlonium* in places) and diatom algal mats. As described in previous sections, fennel pondweed *Potamogeton pectinatus* was also present in Pool 9.

In order to estimate aquatic vegetation cover, 1m^2 quadrats were placed over the area of algal coverage (where present) (Plate 25, Appendix V), and percentage cover was estimated by species at Pools 1, 4 and 9, with results summarised in Table 4. In some cases, vegetation coverage in the quadrats equals more than 100%, due to overlap between different species.

E. lactuca was present at the largest number of sites and can be classed as the most common species of algae throughout the lagoon pools. Also Cladophoraceae (including possibly *Cladophora* and *Rhizoclonium*) had also a large percentage coverage overall, as these filamentous algae were found attached to most hard substrata below the water line. In addition to the information collected from the quadrats, it was noted visually that in the pools with higher salinities (Pools 1 to 6), the most abundant species were the euryhaline *E. lactuca* and *C. linum. E. lactuca* was also frequent and abundant in places at the lower salinity pools, where the creeping bent *Agrostis stolonifera*¸ typical of upper saltmarsh habitat, and the saline intolerant *P. pectinatus* were also found (Pool 9).

Also of note is the presence of the invasive alien species *Crassula helmsii* in Pool 9, which is a species native to Australia and New Zealand and has since been introduced around the world. The species can grow on water margins, semi-submerged in deeper water, or completely submerged with elongated stems (Global Invasive Species Database). It is listed under schedule 9 of the UK Wildlife and Countryside Act 1981 as one which cannot be caused to grow in the wild, as once established it can grow vigorously and does not die back in winter months (UK Wildlife and Countryside Act, 1981).

3.4.2 BENTHIC INFAUNA

A total of 45 benthic invertebrate taxa were sampled quantitatively in the studied lagoons in August 2013, in addition to 3 species (1 sea anemone and 2 bryozoans, including the lagoon specialist *Conopeum seurati*) that were recorded only as presence in the samples (Appendix VI). Several species were at juvenile/larval stage, a likely result of the monitoring being undertaken during the summer season.

The polychaete worm *Capitella capitata* was the most abundant invertebrate species, accounting for 50% of the total benthic numbers recorded overall in the study area. Particularly high numbers of this species (>900 ind/0.05m^2) were found at Pools 4 and 5, in all marginal stations (Table 5 and 6). The lagoon specialist amphipod *Monocorophium insidiosum* was also frequent and abundant in the lagoon samples, occurring with higher numbers (>450 ind/0.05m^2 on average) particularly in all marginal stations of Pool 4 and 5 , but being present also in Pool 6 and 7 (all stations), with 1 individual found also in the deep station 1-A in Pool 1. Localised abundances of Ostracods and Chironomid larvae (>100 ind/0.05m^2) were also found, particularly in Pool 8 and 8/9, respectively. Pool 8 was also the only site where the Jenkin's spire shell *Potamopyrgus antipodarum* was found (293 ind/0.05m^2). This is an introduced (1859) species that has widely spread around the UK, now being the most common freshwater gastropod in Britain.

In addition to *Monocorophium insidiosum* and *Conopeum seurati*, other 2 lagoon specialist species were found in the benthic samples, namely the lagoon slater *Idotea chelipes* and the lagoon cockle *Cerastoderma glaucum*. However, only few individuals of these two latter species were found, with <7 ind/0.05m^2 of *I. chelipes* occurring in Pool 4 (at marginal stations 4-1 and 4-3) and Pool 1 (only at the deep station 1-D), and only 1 lagoon cockle occurring in Pool 6 (at the marginal stations 6.3) (Table 6). It is of note, however, that the presence of lagoon cockles was observed in marginal habitats of Pool 1 (Appendix I)[20], whereas high numbers of *I. chelipes* were associated with macroalgal vegetation in Pool 1, 4 and 5 (Sections 3.4.3 and 3.4.4). Although no lagoon mud snail *Ecrobia ventrosa* was found in the benthic samples, it is of note that the species presence was recorded (as only one individual in Pool 5 (station 5-2) during the push net sampling.

On the whole, Pool 4, 5, 6 (marginal areas) and 8 showed the most diverse and abundant assemblages in the benthic infaunal samples, with >10 species per station (raging 8 to 20)

[20] Dead cockles (as shells only) were generally observed also in Pool 4 and 5, but their presence does not account for viable populations in these lagoons (e.g., it could be the result of transport by birds).

and >1000 ind/0.05m^2 (particularly in Pool 4, 5 and 8) found on average, although different species dominated these assemblages between Pools 4, 5, 6 (mostly *C. capitata*, *M. insidiosum* and Tubificidae polychaetes) and Pool 8 (Ostracoda, chironimid larvae, and *P. antipodarum*), likely reflecting the lower saline intrusion in Pool 8. In general, more impoverished and less abundant assemblages were found in grab samples collected in deeper stations, a likely result of the low oxygen concentration observed in these areas (anoxic sediments and the lower oxygen saturation in deeper water strata). As a result, few species and low abundances were found in Pool 1 and 10 (where only deeper stations were sampled) and in deeper areas of Pool 6 (Table 5 and 6). It is of note, however, that the lagoon sea mat *C. seurati* was recorded in most of the deep stations sampled in Pool 1, 6 and 10 (being the only species found in the samples collected in this latter pool), as well as in marginal stations of Pool 4 (4-1 and 4-2).

A cluster analysis was applied to the species total abundance data in the sampled stations to identify the main differences in the benthic invertebrate assemblage structure among pools (Figure 8). The results confirmed the community description given above, with assemblages in deeper stations being highly dissimilar from those sampled along the lagoon margins, due to the very low number of species and benthic abundance. When considering marginal habitats, Pool 4 and 5, and secondarily Pool 6, showed a higher similarity (>40%) in their benthic assemblage, compared to the group of Pools 7-9 and 11 (showing similarity <40%). It is of note that this differentiation between benthic assemblages seems to correlate with differences in salinities among pools, with marginal stations of Pools 4 and 5 showing euhaline conditions (salinity >31[21]), whereas oligo-mesohaline conditions (salinity >31) were found in marginal stations of Pool 7-9 and 11 where benthic samples were collected. However, salinity cannot be the only driving factor affecting the differences in benthic assemblages, as mesohaline conditions were found also in marginal areas of Pool 6, which in turn showed species assemblages more similar to those found in Pool 4 and 5.

Table 5. Mean total numbers of benthic invertebrates recorded per station in the monitored pools (ind/0.05m2). Where both deep and marginal stations have been sampled (number of stations in each pool is indicated in the 3rd heading row), mean

[21] Based on the Venice System, brackish/marine waters can be classified according to salinity into: limnetic (salinity 0-0.5), oligohaline (0.5-5), mesohaline (5-18), polyhaline (18-30), euhaline (>30). The Venice System is so called as it was derived at the International Symposium for the Classification of Brackish Waters, sponsored by the International Association of Limnology and the International Union of Biological Sciences, and held in Venice (8-14 April 1958).

values were calculated separately, considering the different sampling method used. Lagoon specialist species are highlighted in grey.

			Pool 1	Pool 4	Pool 5	Pool 6		Pool 7	Pool 8	Pool 9	Pool 10	Pool 11
			deep	margin	margin	margin	deep	margin	margin	margin	deep	margin
Group	Taxon		5	3	2	2	2	1	1	1	1	1
Nemertea	Nemertea		3.0	0	6.0	0.5	0	0	0	0	0	0
Nematoda	Nematoda		0	2.0	22.5	0.5	0	0	1.0	0	0	0
Annelida	*Eteone longa*	agg	0	0	0.5	0	0	0	0	0	0	0
	Hediste diversicolor		0	2.0	14.0	24.5	0	1.0	1.0	0	0	0
	Scoloplos armiger		0	0	0	0	0	0	1.0	0	0	0
	Polydora cornuta		0	0	57.5	12.5	0	0	2.0	0	0	0
	Pygospio elegans		0	0	6.0	3.5	0	0	0	0	0	0
	Tharyx "species A"		0	1.7	5.0	2.5	0	0	0	0	0	0
	Capitella capitata		0	912.3	1236.0	0.5	0	0	1.0	0	0	0
	Arenicola marina		0	0	1.5	0	0	0	0	0	0	0
	Paranais litoralis		0	10.7	2.0	2.5	0	8.0	0	0	0	0
	Tubificidae		0	0	135.5	49.5	0	0	1.0	0	0	0
	Heterochaeta costata		0	4.3	53.0	4.0	0	33.0	0	0	0	0
	Tubificoides benedii		0.2	0	0	0	0	0	0	0	0	0
	Enchytraeidae		0	9.0	5.5	15.0	0	0	0	0	0	1.0
Crustacea	Ostracoda		0	1.0	1.0	0.5	0	12.0	615.0	0	0	17.0
	Allomelita pellucida	Juveniles	0	0.3	0	0	0	0	0	0	0	0
	Cheirocratus		0	0	0	0.5	0	0	0	0	0	0
	Aoridae		0	13.7	9.5	0.5	0	0	0	0	0	0
	Microdeutopus gryllotalpa		0	1.3	1.0	0	0	0	0	0	0	0
	Monocorophium insidiosum		0.2	501.0	447.0	34.0	1.0	5.0	0	0	0	0
	Sphaeroma	Juveniles	0	0	0.5	0	0	0	0	0	0	0
	Idotea	Juvenilies	1.4	3.3	0.5	0	0	0	0	0	0	0
	Idotea chelipes		1.4	1.0	0	0	0	0	0	0	0	0
	Decapoda	Zoea	0	0	0	0	0	0	0	1.0	0	0
	Palaemon varians		0	0	0	0	0	0	0	2.0	0	0
Hexapoda	Insecta	Larvae	0	0.3	0	0.5	0	0	0	0	0	0
	Dolichopodidae	Larvae	0	0	0	0	0	0	0	0	0	3.0
	Chironomidae "Species 1"	Larvae	0	1.3	0	1.0	2.5	14.0	300.0	151.0	0	1.0
	Chironomidae "Species 2"	Larvae	0	0	0	0	0	1.0	1.0	7.0	0	0
	Corixidae	Larvae	0	0	0	0	0	0	0	7.0	0	0
	Psychodidae	Larvae	0	0	0	0	0	0	0	0	0	7.0
	Ephydridae	Larvae	0	0	0	0	0	0	0	0	0	3.0
	Coelambus	Larvae	0	0	0	0	0	0	0	0	0	1.0
	Isotomidae		0	0.3	0	0	0	0	0	0	0	0
	Symphypleona		0	0.3	0	0	0	0	0	0	0	0
Mollusca	Gastropoda		0	0	0.5	0	0	0	0	0	0	0
	Peringia ulvae		0	0.7	38.5	0	0	1.0	1.0	0	0	0
	Potamopyrgus antipodarum		0	0	0	0	0	0	293.0	0	0	0
	Littorina	Juveniles	0	0	0	0	0	1.0	0	0	0	0
	Diaphana minuta		0	0	0	0.5	0	0	0	0	0	0
	Kurtiella bidentata		0	0	1.0	0	0	0	0	0	0	0
	Cerastoderma	Juveniles	0	0.3	0	0	0	0	0	0	0	0
	Cerastoderma glaucum		0	0	0	0.5	0	0	0	0	0	0
	Mya arenaria	Juveniles	8.2	0	1.5	15.0	0	0	0	0	0	0
Cnidaria	ACTINIARIA		P									
Bryozoa	*Conopeum seurati*		P	P		P					P	
	Flustra foliacea									P		
Mean number of species (quantitative) per station			1.2	12.3	16.5	13.5	1.5	9.0	11.0	5.0	0	7.0
Mean number of species (all) per station			1.6	13.0	16.5	13.5	2.5	9.0	11.0	6.0	1.0	7.0
Mean total abundance (ind/0.05m2) per station			14.4	1467.0	2046.0	168.5	3.5	76.0	1217.0	168.0	0	33.0

Table 6. Total numbers of benthic invertebrates recorded at each station in the monitored pools. Note that a similar total area (0.05m²) was sampled in deep and marginal stations, but a different sampling method was used (0.025m² Ekman grab (2 repl.) in deep stations, 0.01m² corer (5 repl.) in marginal stations). Lagoon specialist species are highlighted in grey.

			Pool 1					Pool 4			Pool 5		Pool 6				Pool 7	Pool 8	Pool 9	Pool 10	Pool 11
			1-A	1-B	1-C	1-D	1-E	4-1	4-2	4-3	5-1	5-2	6-1	6-3	6PM1	6PM2	7-1	8-1	9-1	10PM3	11-1
Group	Taxon		deep	deep	deep	deep	deep	margin	margin	margin	margin	margin	margin	margin	deep	deep	margin	margin	margin	deep	margin
Nemertea	Nemertea		0	0	0	15	0	0	0	0	0	12	0	1	0	0	0	0	0	0	0
Nematoda	Nematoda		0	0	0	0	0	2	0	4	8	37	1	0	0	0	0	1	0	0	0
Annelida	*Eteone longa*	agg	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Hediste diversicolor		0	0	0	0	0	3	0	3	27	1	23	26	0	0	1	1	0	0	0
	Scoloplos armiger		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Polydora cornuta		0	0	0	0	0	0	0	0	0	115	2	23	0	0	0	2	0	0	0
	Pygospio elegans		0	0	0	0	0	0	0	0	9	3	6	1	0	0	0	0	0	0	0
	Tharyx "species A"		0	0	0	0	0	0	0	5	0	10	0	5	0	0	0	0	0	0	0
	Capitella capitata		0	0	0	0	0	1504	659	574	893	1579	0	1	0	0	0	1	0	0	0
	Arenicola marina		0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
	Paranais litoralis		0	0	0	0	0	21	8	3	4	0	0	5	0	0	8	0	0	0	0
	Tubificidae		0	0	0	0	0	0	0	0	0	271	2	97	0	0	0	1	0	0	0
	Heterochaeta costata		0	0	0	0	0	8	5	0	11	95	7	1	0	0	33	0	0	0	0
	Tubificoides benedii		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enchytraeidae		0	0	0	0	0	1	9	17	5	6	30	0	0	0	0	0	0	0	1
Crustacea	Ostracoda		0	0	0	0	0	3	0	0	1	1	1	0	0	0	12	615	0	0	17
	Allomelita pellucida	Juveniles	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cheirocratus		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Aoridae		0	0	0	0	0	3	4	34	0	19	1	0	0	0	0	0	0	0	0
	Microdeutopus gryllotalpa		0	0	0	0	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0
	Monocorophium insidiosum		1	0	0	0	0	199	676	628	32	862	38	30	1	1	5	0	0	0	0
	Sphaeroma	Juveniles	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Idotea	Juvenilies	0	0	0	7	0	6	0	4	0	1	0	0	0	0	0	0	0	0	0
	Idotea chelipes		0	0	0	7	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0
	Decapoda	Zoea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Palaemon varians		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Hexapoda	Insecta	Larvae	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
	Dolichopodidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Chironomidae "Species 1"	Larvae	0	0	0	0	0	4	0	0	0	0	0	2	0	5	14	300	151	0	1
	Chironomidae "Species 2"	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	7	0	0
	Corixidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0
	Psychodidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
	Ephydridae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Coelambus	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Isotomidae		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Symphypleona		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca	Gastropoda		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Peringia ulvae		0	0	0	0	0	1	0	1	56	21	0	0	0	0	1	1	0	0	0
	Potamopyrgus antipodarum		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	293	0	0	0
	Littorina	Juveniles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Diaphana minuta		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Kurtiella bidentata		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Cerastoderma	Juveniles	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cerastoderma glaucum		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Mya arenaria	Juveniles	0	0	0	41	0	0	0	0	1	2	11	19	0	0	0	0	0	0	0
Cnidaria	ACTINIARIA			P																	
Bryozoa	*Conopeum seurati*					P		P	P						P	P				P	
	Flustra foliacea																		P		
Total number of species (quantitative)			1	0	1	4	0	16	8	13	13	20	12	15	1	2	9	11	5	0	7
Total number of species (all)			1	1	1	5	0	17	9	13	13	20	12	15	2	3	9	11	6	1	7
Total abundance (ind/0.05m2)			1	0	1	70	0	1761	1363	1277	1049	3043	123	214	1	6	76	1217	168	0	33

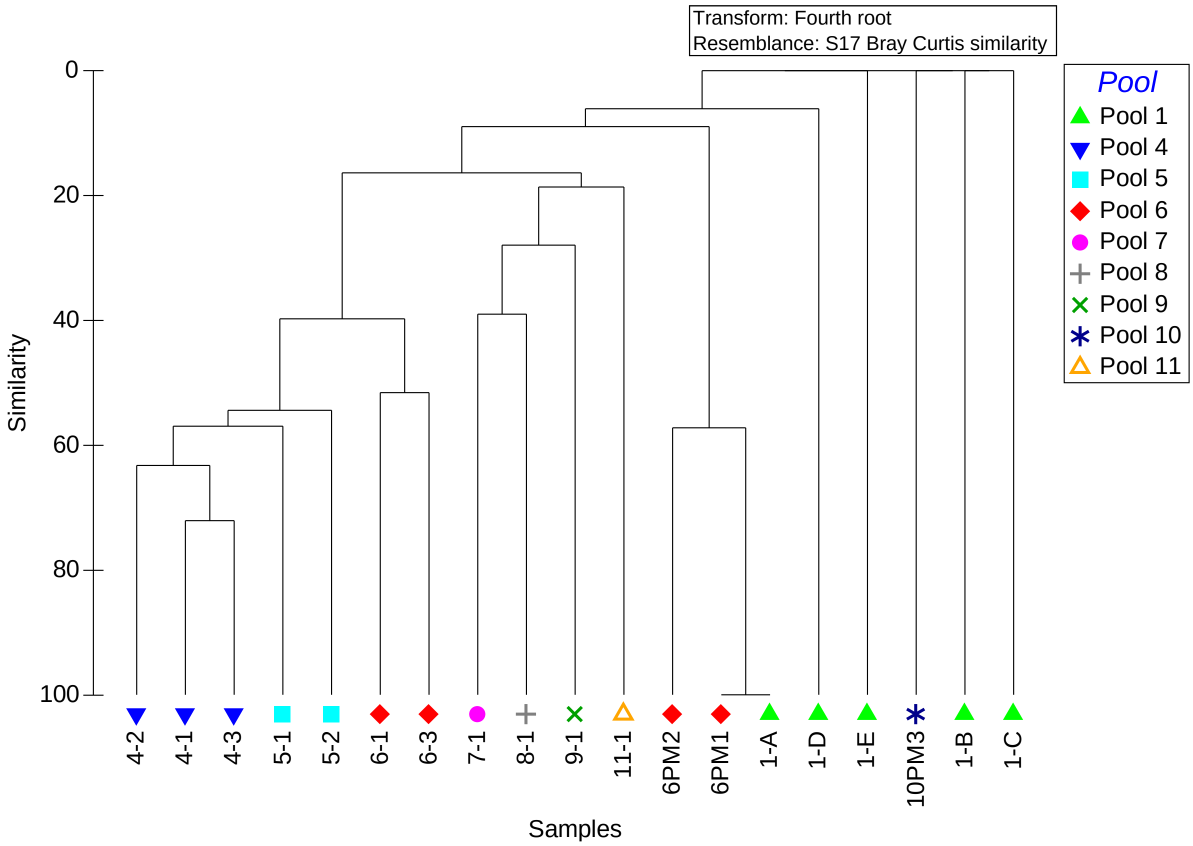

Figure 8. Cluster analysis carried out on total species abundance in stations sampled for benthic invertebrates. Group average algorithm was applied for the cluster analysis. Labels indicate the station, and symbols the pool.

3.4.3 EPIFAUNA WITHIN VEGETATION

Overall, 19 taxa in total were found in epifaunal collected from algal vegetation taken from the margins of pools 1, 4, 5 and 9. (Appendix VII). Abundance data were expressed on a SACFOR scale (Table 7 and 8).

Table 7. SACFOR scale applied to abundance data for epifauna amongst vegetation.

SACFOR scale:		density (ind/1.5L)
S	Superabundant	>1000
A	Abundant	500 to 1000
C	Common	100 to 500
F	Frequent	50 to 100
O	Occasional	10 to 50
R	Rare	1 to 10

Table 8. Total abundance of epifaunal organisms present amongst algal vegetation in sampled stations. Abundance is given on SACFOR scale (empty cells are where the species was not found in the station). Lagoon specialist species are highlighted in grey.

		Vegetation type	*Chaetomorpha linum*	*Enteromorpha*	*Enteromorpha* /filamentous alga (likely *Cladophora)*	*Enteromorpha*	*Enteromorpha/Potamogeton pectinatus*
Group	**Species**	**Qualifier**	**1.4**	**4.1**	**4.2**	**5.1**	**9.1**
Bristleworm	*Polydora ciliata*	sp. agg.	R				
Bristleworm	*Capitella capitata*	sp. agg.	R				
Oligochaete	*Nais elinguis*			R	R		
Oligochaete	*Paranais litoralis*			R	R		
Mite	ACARINA	spp.					R
Mysid/Opossum shrimp	*Praunus flexuosus*				R	R	
Amphipod shrimp	*Nototropis guttatus*				R		
Amphipod/Gammarus shrimp	*Gammarus duebeni*						R
Amphipod/Gammarus shrimp	*Gammarus salinus*			F	R	R	
Amphipod shrimp	*Melita palmata*			R	R		
Amphipod shrimp	*Microdeutopus gryllotalpa*		R	R	C	R	
Amphipod shrimp	*Monocorophium insidiosum*		C	R	C	F	
Isopod shrimp	*Idotea chelipes*		S	F	C	C	
Mud snail	*Peringia ulvae*				R	R	
Bubble shell	*Haminoea*	sp.	O				
Springtail	COLLEMBOLA				R		
Non-biting midge larvae	DIPTERA - Chironomidae	Larvae	R	O	O	R	F
Non-biting midge pupae	DIPTERA - Chironomidae	Pupae			R		
Beetle larvae	COLEOPTERA	Larvae	R		R	R	

In general, the lagoon specialist species *I. chelipes* and *M. insidiosum* were the most abundant and frequent across all pools apart from 9, showing notably higher abundances in comparison with other species. *I. chelipes* in particular was highly abundant amongst algal vegetation, thus being an important grazing habitat for the species. In addition to *M. insidiosum*, other amphipod shrimp were also frequently found across all the pools, but were more abundant in Pool 4, with the brackish herbivorous species *Gammarus salinus* being frequent at station 4.1, and *Microdeutopus gryllotalpa*, which is generally associated with rich detritus, being common at station 4.2 (Table 8). Chironomidae insects were found in larval form across all stations, although they were more abundant (frequent) in Pool 9, where the lower salinity is most favourable to these organisms. Other species were rare in the samples, including. beetle larvae (Coleoptera) in Pools 1, 4 and 5, the presence of these insect larvae perhaps due to the survey being conducted during the summer. Also annelid and oligochaete worms were present in the samples from in Pools 1 and 4, where preferred conditions are present (poly/euhaline waters and fine sand to coarse silt in the sediments). It is of note, however, that although presence of *Polydora ciliata* can be expected, as its position within the ecosystem is generally epibenthic, other species like *Capitella capitata* are normally part of an infaunal community. Species abundance between the pools was highest in Pool 1, due to the high abundances of *I. chelipes* and *M. insidiosum*, whereas the highest species richness was found in Pool 4 (at station 4.2), where the highest diversity of amphipod shrimps was detected. Contrarily, both abundance and species richness was lowest at Pool 9.

3.4.4 NEKTON

A total of 40 taxa were found in the samples collected with push net along the margins of the studied lagoons in August 2013 (Table 9, Appendix VIII). Given the type of sampling (with the push net swept in the water column while also disturbing the boulders/pebbles on the bottom), samples included conspicuous nektonic and epibenthic fauna (e.g., fish, shrimps) as well as some benthic organisms (e.g., worms, molluscs). Some taxa typical of the zooplankton (e.g., copepods and ostracods) were also present in the samples, due to the very fine mesh size (250um) of the net used for sampling. Also taxa typically associated with terrestrial environments and freshwater (e.g., insects, collembola, mites) were present in the samples. Several species were at juvenile/larval stage, a likely result of the monitoring being undertaken during the summer season.

The common goby *Pomatoschistus microps* was the only fish species recorded in the samples, being frequently found in all the pools, except for Pool 9, 10 and 11 (Table 9 and 10). Also mysid shrimps were frequent in the lagoons, with the chameleon shrimp *Praunus flexuosus* being the most abundant mysid species, occurring in all pools except for Pool 8-11. This is a species that can tolerate wide range of salinities and is often associated with algal vegetation. Also amphipod shrimps were relatively frequent in the samples, occurring in all pools, except for Pool 2/3, 5 and 8 (Table 10). The lagoon specialist *Monocorophium insidiosum* was the most abundant and frequent of mysid shrimps, being present in stations with different salinity conditions (poly/euhaline in Pool 1 and 4, mesohaline in Pool 6 and 7, oligohaline in Pool 11), although the highest abundance (24 individuals on the whole) was recorded at station 4-2 in Pool 4 (Appendix VIII). Other lagoon specialist species found in the samples included the lagoon slater *Idotea chelipes* in Pool 1, 4 and 6, with the highest abundance (74 individuals) found in station 1-4 of Pool 1, where the species was associated with the abundant algal vegetation coverage (as confirmed by the high numbers found amongst algal vegetation in this and other stations; Section 3.4.3). Also the lagoon mud snail *Ecrobia ventrosa* was found in the samples, with only one individual occurring in Pool 5 (station 5-2[22]).

[22] It is of note that this species was not found in the core samples collected at this station.

Table 9. Mean abundance (ind./1.25m^2) of faunal taxa sampled with the push net along marginal stations in the South Walney lagoons. Lagoon specialist species are highlighted in grey. (*only 1 sample was collected at station 1.4)

	Pool	1		2/3		4			5		6			7			8	9	10	11
Taxon	**Qualifier**	**1.3**	**1.4***	**2.1**	**3.1**	**4.1**	**4.2**	**4.3**	**5.1**	**5.2**	**6.1**	**6.2**	**6.3**	**7.1**	**7.2**	**7.3**	**8.1**	**9.1**	**10.1**	**11.1**
Polydora ciliata	sp. agg.	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paranais litoralis		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0
ACARINA	spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	0	0
COPEPODA	spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.0	0	54.7
Daphniidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	143.0	0	3.0
Macrothricidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.7
Heterocypris incongruens		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72.3
Heterocypris salina		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.0
Cyprideis torosa		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.3
Cypridopsis aculeata		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38.3
Mesopodopsis slabberi		0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0
Neomysis integer		0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	3.3	0
Praunus flexuosus		1.7	4.0	0.3	3.0	0	9.7	0.3	0.7	1.0	4.7	2.3	0	0.3	0	0	0	0	0	0
Orchestia gammarellus		0.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus duebeni		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	1.0	0
Gammarus salinus		0	0	0	0	0	0	0	0	0	1.0	0	0	0	0	0	0	0	0	0
Melitidae	juv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Microdeutopus gryllotalpa		0	0	0	0	0	0	2.0	0	0	0	0	0	0	0	0	0	0	0	0
Monocorophium insidiosum		0	3.0	0	0	0	1.0	8.0	0	0	1.7	0	2.0	0.3	0	0	0	0	0	0.3
Idotea chelipes		0.3	74.0	0	0	0	0.3	0	0	0	1.0	0	0	0	0	0	0	0	0	0
CARIDEA	juv.	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	22.0	0	0
Palaemon varians		0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0
Littorina saxatilis		0	1.0	0	0	0	0	0	0	0	0.7	1.3	0	0	0	0	0	0	0	0
Ecrobia ventrosa		0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0
Haminoea	sp.	2.3	11.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria		0	0	0	0	0	0	0	0	0	0.3	0	2.0	0	0	0	0	0	0	0
Pomatoschistus microps	(juv.)	2.0	14.0	0	3.7	1.0	3.7	1.0	2.3	3.7	1.0	2.0	0.7	0	0.7	0	14.7	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7
HEMIPTERA - Corixidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55.0	0	3.3
HEMIPTERA - Notonectidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0
DIPTERA - Ceratopogonidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.0
DIPTERA - Chironomidae	Larvae	2.3	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	8.0	0	2.7
DIPTERA - Chironomidae	Pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0
DIPTERA - Dolichopodidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7
DIPTERA - Ephydridae	Pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7
DIPTERA - Limoniidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7
DIPTERA - Muscidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0.3
DIPTERA - Psychodidae	Larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.0
COLEOPTERA	Larvae	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0.7
COLEOPTERA - Dytiscidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
Total number of species		6	6	2	2	1	5	6	3	3	7	3	4	3	1	0	1	11	2	20
Total mean abundance (ind./1.25m2)		9.3	107.0	0.7	6.7	1.0	15.0	12.0	3.3	5.0	10.3	5.7	5.0	1.0	0.7	0.0	14.7	233.3	4.3	208.0

Pool 9 and 11 showed the most abundant and rich fauna in the samples obtained with push net (Table 10), although the high numbers of taxa and animals in these cases were due to brackish-water ostracods, often preferring salinities <20 (Ganning, 1971), and to taxa associated with terrestrial and freshwater habitats (insect larvae). Pool 8 and 10, in turn, showed the lowest species richness, with only two mysid species found in Pool 10 and only common gobies found in Pool 8 (although with relatively high abundance, with 44 individuals, mostly at juvenile stage, found at station 8.1; Appendix VIII).

Table 10. Mean abundance (ind./1.25m^2) of faunal taxa sampled by pool. Lagoon specialist species are highlighted in grey.

station (ind/1.25m2)			Pool									
Group	**Taxon**	**Qualifier**	**1**	**2/3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Bristleworm	*Polydora ciliata*	sp. agg.	0	0.2	0	0	0	0	0	0	0	0
Oligochaete	*Paranais litoralis*		0	0	0	0	0	0	0	0.3	0	0
Mite	ACARINA	spp.	0	0	0	0	0	0	0	1.7	0	0
Cyclops/Water flea	COPEPODA	spp.	0	0	0	0	0	0	0	2.0	0	54.7
Daphnia/Water flea	Daphniidae		0	0	0	0	0	0	0	143.0	0	3.0
Daphnia/Water flea	Macrothricidae		0	0	0	0	0	0	0	0	0	10.7
Ostracod/Seed shrimp	*Heterocypris incongruens*		0	0	0	0	0	0	0	0	0	72.3
Ostracod/Seed shrimp	*Heterocypris salina*		0	0	0	0	0	0	0	0	0	7.0
Ostracod/Seed shrimp	*Cyprideis torosa*		0	0	0	0	0	0	0	0	0	5.3
Ostracod/Seed shrimp	*Cypridopsis aculeata*		0	0	0	0	0	0	0	0	0	38.3
Mysid/Opossum shrimp	*Mesopodopsis slabberi*		0	0	0.1	0	0	0	0	0	0	0
Mysid/Opossum shrimp	*Neomysis integer*		0	0	0	0	0	0.1	0	0	3.3	0
Mysid/Opossum shrimp	*Praunus flexuosus*		2.3	1.7	3.3	0.8	2.3	0.1	0	0	0	0
Amphipod shrimp	*Orchestia gammarellus*		0.5	0	0	0	0	0	0	0	0	0
Amphipod/Gammarus shrimp	*Gammarus duebeni*		0	0	0	0	0	0	0	0.3	1.0	0
Amphipod/Gammarus shrimp	*Gammarus salinus*		0	0	0	0	0.3	0	0	0	0	0
Amphipod shrimp	Melitidae	juv.	0	0	0	0	0	0	0	0	0	0.3
Amphipod shrimp	*Microdeutopus gryllotalpa*		0	0	0.7	0	0	0	0	0	0	0
Amphipod shrimp	*Monocorophium insidiosum*		0.8	0	3.0	0	1.2	0.1	0	0	0	0.3
Isopod shrimp	*Idotea chelipes*		18.8	0	0.1	0	0.3	0	0	0	0	0
Prawns/shrimps	CARIDEA	juv.	0	0	0	0.2	0	0	0	22.0	0	0
Atlantic ditch shrimp	*Palaemon varians*		0	0	0.1	0	0	0	0	0	0	0
Rough periwinkle	*Littorina saxatilis*		0.3	0	0	0	0.7	0	0	0	0	0
Spire snail	*Ecrobia ventrosa*		0	0	0	0.2	0	0	0	0	0	0
Bubble shell	*Haminoea*	sp.	4.5	0	0	0	0	0	0	0	0	0
Sand gaper	*Mya arenaria*		0	0	0	0	0.8	0	0	0	0	0
Common goby	*Pomatoschistus microps*	(juv.)	5.0	1.8	1.9	3.0	1.2	0.2	14.7	0	0	0
Springtail	COLLEMBOLA		0	0	0	0	0	0	0	0	0	0.7
Lesser waterboatmen	HEMIPTERA - Corixidae		0	0	0	0	0	0	0	55.0	0	3.3
Greater waterboatmen	HEMIPTERA - Notonectidae		0	0	0	0	0	0	0	0.3	0	0
Biting midge larvae	DIPTERA - Ceratopogonidae	Larvae	0	0	0	0	0	0	0	0	0	3.0
Non-biting midge larvae	DIPTERA - Chironomidae	Larvae	1.8	0	0	0	0.1	0	0	8.0	0	2.7
Non-biting midge pupae	DIPTERA - Chironomidae	Pupae	0	0	0	0	0	0	0	0.3	0	0
Long legged fly larvae	DIPTERA - Dolichopodidae	Larvae	0	0	0	0	0	0	0	0	0	0.7
Shore fly larvae	DIPTERA - Ephydridae	Pupae	0	0	0	0	0	0	0	0	0	1.7
Limonid crane fly larvae	DIPTERA - Limoniidae	Larvae	0	0	0	0	0	0	0	0	0	0.7
House fly larvae	DIPTERA - Muscidae	Larvae	0	0	0	0	0	0	0	0.3	0	0.3
Moth fly larvae	DIPTERA - Psychodidae	Larvae	0	0	0	0	0	0	0	0	0	2.0
Beetle larvae	COLEOPTERA	Larvae	0	0	0.1	0	0	0	0	0	0	0.7
Diving beetle	COLEOPTERA - Dytiscidae		0	0	0	0	0	0	0	0	0	0.3
		Total number of species	8	3	8	4	8	4	1	11	2	20
		Total mean abundance (ind./1.25m2)	33.8	3.7	9.3	4.2	7.0	0.6	14.7	233.3	4.3	208.0

A cluster analysis was applied to the species mean abundance data in the sampled stations to identify the main differences in the nektonic/epibenthic assemblage structure among pools (Figure 9). The results confirmed that the community in the oligo/mesohaline Pool 9 and 11 tends to be highly dissimilar (similarity <10%) from communities in the other more saline pools. The cluster shows also that the assemblage found in Pool 10 (station 10.1) seemed to be more similar to those in Pool 9 and 11 that to assemblages in other lagoons, although this was likely ascribed to the absence of the common goby in the samples from Pools 9, 10 and 11, whereas the species was found in all the other pools. Station7.3 was also highly differentiated from all the other stations, but this was due to the absence of any fauna in these samples. As regards the rest of the samples, although variability in the assemblages was found between stations (even within a same lagoon), the assemblages in the other lagoons were relatively similar to each other[23].

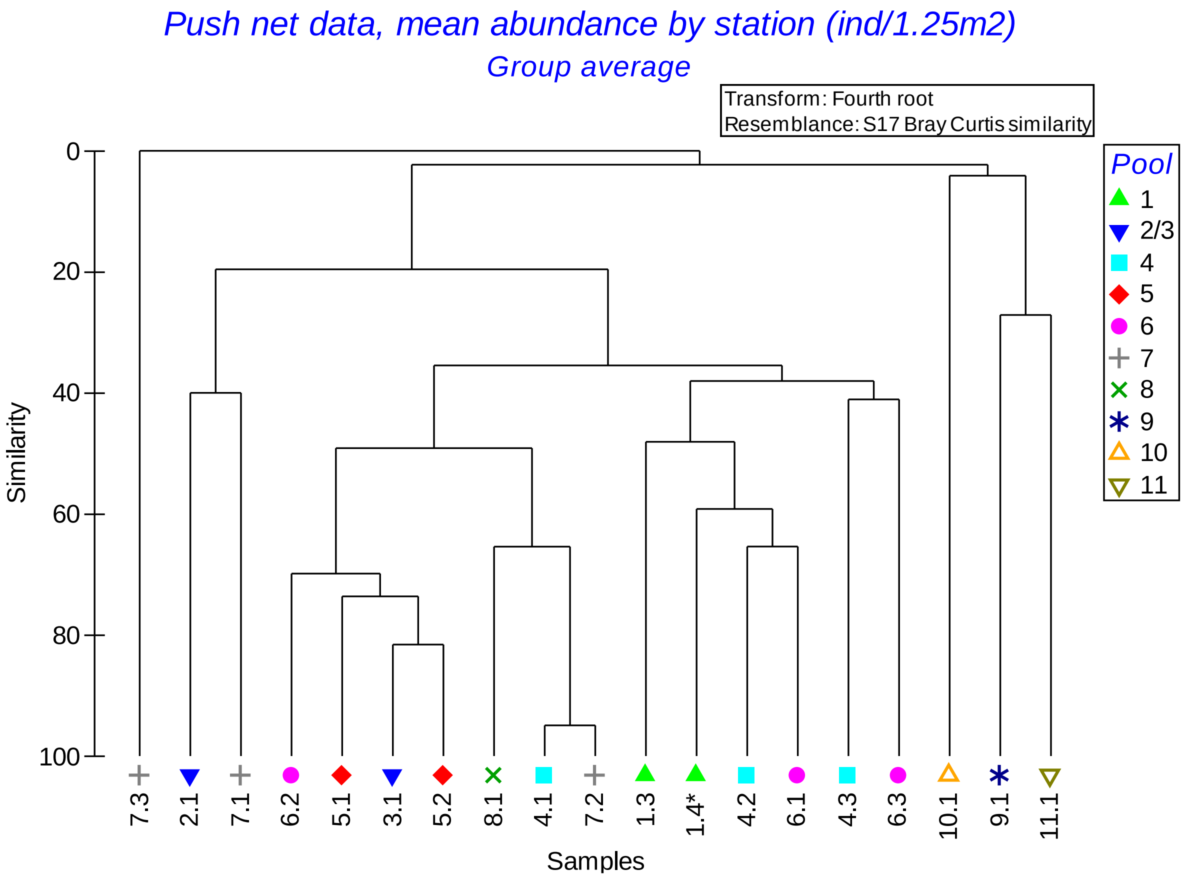

Figure 9. Cluster analysis carried out on mean species abundance in marginal stations sampled with push net. Group average algorithm was applied for the cluster analysis. Labels indicate the station, and symbols the pool.

[23] Simprof test applied to the cluster analysis confirmed that no significant differences occurred in the community structure between stations of Pools 1 to 8.

4. DISCUSSION

The principle aim of this report was to conduct a condition monitoring study on behalf of Natural England to establish the current biological, physical and chemical composition of the South Walney lagoons with particular regard to specific attributes as indicated before. It was important that statistically rigorous methods were applied in order to complete the survey, for ease of replication for future surveys, and to that end the techniques used in previous surveys (Bamber et al., 2001) were consulted when developing the methodology for the 2013 report. In addition, the Common Standards Monitoring Handbook for lagoons (JNCC, 2004), Water Framework Directive and National Marine Biological Analytical Control Scheme (NMBAQCS) were also consulted during methodology development and condition assessment against set targets.

4.1 Extent

The current lagoon complex located in South Walney consists of approximately 16.7ha of lagoon habitat, divided into 11 pools, ranging in maximum depth from 0.13m to 5.7m. The extent of each basin was mapped at site, and compared to OS maps and aerial photograph from 2003 (Figure 10). The overlay of data shows how little the pools have changed with regards to surface area coverage from 2003 to 2013. Where there are points out of place from the outskirts of the pool, this represents an inability to take the coordinate from the current border of the pool, due to unfirm ground etc. The only exception was for Pool 11, which in 2003 was dry, whereas in 2013 it was partly covered by water; only the pool to the left of the imaginary line connecting points 11-3, 11-4 and 11-5 (Figure 10) was not open water in 2013, this area corresponding to a wetland area, where dense and tall reeds (mostly *Phragmites australis*) were observed.

When compared to the basin extent values given by Bamber et al. (2001; with a cumulative extent of 15.71ha throughout the system), a general increase in the basin extent was observed. This was mostly due to the increase in the area of Pool 2/3 and Pool 5. The larger area of Pool 2/3 in 2013 is due to the joining of the two lagoons that were partly separated by a split in 2001; this change most likely occurred between 2001 and 2003 as the split is not evident in aerial photos taken that year (Figure 10). As for Pool 5, the comparison with maps given in Bamber et al. (2001) showed that the smaller extent of the basin in 2001 was most likely due to larger dry areas occurring on the western side of the pool (both along the northern and southern margins). It is of note that in 2013 Pool 11 had a notably smaller area compared to 2001, when most of the lagoon was inundated (Bamber et al., 2001). Comparison between information from 2001, 2003 and 2013 shows how the extent of the water in this pool is highly variable, likely depending on the seasonal/annual precipitation regime. The fact that this pool tends to undergo dry periods was confirmed by the cracking patterns observed on the bottom sediments, and this frequent emersion makes more difficult to estimate the basin extent with precision.

Considering the increase in extent recorded overall in 2013 compared to the 2001 baseline, and that the notable reduction in the extent of Pool 11 can be ascribed to the natural variability in the seasonal/annual precipitation regime, the condition of this attribute can be considered as favourable.

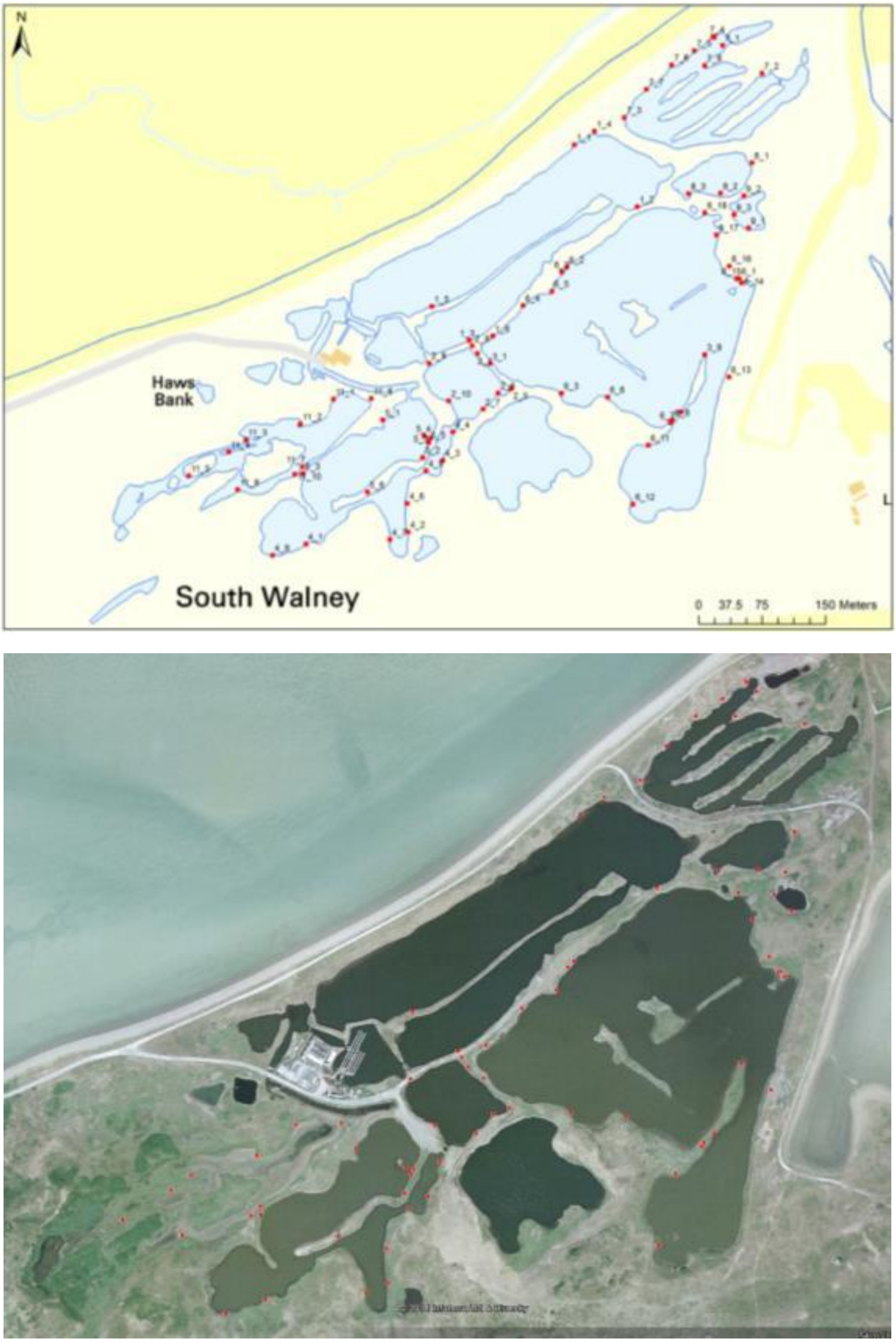

Figure 10. Extent of basin coordinates taken in 2013, over OS map (above) and aerial photograph showing extent in 2003 (below).

4.2 Isolating barrier and water inputs

The isolating barrier corresponding to the South Walney lagoon system separates Pool 1 and 7 from the Piel Channel, part of the Morecambe Bay EMS. The barrier was in good status and no notable issues were detected. Similarly to what has been reported by Bamber et al. (2001), connectivity with the bay is maintained through a sluice to the West of the site, controlled by the oyster farm on site. Inflow and outflow of water across the barrier is somewhat dictated by the tide, which maintains a supply of saline water to the sluice, and subsequently Pool 1, and by the management from the oyster farm. The pools in this lagoon system were artificially made, and the soft sediment basins maintain a groundwater percolation system which inundates the more inland isolated pools (6-11) with small amounts of saline water. Other than this, water inputs are fresh waters, entering the pools through surface run-off, direct rainfall or groundwater percolation. Although a narrow stream providing Pool 5 with low salinity water from Pool 11 was reported previously (Bamber et al. 2001), this could not be detected in 2013. Also no evident freshwater inputs as surface water were observed in 2013, contrary to what has been observed in 2001, although this is most likely a result of the different season of the two monitoring surveys.

Considering the status of the isolating barrier and the connectivity with the bay, the overall condition of this attribute can be considered as favourable.

4.3 Water circulation and salinity regime

Pools 1-5 all maintain varying degrees of connectivity with each other. In addition to saline water flow from the sluice pool to Pool 1 (with a clockwise circulation within this pool), water also appears to flow from the sluice pool into Pool 5 at the northern corner, and through to Pool 4 via the channel at the southern corner of Pool 5. Pool 4 is connected to Pool 2/3 via a shallow channel at the north corner, through which water flows in this direction, and back into Pool 1. An open drain is also present between Pool 1 and 6, thus allowing intake of more fresh water from Pool 6 into Pool 1.

Due to the nature of water inputs and connectivity within the lagoon system, salinity can be variable, and can therefore be considered an important contributing factor to the formation of floral and faunal communities within lagoon systems. The salinity regime reflects the water inputs, circulation and connectivity within the lagoon system, with the highest salinities (polyhaline to euhaline conditions) found in the pools that have direct (through the outfall; Pool 1 and 5) or indirect (through other pools; Pool 2/3 and 4) input of seawater from the bay. Within this circulation cell, a notable salinity change (from euhaline to polyhaline conditions) has been observed at the water surface in Pool 1 between the northern and southern-eastern areas, this reflecting the input of less saline fresh water from Pool 6 through the open drain mentioned above. Lower salinities were found in the other pools which do not have any input of fresh seawater (mesohaline conditions in Pools 6 to 10 and oligohaline conditions in Pool 11).

At present, pools 1-5 cohere to the guideline suggested by Bamber *et al*. (1992) which recommends salinities >20‰ to be able to support functioning saline lagoonal communities, which accounts for the higher abundances of lagoon specialist species in pools 1-5. Within pools, stratification occurred predominantly in Pool 1, likely due to the combined direct saline water input from the sea at the bottom and less saline waters at the surface from Pool 6. Stratification elsewhere is less marked, likely caused by increased mixing in the water column due to currents or water flow (pools 2, 3, 4 and 5) or variable sheltering from the margins. For example, a high vertical mixing was observed in Pool 10 that be attributed to lack of sheltering (low margins surrounding Pool 10) combined with the windy conditions during the survey of that lagoon. Thermal stratification, with warmer water seen towards the surface and cooler waters towards the bottom, was generally expected due to seasonality of the survey. However this was highly affected by the wind conditions on the day of survey and the relative shelter of the pool (e.g., with vertical thermal gradient was more evident in Pool 6, whereas it was less notable in Pool 10, where vertical mixing of water occurred).

When comparing 2013 data with previous observations, salinity in pools 1-5 notably increased between 1988 and 2001, but remained at a similar level between 2001 and 2013 (Table 11). Pool 1 showed the highest stability in salinity conditions over time compared to other pools, a likely effect of the sea water inflow into this pool, as maintained by the oyster farm through regulation of the sluice opening located in the western side of the pool. It is evident from the salinity data provided by Lumb (1988) and Hill et al. (1987), that, historically, pools 2 to 5 had much lower salinities (indicating mesohaline conditions) compared to 2001-2013 (when poly/euhaline conditions were observed). It is possible that this is due to natural freshwater inflows, such as direct rainfall, surface runoff and groundwater percolation, as well as a lower level of connectivity between pools 2 to 5 and Pool 1 than there exists today (and in 2001), and through it, of water inflow from the sea (excluding percolation through the isolating barrier). In turn, salinity in pools 6-11 showed a decrease between 2001 and 2013 (no data for 1988 were available), suggesting a likely increase in freshwater inflows (through direct rainfall, surface runoff and groundwater percolation) and a possible increased degree of isolation from exchanges with sea water. This seems to agree with the reported tendency of percolation lagoons to become fresh water, as a result of natural siltation preventing percolation of seawater into the system (JNCC, 2004).

Table 11. Recent (2013) and historic salinity data from Hill et al. (1987), Lumb (1988) and Bamber et al. (2001). To allow comparability, range and mean value of surface salinity is reported for 2013. Highlighted in grey are salinities below the value (20) recommended by Bamber et al. (1992) for supporting successful coastal saline lagoon communities.

Pool No	1986 data	1988 data	2001 data	2013 data (mean)
1	26.5	22-29	30	24.8-31.8 (29.7)
2/3	12.5	8-10	29-30	29.9-31.5 (30.9)
4	10.1	8-10	29	31.1-31.7 (31.3)
5	12.2	8-10	29	31.4-31.6 (31.5)
6	12.0		21	15.6-16.9 (16.7)
7	8.7		23	16.9-17.8 (17.3)
8			17	10.1
9	8.0		12	6.5
10			20	12.4
11			9	2.6

It is of note that the salinity regime highly affects the biotic composition of the lagoons and the above mentioned changes over the years are most likely responsible for some of the changes in the distribution of certain species in the pools (see Section 4.7). On the whole, a favourable condition could be identified, particularly in Pools 1 to 5, thanks also to the fact that they retain a certain degree of connectivity with the sea. In turn, salinity in Pools 6 to 11 does not meet the criteria for these pools to support successful saline lagoon communities, as confirmed also by the species composition (Section 4.7). It is of note however that the observed changes in the salinity regime are likely due to natural processes. In addition, uncertainty is associated to this assessment, as a one-off salinity measurement is not considered enough to fully assess the salinity regime in coastal lagoons, considering the natural fluctuations of this parameter.

4.4 Water depth

With the exception of Pool 1, the depth variability of the South Walney lagoons reflects their origin (following gravel extraction), with a gradual increase from few centimetres at the shallow margins to maxima between 2.3 and 5.7m measured in central areas of the basins. Higher maximum depth (>5m) was recorded in Pools 5 and 10. In turn, very shallow depth (always <30cm) were observed throughout Pool 11.

Comparison with previous data was possible, as the survey design in 2013 allowed for some overlap with stations sampled in 2001 (Bamber et al., 2001). No major changes could be detected when considering overlapping stations[24] (Table 12). However, central (deeper) areas in several pools were not surveyed in 2001 therefore 2013 data likely provide a more comprehensive baseline dataset (Table 12).

Table 12. Recent (2013) and historic depth data (m) from Bamber et al. (2001). Values in brackets indicate depth of additional stations, not sampled in 2001. No deep areas are present in Pool 11.

[24] As no coordinates were available for 2001 stations, their position was derived from visual examination of the site map, therefore the correspondence between stations in 2013 and 2001 was approximate. This likely contributed to minor variability in depth between the two years.

Pool	Station type	2001 data	2013 data
1	shallow	-	0.3
1	deep	1.25-4.5	1-4.5
2/3	shallow	0.3	0.2-0.3
2/3	deep	-	3.9
4	shallow	0.25-0.8	0.2-0.3
4	deep	-	1.2-2.3
5	shallow	0.2	0.2
5	deep	-	1.4-5.7
6	shallow	0.2-0.4	0.2-0.25
6	deep	1.5-2	1.9-2.4 (to 4.5)
7	shallow	0.15-0.2	0.15-0.35
7	deep	-	1.9-2.8
8	shallow	0.7	0.2
8	deep	-	1.5-2.8
9	shallow	0.15	0.23
9	deep	-	2.4
10	shallow	-	0.3
10	deep	4.5	5.5 (1.8-5.2)
11	shallow	0.15	0.13

Shallow habitats (≤ 1m depth) are considered as the most relevant to lagoonal invertebrates or plants (Bamber et al., 1993), therefore marginal areas of the studied pools represent an optimal condition in the lagoon environment. However, the presence of deeper water within the lagoons likely increases their ability in buffering against impact events, for example leading to lower fluctuations in the water conditions following weather changes. The lack of this buffering effect of deeper waters was particularly evident in Pool 11, a very shallow pool, where reduced water extent (with consequent encroaching of riparian vegetation into the lagoon basin) and signs of reduced water levels and previous exposure of the habitat to air (deep cracks in the mud) were observed, due to dry weather conditions earlier in the year.

Considering the minor changes in the water depth compared to previous data as well as the possible effect of seasonal changes in the balance between precipitation (rainfall) and evaporation rates, the overall condition of this attribute can be considered as favourable.

4.5 Water quality

In general, results for temperature and pH measurements revealed some homogeneity across all pools within the lagoon system, with temperature having a range of approximately 5°C, although with changes along the depth profile present at some pools and pH typically ranging between 8 and 10 (with sea-water regularly ranging between 7.8 and 8.4). In terms of temperature, short term fluctuations are likely to be due to season and temperature of inputs, whilst in the longer term the shallow nature of most pools will likely lead to rapid influence from both insulation and evaporative cooling (Bamber, 2010). pH balances are known to fluctuate temporally (seasonally) and spatially, and therefore continuing assessment may be required. Fluctuations in pH due to season can be instigated by phytoplankton blooms, caused by high organic content in the water and higher temperatures. Increases in phytoplankton abundance subsequently lead to higher rates of photosynthesis and a reduction in CO_2 content in the water (Bamber, 2010). This causes an increase in pH, and as the 2013 survey was conducted during the summer, this is likely to account for the pH rates at South Walney being higher than sea water. However, wide pH ranges (from <7 to >9) and temperature variability as observed in the South Walney lagoons are common natural conditions reported for coastal lagoons (Bamber, 2010).

Percentage saturation of dissolved oxygen exhibited tendencies that might be expected, in particular because in general, higher mobility of water means higher dissolved oxygen content in the water column. In 2013, dissolved oxygen was slightly lower in the isolated Pools 7, 9 and 10 than it was in the pools with greater connectivity and therefore higher water movement such as Pools 3, 4 and 5; however the differences between these were marginal in places, with saturation levels in the water being close or higher than 100% in most of cases.

In general, nutrient concentration (mg/L) was higher in the pools with higher connectivity with sea water, and therefore greater water flow, such as pools 1, 2, 3, 4 and 5, than it was in the pools not receiving sea water inputs[25] (Pools 6, 7, 8, 9, 10, 11). The key exception to this was the concentration of silicate found in Pool 10, which was notably higher than in the other pools. Also, levels of orthosphosphate were notably higher at Pool 1 than in the other lagoons. It is unclear whether the concentrations of the nutrients measured here are within the boundaries to allow lagoonal communities to develop, as guidelines for lagoonal habitats are yet to be developed. As no previous assessment of nutrient enrichment was undertaken, the data obtained in 2013 are to be considered as a baseline for future comparisons.

The oyster farm staff reported possible algal blooms, oxygen depletion and consequent mortalities of oysters earlier in the summer 2013, signs of possible indication of nutrient enrichment (Johnston and Gilliland, 2000). However, these blooms were a consequence of high water temperatures recorded at the ponds, and measures were taken (through sluice management) to re-establish favourable conditions. At the time of the survey, abundant algal vegetation, with filamentous algae and epiphytes was still observed on site, but this did not reflect on poor oxygenation levels and it is considered within the normal variability characterising summer conditions in coastal lagoons. Therefore the conservation interest of the feature was not compromised and condition for nutrient enrichment is suggested to be favourable. A degree of uncertainty is associated with this assessment as a one-off measurement is not considered enough to fully assess the nutrients enrichment in coastal lagoons, considering the natural fluctuations of these variables.

4.6 Sediment characteristics

Sediment composition of lagoon pools are generally a combination of the original sediment present prior to lagoon closure, and the subsequent input of finer silts and clays, where it is coarser than this, such as sand or gravel, so that the substratum gradually becomes finer over time (Bamber, 2010).

In general, the type of sediment encountered in South Walney lagoons in 2013 related to position within the pool, as opposed to differences between pools. For example along the water line, patches of cobbles and boulders were found in almost every pool, typically covered in diatom algal mats. Sediment samples taken from deep stations had higher content in finer particles (mostly silt), while, where soft sediments were presents along the margins, these had a higher content in fine sand. Similarly, in the 2001 survey, shingle with overlying sand was found in shallow areas, with transitioning to finer mud in deeper parts of the larger pools. This

[25] Not taking into account inputs through percolation.

sediment type zonation is repeated in the 2013 survey, but with a finer sediment composition overall, possibly confirming the tendency of sediments to become finer with time, as suggested by Bamber et al. (2010).

Sediments in the South Walney lagoons were mostly in anoxic conditions, with the surface RPD layer often <1cm. This was more evident in sediments obtained from deeper areas of the pools, where anoxic conditions were found to the sediment surface.

Coastal saline lagoons can be described as sinks for organic matter, as the input of material is generally greater than the output, due to lagoon hydrodynamics and further organic material being generated in the lagoon (Bamber, 2010). In the South Walney lagoons, higher organic content was found in the sediments of Pool 11 (8%), Pool 10 (5%) and Pool 1 (3%) compared to sediments in the other pools (where the organic content was below detection limit). However, these are relatively low values compared to the organic content of 10-15% reported as typical for lagoon sediments, and are more similar to values generally observed in costal muddy-sands (3 to 8%) (Bamber, 2010).

Regarding contaminants within the sediment, high levels of both organic and inorganic compounds were noted in several sites, but levels of Polycyclic Aromatic Hydrocarbons (PAHs) were found to be particularly high in Pool 1. PAHs contamination was detected also in Pools 5, 6 and 10, although this was limited only to high concentrations of Naphthalene. Further assessment of PAHs in Pools 1, 5, 6 and 10 is required, as the behaviour of PAHs in aquatic systems can be influenced by a number of biological, chemical and physical processes, and whilst some, such as biotransformation or biodegradation can result in the transformation of PAHs into other substances; other processes such as adsorption, desorption or resuspension are responsible for the recycling of these substances throughout the aquatic environment (CCME, 2001). Pool 1, as well as Pools 11 and 10 showed also metals contamination. Although contaminant concentrations were never above probable effects levels (PELs; CCME, 2001), hence excluding high likelihood of toxic effect on bottom dwelling organisms (e.g., decreased abundance, diversity and growth), moderate likelihood of these effects was identified in Pools 1, 5, 6, 10 and 11, following high contaminant levels highlighted above (> Interim Sediment Quality Guidelines, ISQGs; CCME, 2001). Although in most pools no evident sources of toxic contaminants could be identified, metal contamination in Pool 7 is likely to be associated with the former presence in this site of a military construction which was abandoned before completion and dismantled (with remnant material still present on site). In turn, contamination in Pools 2/3, 4, 7, 8 and 9 were always below ISQG levels (and often below detection limit for measurement apparatus), therefore these pools were assessed as in favourable condition.

Due to the level of water exchange in lagoonal environments, they can be particularly susceptible to toxic contamination. The characteristics of lagoons, such as singular pools or basins with few inflow or outflow opportunities, means that once impacted by inputs from toxic contaminants, recoverability from associated impacts is likely to be slow, and detrimental to communities supported by the lagoon habitat (Common Standards Monitoring report). Therefore, it is essential that sediments be assessed regularly for fluctuations in their compound concentrations, as early detection of any instability associated with the substrata is preferable.

4.7 Biotic composition

4.7.1 Floral communities

In contrast to what was reported during the previous monitoring survey (in January 2001), the pools in 2013 where highly vegetated, with *Enteromorpha* being the most widespread and abundant algal species, and with sediment and hard substrata (boulders etc.) being largely covered by epiphyte and filamentous algae (Cladophoraceae). These results were markedly different from the general absence of algal vegetation reported in 2001, and this difference is most likely the result of seasonal variability between the 2001 (January) and 2013 (August) surveys, with the 2013 being carried out during the summer period when peak vegetation coverage is expected.

General habitat composition across the lagoon system with regards to floral communities, typically consisted of grasses and plants more typical of terrestrial and upper saltmarsh habitats, fronted by mid marsh species, and then more euryhaline species towards the water line, with abundant algae at and below the surface.

In addition, the western area of Pool 11 appeared to have little saline influence, and vegetation species found in this section of the lagoon system included the terrestrial species *Phragmites australis*, and several species of bracken and grasses, thus reflecting highlighting the differences in vegetative community that can occur with salinity changes.

Differences in species according to salinity changes are most notably shown in the algal composition between pools, where the salinity tolerant *Enteromorpha* and Cladophoraceae algae (possibly *Cladophora* and *Rhizoclonium*) were found in large patches fringing most pools, and generally with high abundances. A slightly different composition was found in Pool 9, which was mesohaline and therefore supported the species such as the fennel pondweed *Potamogeton pectinatus*. This was briefly referred to in the 1988 data supplied by Lumb (1988) where lower salinity particularly in pools 3 and 4 was associated with the presence of this species, an aquatic macrophyte with a low tolerance for saline conditions. The increase in salinity observed in Pools 3 and 4 since 1988 accounts for the disappearance of *P. pectinatus* in both the 2001 and 2013 data, with a consequent increase in presence of brackish faunal species such as *Monocorophium insidiosum* and *Idotea chelipes*. In turn, the decrease in salinity likely accounts for the presence in 2013 of *P. pectinatus* in Pool 9 where it was absent in 2001. In addition, the non-native invasive alien *Crassula helmsii* was noted as inhabiting the western margin at Pool 9, and abundance is likely to increase due to its fast and aggressive nature (Global Invasive Species Database).

4.7.2 Faunal communities

Highly diverse and abundant faunal assemblages were recorded in 2013 (78 taxa and 14,621 individuals overall; Appendix IX) compared to 2001 (33 taxa and 7,225 individuals overall), this result being highly influenced by the seasonal variability of faunal assemblages, with predominant recruitment in the summer (2013) and higher mortalities in the winter (2001). Also the presence of abundant vegetation in the summer (and the additional assessment of associated fauna) influenced these findings in 2013[26].

Similarly to 2001, faunal assemblages were generally more abundant and diverse in the shallow marginal areas compared to deeper areas, this result being likely related with the higher anoxic conditions in deeper sediments and the seasonal abundance of algal vegetation along the margins in 2013 creating a suitable feeding habitat for several species. Also differences in salinities among pools seem to partly explain some of the differences observed in the faunal assemblages sampled at the lagoon margins in 2013. Marginal assemblages in pools with poly/euhaline conditions (Pools 4 and 5) were generally characterised by higher abundances of typical estuarine taxa (e.g., tubificid worms) and lagoonal species (e.g., *M. insidiosum*), whereas insect larvae and other species less tolerant of saline waters and preferring fresh water conditions (e.g., *Potamopyrgus antipodarum*) were more abundant and frequent in oligo-mesohaline pools (Pool 7-9 and 11).

The survey season is an important factor to be taken into account when assessing biological assemblages, as, through temperature changes and consequent changes in populations (e.g., with peaks in vegetative growth and in recruitment mostly occurring in the summer), the distribution and variability of biological communities may highly vary. It is of note that the weather at time of survey (August 2013) was hotter than expected and predicted, and pool temperatures in some places were recorded as 26°C by the oyster farm onsite. With the higher temperatures, the oyster farm was regulating their sluice pool more frequently, flushing the excess algae and renewing DO content in Pool 1 (and, indirectly, in Pools 2 to 5). With algal blooms likely higher in the isolated pools due to relatively high temperatures in 2013, DO content could be lower in this survey in comparison to future surveys, where even summer temperatures are likely to be lower than those observed on this survey. Factors such as this should be considered with regard to comparisons between the 2013 data and 2001 data also, as these were conducted in January, and therefore differences will occur due to seasonality as much as temporal scale. All comparisons made here are therefore to be taken with caution.

The faunal assemblage has retained many of the specialist species which are important indicators regarding the development and condition of an ecosystem such as saline lagoons. The species highlighted as specialised for saline lagoon environment are the amphipod *Monocorophium insidiosum*, isopod *Idotea chelipes*, and the molluscs *Ecrobia ventrosa* and *Cerastoderma glaucum*. Regarding vegetation, two key lagoonal species that should have further monitoring along with the bryozoan *Conopeum seurati* are *Enteromorpha spp*. and *Chaetomorpha spp*., which were found throughout the lagoon system in the 2013 survey. The continued presence of these species would mean the further development of the South Walney lagoon system.

In 2013, *Monocorophium insidiosum* was found in most of pools (Pool 1, 4 to 7 and 11). Its presence in Pool 4 to 7 confirmed previous observations in 2001, although variable abundance was found in benthic samples between the two years, with a decrease in Pool 7 and a general

[26] When samples of epifauna amongst vegetation are excluded (for comparability with 2001 data), 2013 faunal abundance (12,118 individuals) is still higher than abundance in 2001.

increase in the other pools (particularly Pool 4 and 5, where the presence of the species was reported also in 1988) (Table 13). Notably, in 2013, the amphipod was absent from Pool 2/3, where the species was highly abundant in 2001 and frequent in 1988 (Bamber et al., 2001), and from Pool 8, where it was recorded in 2001 (Table 13). In most of cases, the temporal changes in the distribution of the *M. insidiosum* across the lagoons can be related with changes in the salinity regime of pools, reflecting the species preference for brackish habitats. For example, the decrease in Pool 7 and increase in Pool 4 and 5 between 2001 and 2013 are likely to reflect the increase and decrease in salinity, respectively (from polyhaline conditions in 2001 to mesohaline conditions in Pool 7 and to euhaline conditions in Pool 4 and 5 in 2013). The decrease in salinity might be responsible also for the disappearance of *M. insidiosum* from Pool 8. However, the novel presence of the species in Pool 1 and 11 (the latter recorded from nekton samples) in 2013 compared to previous data suggests a wide tolerance of the species for variable salinity, as these two pools were at the opposite extremes of the salinity range in the system (Table 13).

Table 13. Abundances of specialist lagoon species in benthic samples collected in 2001 and 2013 (ind./0.05m^2).

		Pool average 2001 (ind./0.05m²)											
Group	Taxon	1	2*	3*	4	5	6	7	8*	9*	10*	11*	Total
Amphipod shrimp	Monocorophium insidiosum	0	892	201	36.0	14.5	13.2	151	36	0	0	0	1344
Isopod shrimp	Idotea chelipes	0	0	0	0	0	0	3.5	5	0	0	0	8.5
Lagoon cockle	Cerastoderma glaucum	0	0	0	0	0	0.4	0	0	0	0	0	0.4
Bryozoan	Conopeum seurati	0	0	0	0	0	P	P	P	0	0	0	P

		Pool average 2013 (ind./0.05m²)											
Group	Taxon	1	2	3	4	5	6	7*	8*	9*	10*	11*	Total
Amphipod shrimp	Monocorophium insidiosum	0.2	N/A	N/A	501	447	17.5	5	0	0	0	0	970.7
Isopod shrimp	Idotea chelipes	1.4	N/A	N/A	1	0	0	0	0	0	0	0	2.4
Lagoon cockle	Cerastoderma glaucum	0	N/A	N/A	0	0	0.3	0	0	0	0	0	0.25
Bryozoan	Conopeum seurati	0	N/A	N/A	0	0	0	0	0	0	P	0	P

The isopod *Idotea chelipes* was found in pools 1, 2/3, 4 and 5 in 2013, with particularly high abundance particularly amongst macroalgal vegetation. Abundance of the species was reported in Pool 1 also in 1988, whereas its distribution was restricted to Pool 7 and 8 in 2001 (Table 13; Bamber et al., 2001). The decrease in salinity between 2001 and 2013 could be responsible for the disappearance of the species from samples collected in these two latter pools, whereas the high vegetation coverage recorded in the summer of 2013 might be responsible for the recent occurrence also in Pools 2/3, 4 and 5. *I. chelipes*, in fact, are reported to consume macroalgae of the genera *Ulva* (*Enteromorpha*) and *Cladophora*, and also to graze on epiphytic diatoms and cyanobaceria (Sommer, 1997; Leindenberger et al., 2012). Therefore the increased availability of their preferred feeding habitat in 2013 (also due to seasonal factors) is likely responsible for the wider distribution of the species, with the connections between Pools 1 to 5 likely favouring the spread of the species.

The lagoon cockle *Cerastoderma glaucum* has been reported in the past only in marginal areas of Pool 6 (a total of 2 individuals was found at stations 6-3 and 6-2; Bamber et al., 2001; Table 13). In 2013, only one individual of the species was found in the sample collected in station 6.3, confirming the sparse distribution of the species in this pool.

In 2013, the lagoon mud snail *Ecrobia ventrosa* was found (albeit not in benthic samples, and with only 1 individual) in the marginal station 5.2 in Pool 5, where no previous records are reported. In turn, a record of the species is only reported in 1988 in Pool 1, where this mollusc was reported as common (Lumb, 1988), whereas the species was notably absent from all the pools in 2011 (Bamber et al., 2001).

As regards the bryozoans *Conopeum seurati*, in 2013 the species was detected in benthic samples from Pools 1, 4 and 6 and attached marginal boulders in Pool 2/3. The occurrence of the species in Pool 2 and 6 was also reported in 1988 and 2001, respectively. In turn, the notable presence of the species in Pool 8, where it was found in 2001 in unusual maer-like accretions, was not confirmed in 2013. However, it is of note that the high turbidity of water detected in this pool in 2013 prevented to see any possible formations on the bottom of the lagoon; therefore the presence of *C. seurati* in Pool 8 cannot be excluded in 2013.

On the whole, an improvement in biotic composition has been observed in the South Walney lagoons between 2001 and 2013, due to the seasonal availability and abundance of aquatic vegetation providing a preferred feeding habitat for a number of species. The faunal assemblage has retained the specialist species found previously on site, confirming the presence of typical lagoonal communities, particularly in Pools 2/3, 4, 5, 6 (with also abundance of typical estuarine species including annelid polychaetes, tubificid oligochaetes and crustaceans). Some changes in the distribution of communities and lagoonal species within the system have been observed, often associated with the variability in salinity conditions between 2001 and 2013. Similarly to 2001, floral and faunal communities in Pools 9 and 11 reflected freshwater influences, with the presence of species preferring such conditions (e.g., *Potamogeton pectinatus*, *Potamopyrgus antipodarum*, diptera larvae) and the absence of lagoonal specialists. In 2013 similar conditions were found also in Pools 7, 8, and 10 where a decrease in salinity was recorded compared to 2001. In turn, lagoonal specialist species were found in Pool 1, contrary to 2001, but in agreement with previous observations (Lumb, 1988). Considering the biotic composition and changes highlighted above, a favourable condition is suggested for this attribute in 2013.

4.7.3 Biotope distribution

It is suggested by the Common Monitoring Handbook for lagoons (JNCC) that biotope composition is an essential structural component, and therefore should be addressed in a condition assessment. However, it should also be considered that the South Walney lagoons are a fragile ecosystem, which too much disturbance, i.e. through the plotting of transects, could cause undue stress and disturbance to the lagoonal communities. Therefore, biotopes could not be quantitatively mapped (as in other intertidal or subtidal environments) as disturbance had to be reduced at the minimum, therefore qualitative and quantitative data obtained in 2013 were combined to identify biotopes in agreement with their characteristics as described by Bamber et al. (1997).

It is suggested by Bamber et al. (1997) that lagoons are fundamentally uniform regarding sedimentary biotope, and this is largely true here. In general, regardless of size or water condition, sediment assemblages at the pools consisted of larger pebbles, boulders and gravel, transitioning into finer, usually anoxic sands at the margins, with siltier sediments towards to bottom of the basin, sometimes including a layer of clay. It is further suggested that variations in community are controlled by salinity within the lagoon, which has also been shown by the data collected on this survey.

The biotope **ENLag.Veg** is characterised by a community associated with submerged vegetation, irrespective of substratum or plant species. The vegetation may or may not be attached to the substratum with relevant characterising species *Enteromorpha spp*., *Chaetomorpha spp*., *I. chelipes*, *M. insidiosum*, *Gammarus spp.* and *E. ventrosa*. Within the South Walney lagoons, this biotope is widely spread. Examples of appropriate assignation of this biotope include station 1.4 in Pool 1, and along the northern margin of this pool; along the southern margin of Pool 4, including stations 4.1 and 4.2; station 5.1 and the margins directly to the East and West of the station in Pool 5; and the eastern margin at Pool 6, encompassing station 6.1. All these stations and surrounding areas are characterised by the presence of either or both algal species, and at least 2 of the identifying faunal species.

Station 9.1 in Pool 9 and Station 11.1 in Pool 11 are identified as low salinity habitat, with the biotope **ENLag.Veg.Pot** being found particularly at station 9.1, due to the presence of salinity intolerant aquatic macrophyte *Potamogeton pectinatus.*

Another possible biotope which may be suitable, are **ENLag.IMS.Ann**, which describes fine sandy sediments with an annelid worm dominated community. This could apply to station 1.4 in Pool 1, as both characterising species *Polydora ciliata* and *Capitella capitata* are present at this site. However, as the abundance of *I. chelipes* and *M. insidiosum* is so dominant in this community, it is more likely the initial assessment for Station 1.4 is accurate.

Compared to data from 2001 monitoring, in 2013 it is evident the presence and wide distribution of the vegetated habitat in the lagoon system (including ENLag.Veg), particularly in shallow marginal areas, with a low salinity variant in Pool 9 (ENLag.Veg.Pot). Vegetated habitats were identified also in 1988, particularly in Pool 1 and Pools 4 and 5 (low salinity habitats). In turn, the bare habitat characterising most of the lagoon margins in 2001 (ENLag.IMS.Ann) was less represented in 2013, particularly in marginal areas. This variability in habitat presence and distribution is mostly ascribed to the seasonal differences occurring between the surveys in 2001 and 2013, and, on the whole, the condition of this attribute is considered as favourable in 2013.

4.8 Conclusions

The overall results of the condition assessment of South Walney lagoons are summarised in Table 14.

It can be seen from the results and consequent assessment that in general, lagoon habitats are variable and fragile, with this variation occurring spatially and temporally in extremes of both. Although the South Walney lagoon feature is assessed as a whole, variability within the system has been observed, mostly associated with the salinity gradient among pools reflecting water circulation and inputs and different degree of isolation from water exchanges. Most parameters measured are related to one another (e.g., water exchanges with salinity and this latter with biotic composition; biotic diversity and depth) and spatial patterns can be identified in the system. Natural stochastic variability is inherent in this type of systems, in addition to cyclical changes associated with natural fluctuations in the environmental conditions (e.g., with season, tidal condition, inter-annual variability). Therefore taking into account the natural variability of the system (on spatial and temporal scales) is highly important to develop appropriate baseline datasets, hence to identify relevant changes.

The water parameter which appears to affect distributions in community composition the most is salinity. In ephemeral habitats such as lagoons, this parameter is likely to undergo natural fluctuations within and among years, in relation to seasons and tidal regimes, weather conditions, and sluice management. Therefore it is clear that a one-off value, as measured in this and previous monitoring studies, cannot be considered as representative of the salinity regime of the system. There is a need for on-going monitoring of salinity in order to allow the establishment of an appropriate baseline (including natural variability) hence the assessment of this attribute. The use of long-term salinity loggers would be highly beneficial for this purpose, and it is acknowledged that this option is under consideration with Natural England. In addition, the natural evolution of lagoon systems (e.g., of percolation lagoons towards freshwater) needs to be taken into account in the condition assessment, e.g. by regularly revising targets so that natural changes in the salinity regime can be considered within a wider geomorphological context (JNCC, 2004).

Similarly, continued monitoring of faunal communities is required to establish trends in faunal composition and distribution, in particular those species identified as 'lagoon specialists'. In addition, the invasive alien plant *Crassula helmsii* in Pool 9 should be further monitored, to chart its progression through the pool, and perhaps the lagoon system.

Considering the small number of saline lagoon ecosystems along the north-western coast of England, and the unique nature of abiotic and biotic parameters featured at each, South Walney represents an important ecological resource, and therefore should be seen as a conservation priority. Regular monitoring and assessment is an important part of any conservation effort, as maintaining a database may provide insight into future issues, helping to solve or prevent them before any action detrimental to the holistic integrity of the lagoon system is permitted.

Table 14. Condition assessment of South Walney lagoons (2013).

South Walney lagoon system, 2013 monitoring					
Attribute	**Previous baseline**	**Status 2013 (Summer)**	**Change**	**Condition 2013**	**Comments**
Extent	2001 (January)	16.7ha	Overall increase (from 15.7ha)	Favourable	A notable reduction in the water extent was observed in Pool 11 (25% covered by riparian vegetation), but this was ascribed to the natural variability in the seasonal/annual precipitation regime
Isolating barrier and water inputs	2001 (January)	Barrier in good status; no notable issues detected. Water inputs from sluice maintained and operated by oyster farm.	No change	Favourable	
Salinity regime	2001 (January)	Pools 1-5: salinity >20 (polyhaline to euhaline). Pools 6-11: salinity <18 (mesohaline) with values <5 in Pool 11 (oligohaline). Some water stratification observed. No notable freshwater input (as surface water) observed.	Pools 1-5: no major change. Pools 6-11: decrease in salinity to values <20. No water stratification in 2011, when some freshwater input (as surface water) were also observed.	Likely* favourable in Pools 1-5 Possibly* unfavourable in Pools 6-11	Favourable conditions meet guidelines given by Bamber et al. (1992; salinity >20). Also changes from baseline are considered, although these are likely attributable to natural processes. *Uncertainty is associated to this assessment, as a one-off salinity measurement is not considered enough to fully assess the salinity regime in coastal lagoons.
Water depth	2001 (January)	Margin depth = 0.15 - 0.3m Maximum depth = 2.3 - 5.7m	No change	Favourable	
Nutrient enrichment	no previous assessement	Ammoniacal Nitrogen = <0.02 - 0.071 mg/L Nitrite = <0.004 - 0.0136 mg/L Nitogen:total oxidised ≤0.01 mg/L Ortophosphate = <0.01 - 0.475 mg/L Silicate = <0.20 - 1.84 mg/L	n.a. (2013 constitutes baseline)	Possibly* favourable	Guideline concentrations (e.g., Environmental Quality Standards) are not available as yet for coastal lagoons. Additional possible indicator of nutrient enrichment (algal blooms, oxygen depletion) were also considered. *Uncertainty is associated to this assessment, as a one-off measurement is not considered enough to fully assess the nutrient regime in coastal lagoons.
Toxic contamination	no previous assessement	Metals (dry weight in the sediment): Mercury = <0.002 - 0.372* mg/kg Aluminium (HF digest) = 9230 - 42400 mg/kg Iron (HF digest) = 6770 - 32300 mg/kg Arsenic (HF digest) = 1.37 - 18.7* mg/kg Cadmium (HF digest) = <0.03 - 1.01 mg/kg Chromium (HF digest) = 6.86 - 195* mg/kg Copper (HF digest) = 2.52 - 46.8* mg/kg Lead (HF digest) = 5.15 - 65.2* mg/kg Lithium (HF digest) = 6.64 - 43 mg/kg Manganese (HF digest) = 118 - 538 mg/kg Nickel (HF digest) = 3.9 - 123 mg/kg Zinc (HF digest) = 15.6 - 252* mg/kg (* indicates values higher than ISQG levels, suggeting moderate likelyhood of toxic effect on bottom dwelling organisms)	n.a. (2013 constitutes baseline)	Favourable in Pools 2/3, 4, 7, 8 and 9 Contamination issues in Pool 1 (metal & organic), Pools 5 and 6 (Naphthalene), Pool 10 (Chromium, Copper and Naphthalene) and Pool 11 (metals)	Contamination issues were identified with contaminants in concentrations associated with moderate likelyhood of toxic effects on bottom dwelling organisms (>ISQG but <PEL levels). Pool 1 in particular needs attention as contamination was identified for several metals and PAH compounds. Metal contamination in Pool 11 is likely due to presence of remnants on site from abandoned military construction.

Table continued ...

South Walney lagoon system, 2013 monitoring					
Attribute	**Previous baseline**	**Status 2013 (Summer)**	**Change**	**Condition 2013**	**Comments**
Toxic contamination (continued)	(see above)	Organic compounds (dry weight in the sediment): Hexachlorobenzene = <1 - ug/kg Hexachlorobutadiene = <1 - ug/kg Anthracene = <2 - 85.5* ug/kg Benzo(a)anthracene = <2 - 574* ug/kg Benzo(a)pyrene = <2 - 663* ug/kg Benzo(ghi)perylene = <10 - 335 ug/kg Chrysene + Triphenylene = <3 - 601* ug/kg Fluoranthene = <2 - 1020* ug/kg Indeno(1,2,3-c,d)pyrene = <30 - 384 ug/kg Naphthalene = <10 - 95.7* ug/kg Phenanthrene = <3 - 497* ug/kg Pyrene = <4 - 889* ug/kg Tributyl Tin = <4 - <10 ug/kg (* indicates values higher than ISQG levels, suggeting moderate likelyhood of toxic effect on bottom dwelling organisms)	(see above)	(see above)	(see above)
Species composition	2001 (January)	Abundant aquatic vegetation, with diverse and abundant faunal communities. Lagoonal specialists retained in the system. Typical lagoonal communities occurring in Pools 2/3, 4, 5, 6 and marginally in Pool 1 (but with lower diversity in deeper areas). Fauna related more to freshwater habitat in Pools 7 to 11, although with sparse lagoonal specialists in Pools 7 and 11.	Increased faunal abundance and diversity associated with presence of aquatic vegetation in 2013 (not detected in 2001). Some changes in the distribution of communities and lagoonal species within the system due to variability in salinity conditions between 2001 and 2013.	Favourable	Presence of invasive aline plant (*Crassula helmsii*) detected on site (Pool 9) needs attention due to its spreading potential.
Biotope (Habitat) distribution	2001 (January)	Vegetated habitat with associated fauna widespread in most of the pools, with ENLag.Veg identified in Pool 1 (N margin), Pool 4 (N margin), Pool 5 (NE corner and adjacent margins), Pool 6 (E margin), and low salinty variant ENLag.Veg.Pot identified in Pool 9. Patches of unvegetated muddy-sandy habitat interspersed within vegetation at lagoon margins (likely reflecting biotope ENLag.IMS.Ann) and occurring in deeper areas (generally with impoverished faunal communities).	Vegetated habitats (ENLag.Veg or ENLag.Veg.Pot) not occurring in 2001, due to seasonality of the survey, but detected in 1988. Unvegetated habitat (ENLag.IMS.Ann) less represented, particularly in marginal areas, due to seasonal abundance of aquatic vegetation.	Favourable	

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Appendix I. Stations sampled for biological communities in the South Walney lagoons (August 2013).

The number of replicate samples collected per station is given, as well as a general description of the habitat in the stations, based on qualitative observation on site.

			method	*corer*	*Eckman grab*	*push net (250um)*	*quadrat*	*weed vegetation*
			sampling unit	*$0.01m^2$*	*$0.025m^2$*	*5m haul ($1.25m^2$)*	*$1m^2$*	*0.5L weed*
Pool	**Station**	**stat. Type**	**Habitat description**	**Infauna**	**Infauna**	**Nekton**	**Algal veg.**	**Epifauna**
1	1.3	margin	Pebbles and boulders. Water depth 27cm	-	-	3	-	-
1	1.4	margin	Sandy substratum covered by dense *Chaetomorpha linum* coverage (down to 1-1.5m from shore); speckles of bare sand with presence of *Cerastoderma glaucum*, *Mya arenaria* and *Arenicola* casts. Water depth 27cm.	-	-	1	3	3
1	1.A	deep	Anoxic sediment. Water depth 2.9m.	-	2	-	-	-
1	1.B	deep	Anoxic sediment to the surface. Water depth 2.7m.	-	2	-	-	-
1	1.C	deep	Anoxic sediment. Water depth 3.3m.	-	2	-	-	-
1	1.D	deep	Difficult penetration of the grab, due to presence of dense bivalves (*Mya arenaria*). Water depth 1m.	-	2	-	-	-
1	1.E	deep	Anoxic sediment to the surface. Water depth 4.5m.	-	2	-	-	-
2	2.1	margin	Pebbles and boulders, with very sparse *Chaetomorpha* and *Enteromorpha* on the margin. Presence of *Idotea cheilpes*, *Littorina saxatilis*, *Haliplanella lineata* (anemone) and *Conopeum seurati* under boulders. Water depth 20cm.	-	-	3	-	-
3	3.1	margin	Thin sand layer (max 5cm deep) on boulders with no vegetation. Water depth 30cm.	-	-	3	-	-
4	4.1	margin	Small sandy embayment surrounded by pebbles. Steep shore with sparse *Enteromorpha,* more abundant along the margin (upper shore). Water depth 20cm. Sediments anoxic almost to the surface (RPD layer 1cm).	5	-	3	3	3
4	4.2	margin	Sandy area with sparse pebbles/boulders; sparse vegetation, *Enteromorpha* and filamentous algae (Cladophoraceae, possibly *Cladophora*). Water depth 30cm. Sediments anoxic almost to the surface (RPD layer 1cm on average, slightly deeper in lower shore).	5	-	3	3	3
4	4.3	margin	Pebbles highly vegetated (dense *Enteromorpha,* and filamentous algae (Cladophoraceae, possibly Cladophora)), with speckles of sand in lower shore. Presence of numerous gobies. Water depth 30cm (gentle slope). Sediments anoxic almost to the surface (RPD layer 1cm).	5	-	3	3	-
5	5.1	margin	Shallow grassy margin with sandy/gravelly sediment. Sparse vegetation (mostly *Enteromorpha*). Presence of *Mya areanaria* and *Arenicola casts* (nearby). Water depth 20cm. Sediments anoxic almost to the surface (RPD layer few millimeters).	5	-	3	3	3
5	5.2	margin	Shallow embayment, with soft substratum and sparse pebbles/boulders near the margin. Presence of *Arenicola* casts, and numerous gobies. Very sparse Enteromorpha vegetation. Water depth 23cm. Sediments anoxic almost to the surface (RPD layer few millimeters), with diatoms and presence of numerous air bubbles on the sediment surface.	5	-	3	3	-
6	6.1	margin	Sandy/gravelly embayment with sparse boulders/pebbles (denser in upper shore), encrusted with small filamentous algae (Cladophoraceae, possibly *Cladophora*). Numerous gobies on sand and around pebbles. Water depth 20cm. Sediments anoxic almost to the surface (RPD layer approx. 1cm).	5	-	3	-	-
6	6.2	margin	Pebbles and boulders, sparsely encrusted with filamentous algae (Cladophoraceae, possibly *Cladophora*), particularly in lower shore. Presence of amphipods (*Gammarus duebeni, Microdeutopus gryllotalpa, Monocorophium insidiosum*), isopods (*Jaera sp*.), *Littorina saxatilis*, anemones and *Conopeum seurati* under boulders. Steep shore. Water depth 25cm.	-	-	3	-	-
6	6.3	margin	Sheltered embayment with sandy sediment and pebbles/stones on the margin with encrusting algae (Cladophoraceae, possibly *Cladophora).* Steep shore. One moon jellyfish *(Aurelia aurita*) observed. Water depth 25cm. Sediments anoxic almost to the surface (RPD layer <1cm).	5	-	3	-	-
6	6.PM1	deep	Anoxic sediment to the surface. Water depth 2.4m.	-	2	-	-	-
6	6.PM2	deep	Anoxic sediment to the surface. Water depth 1.9m.	-	2	-	-	-
7	7.1	margin	Small patch of soft sediment amongst pebbles, with presence of algal mat (Cladophoraceae, possibly *Rizochlonium*) in small patch. Water depth 15cm. Sediments anoxic almost to the surface (RPD layer 1-3mm).	5	-	3	-	-
7	7.2	margin	Thin sand layer (max 5cm deep) on boulders/pebbles encrusted with filamentous algae (Cladophoraceae, possibly *Cladophora*). Presence of *Idoeta chelipes* and small hydrobiid gastropods under boulders. Water depth 30cm.	-	-	3	-	-
7	7.3	margin	Thin sand layer (max 5cm deep) on boulders/pebbles with presence of algal mat (Cladophoraceae, possibly *Rizochlonium*). Water depth 23cm.	-	-	3	-	-
8	8.1	margin	Sandy/gravelly sediment. *Scirpus maritimus* on the margin. Water depth 20cm (very turbid water).	5	-	3	-	-
9	9.1	margin	Sandy/gravelly sediment with sparse pebbles/boulders. Good coverage of *Enteromorpha* (closer to the shore) and *Potamogeton pectinatus* (farther from the shore). Water depth 23cm. Sediments anoxic almost to the surface (RPD layer max 1cm).	5	-	3	3	3
10	10.1	margin	Pebbles. No vegetation.	-	-	3	-	-
10	10.PM	deep	Anoxic sediment to the surface. Water depth 1.9m.	-	2	-	-	-
11	11.1	margin	Shallow area with sparse pebbles on clay sediment covered by diatoms. Very sparse tufts of small *Enteromorpha.* Water depth 13cm.	5	-	3	-	-

Appendix II. Vertical profiles of water quality parameters.

Mean values by depth stratum: A: Temperature; B: Salinity; C: Dissolved Oxygen; D: Turbidity; E: pH.

A: Temperature C

depth stratum (m)	1_1	1_A	1_B	1_C	1_D	1_E	1_F	1_G	1_H	1_I	2_1	2_PM	3_1	4_1	4_2	4_3	5_PM5	5_PM6	5_PM7	5_PM8	5_1	5_2	5_PM1	5_PM2	5_PM3	5_PM4
<0.5	16.4	18.1	18.3	18.1	17.8	17.1	17.2	18.1	18.3	18.0	18.6	17.5	17.9	20.0	18.4	18.2	19.6	19.8	20.0	20.1	20.0	20.9	20.3	20.0	20.3	20.1
0.5-<1		18.1	18.3	18.1	18.0	17.2	17.3	18.1	18.1	17.9		17.5					19.3	19.5	19.9	20.1			19.8	20.3	19.8	19.6
1-<1.5		17.9	18.2	18.6			17.9	18.4	18.4	17.9		17.5						19.0	19.8					19.9	19.3	19.4
1.5-<2		17.9		19.1		19.0			18.9	17.9		17.5							19.5						18.9	19.1
2-<2.5		18.5	18.9			19.6																		19.2	18.7	
2.5-<3				18.8								17.6													18.7	
3-<3.5						19.4						17.5													19.0	
3.5-<4						19.1																			18.8	
>4																									18.5	

depth stratum (m)	6_1	6_2	6_3	6_PM1	6_PM2	6_PM3	6_PM4	6_PM5	6_PM6	6_PM7	6_PM8	7_1	7_2	7_3	7_PM1	7_PM2	7_PM3	7_PM4	7_PM5	8_1	8_PM1	8_PM2	9_3	9_PM	10_PM	10_PM2	10_PM3	10_PM4	11_1
<0.5	20.8	18.0	18.2	21.3	20.9	21.1	20.3	20.3	21.1	21.3	21.3	18.8	19.9	19.4	18.3	18.5	18.6	18.5	18.3	18.4	17.6	17.8	18.8	17.9	17.6	17.6	17.7	17.6	14.9
0.5-<1				19.4	20.8	19.6	17.8	18.0	18.2	21.1	21.3				18.3	18.5		18.5	22.8		17.7	17.9		17.9	17.6	17.6	17.5	17.6	
1-<1.5				17.8	18.3	18.1	17.6	17.7	17.6	18.3	18.1				18.3	18.5		18.5			17.5	17.7		16.9	17.6	17.6	17.5	17.6	
1.5-<2				17.6		17.9	17.6	17.6		17.8	17.9				18.3	18.4		18.5				17.6		18.0	17.6	17.6		17.5	
2-<2.5						17.7		17.5		17.6	17.7					18.4		19.7				17.6			17.6	17.3		17.5	
2.5-<3						17.7					17.6														17.6			17.6	
3-<3.5											17.6														17.6			17.5	
3.5-<4											17.5														16.2			17.4	
>4											17.5														14.8			14.7	

B: Salinity (PSU)

depth stratum (m)	1_1	1_A	1_B	1_C	1_D	1_E	1_F	1_G	1_H	1_I	2_1	2_PM	3_1	4_1	4_2	4_3	5_PM5	5_PM6	5_PM7	5_PM8	5_1	5_2	5_PM1	5_PM2	5_PM3	5_PM4
<0.5	30.9	31.9	31.4	24.8	29.0	29.2	29.0	27.0	31.9	31.9	31.3	31.5	29.9	31.6	31.1	31.1	31.8	31.3	31.3	31.2	31.5	31.4	31.5	31.5	31.6	31.6
0.5-<1		31.9	31.8	31.6	29.8	29.2	29.1	31.7	31.9	31.9		31.5					31.9	31.4	31.5	31.3			32.2	31.5	31.9	31.9
1-<1.5		31.9	31.7	31.7			30.8	32.0	31.8	31.9		31.5						31.3	31.4					31.9	32.1	32.1
1.5-<2		31.9		32.4		30.8			32.6	32.1		31.5							31.4						32.1	32.1
2-<2.5		32.9	32.5			32.5																		32.1	32.2	
2.5-<3				32.6								31.5													32.3	
3-<3.5						32.4						31.5													32.8	
3.5-<4						32.3																			33.0	
>4																									33.0	

depth stratum (m)	6_1	6_2	6_3	6_PM1	6_PM2	6_PM3	6_PM4	6_PM5	6_PM6	6_PM7	6_PM8	7_1	7_2	7_3	7_PM1	7_PM2	7_PM3	7_PM4	7_PM5	8_1	8_PM1	8_PM2	9_3	9_PM	10_PM	10_PM2	10_PM3	10_PM4	11_1
<0.5	16.7	16.9	16.8	16.9	15.7	16.9	16.7	16.8	16.8	16.9	16.9	16.9	16.9	17.2	17.1	17.2	17.7	17.5	17.8	10.1	10.2	10.2	6.5	6.6	12.4	12.4	12.3	12.4	2.6
0.5-<1				16.9	16.9	17.0	16.7	16.9	16.9	16.9	16.9				17.1	17.2		17.5	25.0		10.2	10.2		6.6	12.4	12.3	12.4	12.4	
1-<1.5				16.9	16.9	16.9	16.8	16.9	16.8	16.9	16.9				17.1	17.3		17.4			10.2	10.2		6.6	12.4	12.4	12.3	12.4	
1.5-<2				16.8		16.9	16.8	16.8		16.9	16.9				17.1	17.2		17.5				9.0		9.2	12.4	12.4		12.4	
2-<2.5						16.9		16.8		16.8	16.9					17.2		18.6				10.2			12.4	12.4		12.4	
2.5-<3						16.8					16.8														12.4			12.4	
3-<3.5											16.8														12.4			12.4	
3.5-<4											16.8														13.3			12.4	
>4											16.8														14.7			14.1	

C: Dissolved oxygen (%sat)

depth stratum (m)	1_1	1_A	1_B	1_C	1_D	1_E	1_F	1_G	1_H	1_I	2_1	2_PM	3_1	4_1	4_2	4_3	5_PM5	5_PM6	5_PM7	5_PM8	5_1	5_2	5_PM1	5_PM2	5_PM3	5_PM4
<0.5	67.7	103	106	102	122	82.6	104	112	100	99.8	112	93.6	150	120	115	93.6	120	122	121	118	129	115	119	117	121	121
0.5-<1		98.3	99.5	85.9	186	73.5	117	107	79.1	96.6		92.3					120	113	118	108			113	119	125	117
1-<1.5		90.2	98.3	63.2			183	105	61.5	99		92.9						108	114					121	125	120
1.5-<2		86		52.1		61.7			76.8	102		92.9							107						109	111
2-<2.5		104	106			47.6																		112	94.3	
2.5-<3				93.8								88.1													78.8	
3-<3.5						28.4						87.2													50.9	
3.5-<4						49.4																			26.2	
>4																									64.6	

depth stratum (m)	6_1	6_2	6_3	6_PM1	6_PM2	6_PM3	6_PM4	6_PM5	6_PM6	6_PM7	6_PM8	7_1	7_2	7_3	7_PM1	7_PM2	7_PM3	7_PM4	7_PM5	8_1	8_PM1	8_PM2	9_3	9_PM	10_PM	10_PM2	10_PM3	10_PM4	11_1
<0.5	122	112	117	130	128	133	135	127	131	128	129	115	111	102	101	98.8	103	92.7	87.2	114	106	107	101	84.8	85.4	86.6	87.2	83.5	100
0.5-<1				113	128	127	124	113	118	127	124				102	98.3		90.8	103		111	106		47.6	84.6	85.7	88	82.2	
1-<1.5				107	113	119	118	102	110	113	115				104	98.1		87			172	104		17.9	84.4	84.4	101	78.6	
1.5-<2				111		112	116	94.6		103	111				113	99.1		65				101		58.9	84.3	82.8		75.5	
2-<2.5						111		107		106	105					102		90.3				106			82.2	80.6		69	
2.5-<3						127					99.3														70.1			57.3	
3-<3.5											89.3														15.6			32.9	
3.5-<4											86.5														15.3			17.7	
>4											102														44.3			36.1	

D: Turbidity (NTU)

depth stratum (m)	1_1	1_A	1_B	1_C	1_D	1_E	1_F	1_G	1_H	1_I	2_1	2_PM	3_1	4_1	4_2	4_3	5_PM5	5_PM6	5_PM7	5_PM8	5_1	5_2	5_PM1	5_PM2	5_PM3	5_PM4
<0.5	38.1	3.65	2.7	6.8	6	4.7	12.4	4.75	4.6	4.65	0.4	0.4	2.2	0	0	0.2	6.1	0.15	0	0.7	0	0	0	0	0	0
0.5-<1		3.4	3.8	6.3	3.9	3.2	5.7	3.1	14.6	7.4		0.5					52	0.8	0	75.2			0.2	0	0.8	0
1-<1.5		3.5	4.1	5.9			10.3	52.5	14.2	8.3		3.3						50.5	0					1	1.9	0
1.5-<2		3.7		22.3		1.2			28.3			6.1							36.4						2.4	0
2-<2.5			82.4			0.9																		15.6	2.3	
2.5-<3				88								5.5													2.9	
3-<3.5						1.1						2.8													3.4	
3.5-<4						10																			1.2	
>4																									16.9	

depth stratum (m)	6_1	6_2	6_3	6_PM1	6_PM2	6_PM3	6_PM4	6_PM5	6_PM6	6_PM7	6_PM8	7_1	7_2	7_3	7_PM1	7_PM2	7_PM3	7_PM4	7_PM5	8_1	8_PM1	8_PM2	9_3	9_PM	10_PM	10_PM2	10_PM3	10_PM4	11_1
<0.5	29.4	15.3	16.7	16	15.8	15.9	16.1	16.2	15.9	15.1	15.2	0.6	0	2.2	0.6	0.8	0.1	0.1	0	41.1	39.2	39	2.5	2.1	19.8	19.3	19.5	20.4	6
0.5-<1				15.5	15.4	16.6	17.6	16.8	16.7	15.6	16.5				0.3	0.7		0.4	21.4		38.7	38.9		2.5	19.4	19.7	19.3	19.9	
1-<1.5				14.8	64	16	16.6	16.7	15.5	17.3	16.6				0	0.8		0.5			37.5	38.6		1.9	19.5	19.5	58.1	20	
1.5-<2				25.2		15.4	18	17.9		16.7	15.6				0.1	0.3		0.3				37.7		69.6	19.4	19.5		20.3	
2-<2.5						14.5		24.1		57.3	15.2					0.1		3.3				52.6			19.4	35.8		20.6	
2.5-<3						14.7					14.8														20.3			19.8	
3-<3.5											13.9														19.8			21.7	
3.5-<4											48.9														15.2			33.9	
>4																									11.2			13	

E: pH

depth stratum (m)	1_1	1_A	1_B	1_C	1_D	1_E	1_F	1_G	1_H	1_I	2_1	2_PM	3_1	4_1	4_2	4_3	5_PM5	5_PM6	5_PM7	5_PM8	5_1	5_2	5_PM1	5_PM2	5_PM3	5_PM4
<0.5	9.09	9.32	9.43	9.53	9.39	9.29	9.32	9.5	9.34	9.3	9.13	9.23	9.14	9.18	9.3	9.27	9.29	9.3	9.3	9.29	9.17	8.91	9.2	9.26	9.27	9.28
0.5-<1		9.33	9.37	9.37	9.4	9.27	9.34	9.37	9.3	9.29		9.23					9.3	9.28	9.29	9.3			9.07	9.26	9.26	9.26
1-<1.5		9.31	9.36	9.3			9.3	9.33	9.24	9.12		9.23						9.26	9.28					9.25	9.28	9.27
1.5-<2		9.28		9.21		9.15			9.17	8.98		9.22							9.28						9.33	9.3
2-<2.5		9.23	9.3			9.06																		9.26	9.25	
2.5-<3				8.75								9.21													9.19	
3-<3.5						8.99						9.17													9.11	
3.5-<4						8.79																			8.98	
>4																									8.85	

depth stratum (m)	6_1	6_2	6_3	6_PM1	6_PM2	6_PM3	6_PM4	6_PM5	6_PM6	6_PM7	6_PM8	7_1	7_2	7_3	7_PM1	7_PM2	7_PM3	7_PM4	7_PM5	8_1	8_PM1	8_PM2	9_3	9_PM	10_PM	10_PM2	10_PM3	10_PM4	11_1
<0.5	9.48	9.53	9.61	9.72	9.69	9.63	9.72	9.73	9.71	9.71	9.72	9.16	9.35	9.45	9.44	9.46	9.42	9.41	9.39	9.78	9.89	9.85	10.1	10.1	9.71	9.72	9.74	9.7	10.5
0.5-<1				9.76	9.69	9.66	9.75	9.76	9.78	9.71	9.72				9.43	9.46		9.41	8.82		9.91	9.85		10.1	9.71	9.71	9.71	9.7	
1-<1.5				9.74	9.74	9.66	9.74	9.74	9.75	9.77	9.77				9.39	9.46		9.41			9.93	9.84		9.93	9.71	9.71	9.7	9.69	
1.5-<2				9.73		9.64	9.71	9.7		9.75	9.76				9.27	9.45		9.4				9.84		8.51	9.7	9.71		9.68	
2-<2.5						9.6		9.68		9.71	9.73					9.45		9.21				9.81			9.7	9.7		9.67	
2.5-<3						9.54					9.72														9.69			9.65	
3-<3.5											9.71														9.63			9.62	
3.5-<4											9.7														8.64			9.44	
>4											9.68														8.49			8.47	

Appendix III. Water nutrient content.

Station	Qualifier	Ammoniacal Nitrogen, Filtered as N (mg/l)	Nitrite, Filtered as N (mg/l)	Nitrogen : Total Oxidised, Filtered as N (mg/l)	Orthophosphate, Filtered as P (mg/l)	Silicate, Filtered as SiO2 (mg/l)
1B	Surface	<0.0200	<0.00400	<0.100	0.187	0.73
1B	Bottom	<0.0200	<0.00400	<0.100	0.186	0.74
1E	Surface	0.042	<0.00400	<0.100	0.208	0.91
1E	Bottom	0.034	<0.00400	<0.100	0.202	0.84
2.1	Surface	<0.0200	0.0091	<0.100	0.162	0.9
3.1	Surface	0.049	0.0113	<0.100	0.161	0.98
4.2	Surface	0.064	0.0136	0.1	0.173	0.95
4.2	Surface	0.039	0.011	<0.100	0.162	0.82
4.3	Surface	0.059	0.0125	<0.100	0.165	0.89
5.1	Surface	0.043	0.0114	<0.100	0.156	0.72
5.2	Surface	0.071	0.0121	<0.100	0.162	0.8
6.1	Surface	<0.0200	<0.00400	<0.100	0.071	0.53
6.2	Surface	<0.0200	<0.00400	<0.100	0.076	0.5
6.3	Surface	<0.0200	<0.00400	<0.100	0.069	0.54
6.PM1	Surface	<0.0200	<0.00400	<0.100	0.068	0.49
6.PM1	Bottom	<0.0200	<0.00400	<0.100	0.065	0.49
6.PM2	Surface	<0.0200	<0.00400	<0.100	0.044	0.46
6.PM3	Bottom	<0.0200	<0.00400	<0.100	0.066	0.46
7.1	Surface	<0.0200	<0.00400	<0.100	<0.0100	<0.200
7.2	Surface	<0.0200	<0.00400	<0.100	<0.0100	0.22
7.3	Surface	<0.0200	<0.00400	<0.100	<0.0100	<0.200
8.1	Surface	<0.0200	<0.00400	<0.100	<0.0100	1.17
9.3	Surface	0.051	0.0126	<0.100	0.475	<0.200
10.1	Surface	<0.0200	<0.00400	<0.100	<0.0100	1.84
10.PM	Bottom	<0.0200	<0.00400	<0.100	<0.0100	1.83
11.1	Surface	0.026	<0.00400	<0.100	<0.0100	0.26

Appendix IV. Particle size analysis - % contribution of grain size classes (Phi) to the sediments in sampled stations.

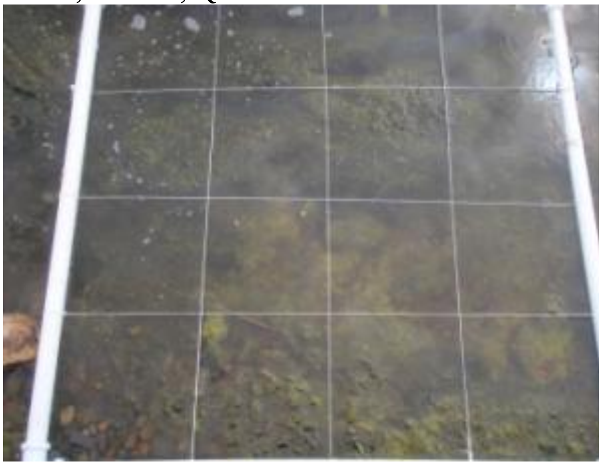
% composition of sediments by grain size fraction (as indicated by phi values) in the sampled stations.

	Station (% Phi)																	
Phi	1A	1B	1C	1E	4.1	4.2	4.3	5.1 S	5.2	6.1	6.3	6PM1	6PM2	7.1	8.1	9.1	10PM	11.1
-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4	0	0	0	0	0	0	0	0	0	21.8	16.2	0	0	10.1	0	0	0	0
-3	0	0	0	0	1.74	4.51	0	0	3.41	1.08	11.95	0	0	0	0	1.13	0	0
-2	0.71	0	7.01	0	1.25	4.91	0	0.87	3.71	1.01	6.08	0	0	0.08	0.53	0.45	0	0.12
-1	0.83	0	0	0	2.21	3.45	0.21	3.38	2.98	2.96	6.31	0	0.12	0.92	0.81	0.09	0	0.27
0	0.22	0	0.04	0	1.71	1.66	0.82	6.39	1.31	7.21	3.69	0	0.3	1.22	1.05	0.25	0	0.38
1	1.68	1.21	0.85	3.35	2.35	6.31	2.13	22.1	3.1	5.6	4.81	0.36	1.88	2.16	1.38	2.2	0.9	2.46
2	6.15	11.2	10.48	16.81	48.4	49.2	53.2	48.4	46.1	38.5	32.4	2.76	18.32	44.3	57	58.6	1.72	45.2
3	8.53	17.4	18.81	18.56	41.7	29.72	39.79	18.83	35.12	19.81	17.03	6.49	23.4	36.12	35.29	37.17	3.44	41.4
4	13.21	16.53	17.06	15.94	0.61	0.24	0.26	0.08	0.48	0.09	0.09	14.22	13.4	0.66	0.06	0.08	10.09	1.05
5	21.49	18.37	17.03	17.83	0	0	1.68	0	1.42	0.89	0.9	23.4	15.79	1.92	1.61	0	19.83	3.33
6	22.7	17.57	14.94	15	0	0	1.2	0	1.24	0.55	0.49	23.9	12.93	1.59	1.23	0	24.1	3.49
7	14.32	10.84	8.46	8.07	0	0	0.45	0	0.62	0.36	0	15.2	7.16	0.62	0.63	0	19.35	1.51
8	6.11	4.4	3.33	2.93	0	0	0.37	0	0.4	0.25	0	7.25	3.57	0.39	0.45	0	10.68	0.77
9	2.22	1.52	1.18	0.98	0	0	0	0	0	0	0	3.41	1.72	0	0	0	5.18	0
10	0.92	0.55	0.44	0.34	0	0	0	0	0	0	0	1.61	0.79	0	0	0	2.52	0

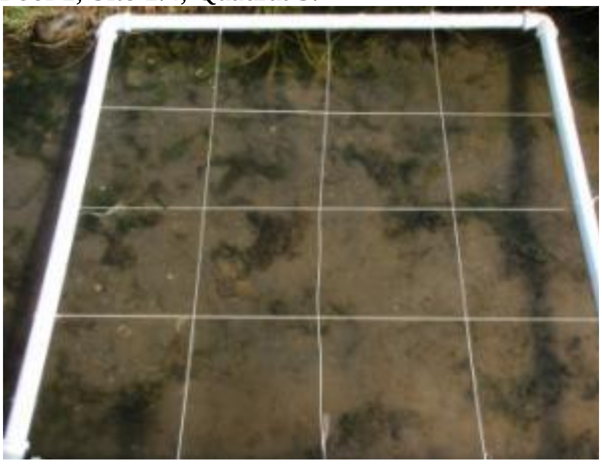
Appendix V. Vegetation quadrat photographs.

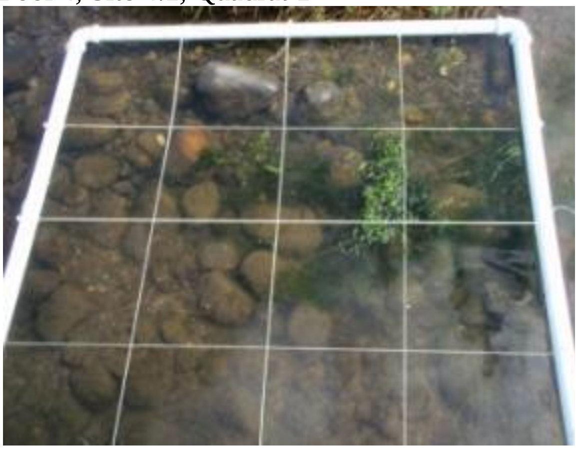

Pool 1, Site 1.4, Quadrat 1.


Pool 1, Site 1.4, Quadrat 2

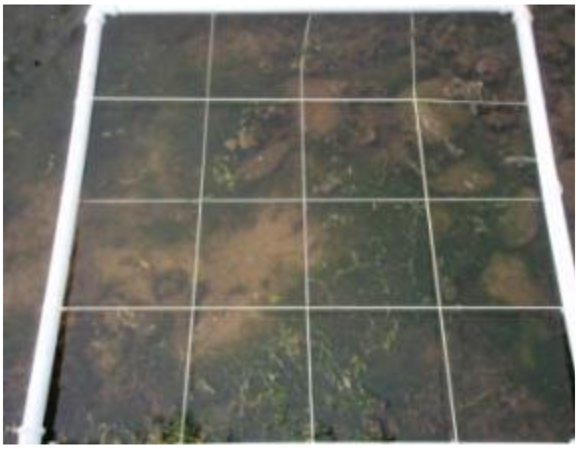

Pool 1, Site 1.4, Quadrat 3.

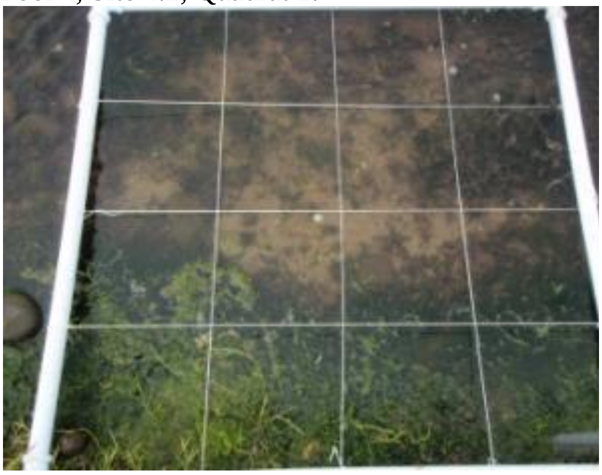

Pool 4, Site 4.1, Quadrat 1

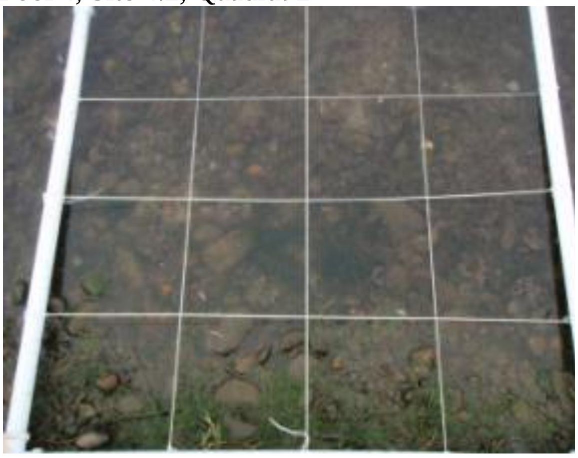

Pool 4, Site 4.1, Quadrat 2.


Pool 4, Site 4.1, Quadrat 3.

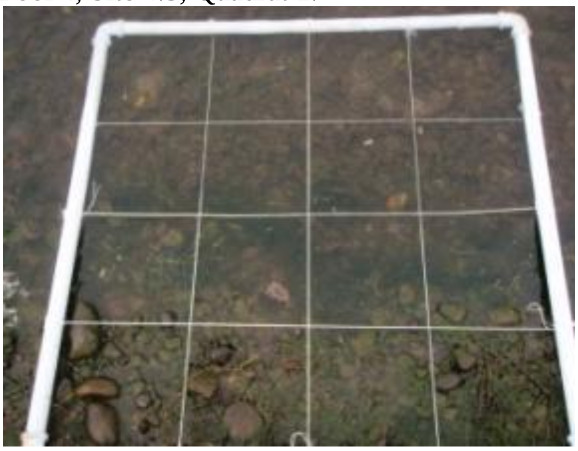

Pool 4, Site 4.2, Quadrat 1.

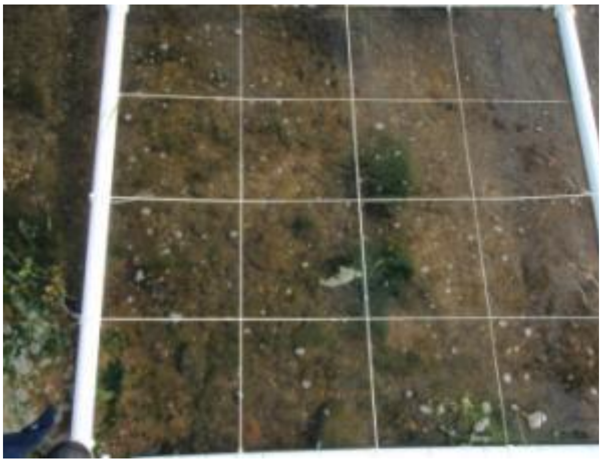

Pool 4, Site 4.2, Quadrat 2

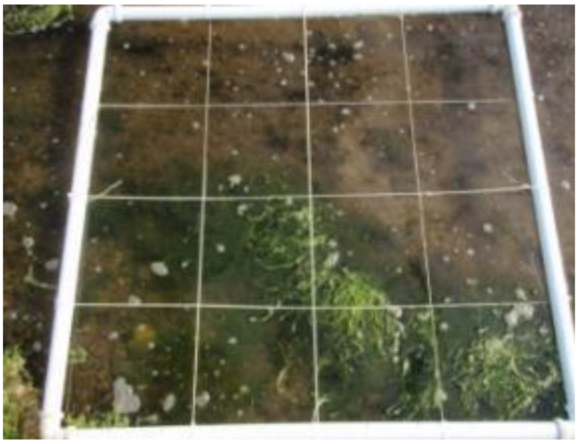

Pool 4, Site 4.2, Quadrat 3.

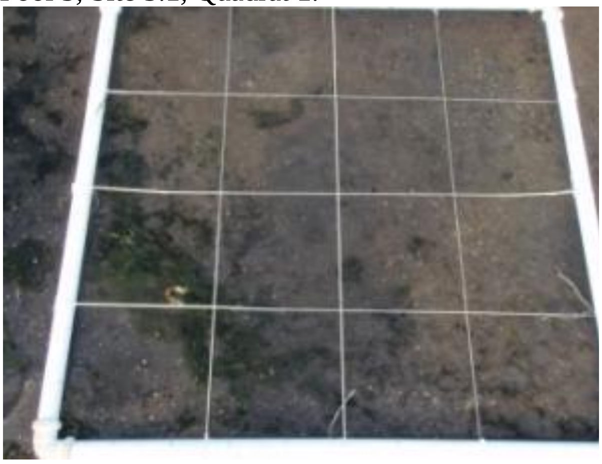

Pool 4, Site 4.3, Quadrat 1.


Pool 4, Site 4.3, Quadrat 2.


Pool 4, Site 4.3, Quadrat 3.


Pool 5, Site 5.1, Quadrat 1.


Pool 5, Site 5.1, Quadrat 2.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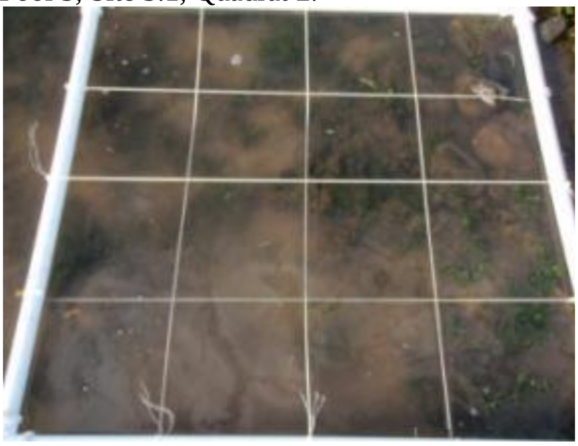
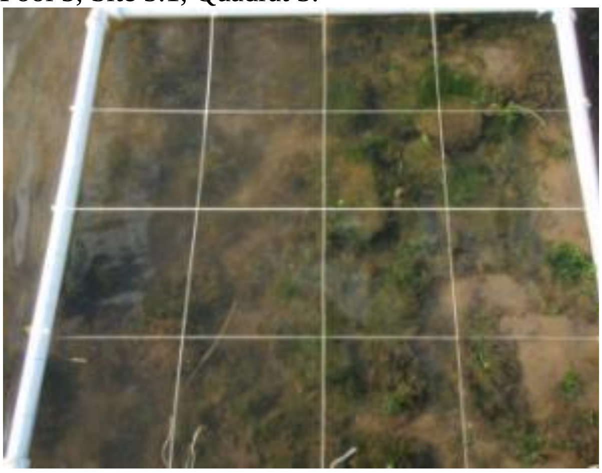
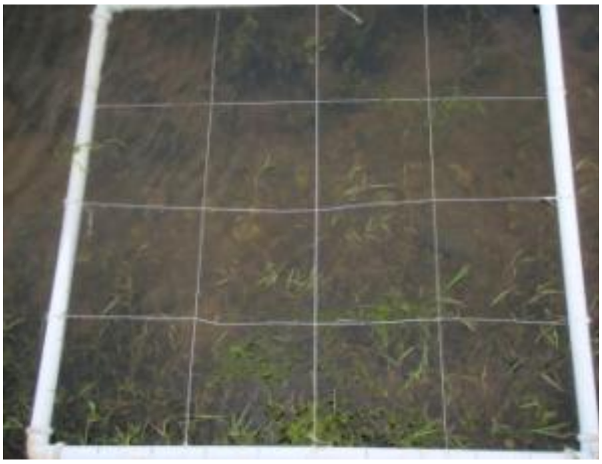
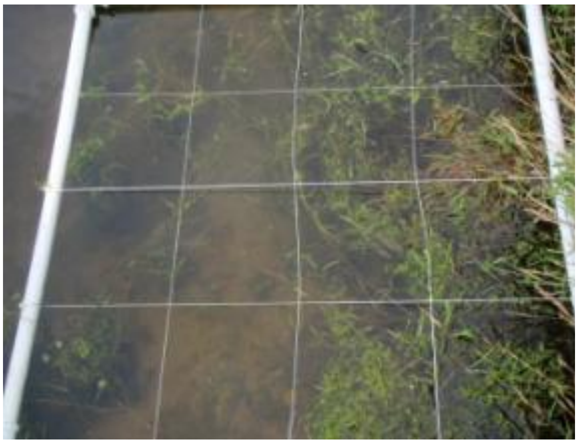

Pool 5, Site 5.2, Quadrat 1.


Pool 5, Site 5.2, Quadrat 2.

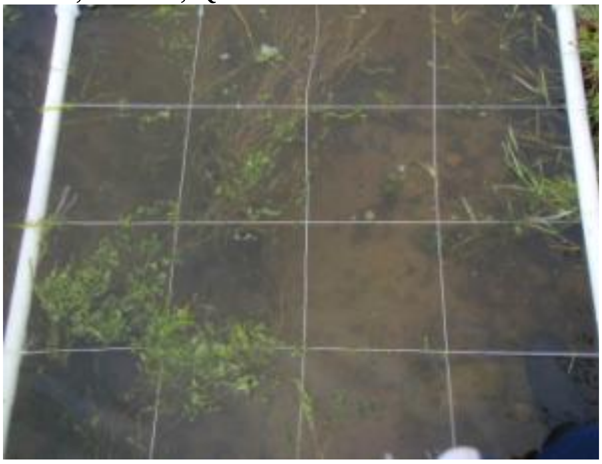

Pool 5, Site 5.2, Quadrat 3.



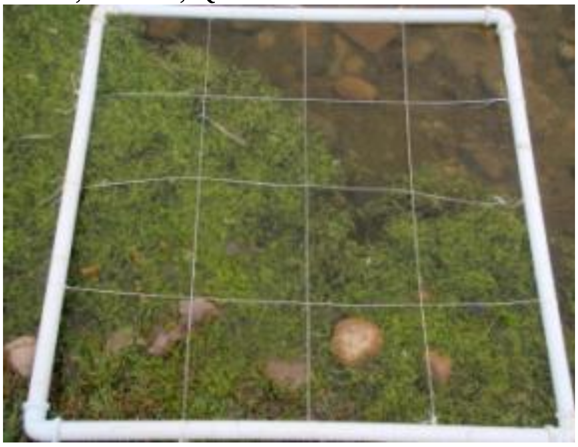
Pool 9, Site 9.1, Quadrat 1.



Pool 9, Site 9.1, Quadrat 2.



Pool 9, Site 9.1, Quadrat 3.



Pool 9, Site 9.3, Quadrat 1.

Appendix VI. Abundance (individuals per sample) of benthic infaunal species in South Walney lagoons (August 2013)

Pool	station	repl	station type	sampl method	sampl area m2	Nemertea	Nematoda	*Eteone longa*	*Hediste diversicolor*	*Scoloplos armiger*	*Polydora cornuta*	*Pygospio elegans*	*Tharyx "species A"*	*Capitella capitata*	*Arenicola marina*	*Paranais litoralis*	*Tubificidae*	*Heterochaeta costata*	*Tubificoides benedii*	Enchytraeidae	Ostracoda	*Allomelita pellucida*	*Cheirocratus*	Aoridae	*Microdeutopus gryllotalpa*	*Monocorophium insidiosum*	*Sphaeroma*	*Idotea*	*Idotea chelipes*	Decapoda	*Palaemon varians*	Insecta	Dolichopodidae	Chironomidae "Species 1"	Chironomidae "Species 2"	Corixidae	Psychodidae	Ephydridae	*Coelambus*	Isotomidae	*Symphypleona*	Gastropoda	*Peringia ulvae*	*Potamopyrgus antipodarum*	*Littorina*	*Diaphana minuta*	*Kurtiella bidentata*	*Cerastoderma*	*Cerastoderma glaucum*	*Mya arenaria*	ACTINIARIA	*Conopeum seurati*	*Flustra foliacea*	**Total number of species (quantitative)**	**Total number of species (all)**	**Total abundance**
1	1-A	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
1	1-A	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**1**	**1**	**1**
1	1-B	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P			**0**	**1**	**0**
1	1-B	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
1	1-C	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
1	1-C	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**1**	**1**	**1**
1	1-D	rep 1	deep	grab	0.025	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41				**4**	**4**	**64**
1	1-D	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**2**	**2**	**6**
1	1-E	rep1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**0**	**1**	**0**
1	1-E	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
4	4-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	174	0	2	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**179**
4	4-1	rep 2	margin	corer	0.01	0	0	0	0	0	0	0	0	77	0	0	0	0	0	0	0	0	0	0	0	61	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**141**
4	4-1	rep 3	margin	corer	0.01	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**2**	**2**	**180**
4	4-1	rep 4	margin	corer	0.01	0	0	0	0	0	0	0	0	679	0	15	0	3	0	1	3	1	0	3	1	35	0	3	2	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0		P		**13**	**14**	**750**
4	4-1	rep 5	margin	corer	0.01	0	2	0	3	0	0	0	0	401	0	4	0	5	0	0	0	0	0	0	1	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0		P		**8**	**9**	**511**
4	4-2	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	193	0	0	0	0	0	1	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0		P		**5**	**6**	**248**
4	4-2	rep 2	margin	corer	0.01	0	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**2**	**3**	**229**
4	4-2	rep 3	margin	corer	0.01	0	0	0	0	0	0	0	0	117	0	0	0	0	0	0	0	0	0	2	0	143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**3**	**3**	**262**
4	4-2	rep 4	margin	corer	0.01	0	0	0	0	0	0	0	0	105	0	1	0	0	0	1	0	0	0	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**174**
4	4-2	rep 5	margin	corer	0.01	0	0	0	0	0	0	0	0	145	0	7	0	5	0	7	0	0	0	2	0	284	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**6**	**6**	**450**
4	4-3	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	1	108	0	0	0	0	0	6	0	0	0	2	0	68	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**7**	**7**	**187**
4	4-3	rep 2	margin	corer	0.01	0	0	0	1	0	0	0	0	82	0	0	0	0	0	1	0	0	0	0	0	134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**218**
4	4-3	rep 3	margin	corer	0.01	0	4	0	0	0	0	0	4	135	0	2	0	0	0	6	0	0	0	2	0	80	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**8**	**8**	**234**
4	4-3	rep 4	margin	corer	0.01	0	0	0	1	0	0	0	0	135	0	1	0	0	0	1	0	0	0	13	1	94	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0				**9**	**9**	**248**
4	4-3	rep 5	margin	corer	0.01	0	0	0	1	0	0	0	0	114	0	0	0	0	0	3	0	0	0	17	1	252	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**7**	**7**	**390**
5	5-1	rep 1	margin	corer	0.01	0	0	0	10	0	0	1	0	164	0	0	0	8	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0				**7**	**7**	**193**
5	5-1	rep 2	margin	corer	0.01	0	0	0	5	0	0	0	0	122	0	0	0	0	0	1	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0				**6**	**6**	**146**
5	5-1	rep 3	margin	corer	0.01	0	1	0	6	0	0	1	0	164	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0				**8**	**8**	**181**
5	5-1	rep 4	margin	corer	0.01	0	0	0	3	0	0	0	0	206	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	30	0	0	0	0	0	0	1				**6**	**6**	**260**
5	5-1	rep 5	margin	corer	0.01	0	7	0	3	0	0	7	0	237	0	4	0	3	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0				**9**	**9**	**269**
5	5-2	rep 1	margin	corer	0.01	2	3	0	0	0	27	0	4	610	0	0	167	1	0	2	1	0	0	15	2	405	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0				**14**	**14**	**1247**
5	5-2	rep 2	margin	corer	0.01	0	33	0	0	0	13	2	0	658	0	0	84	59	0	3	0	0	0	0	0	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	2	0	0	1				**11**	**11**	**1057**
5	5-2	rep 3	margin	corer	0.01	5	0	0	0	0	0	0	2	40	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**5**	**5**	**51**
5	5-2	rep 4	margin	corer	0.01	2	0	1	1	0	29	0	4	99	0	0	20	9	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0				**10**	**10**	**215**
5	5-2	rep 5	margin	corer	0.01	3	1	0	0	0	46	1	0	172	0	0	0	25	0	1	0	0	0	4	0	212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	1				**11**	**11**	**473**
6	6-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	1	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**2**	**2**	**22**
6	6-1	rep 2	margin	corer	0.01	0	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**2**	**2**	**5**

Appendix table continued...

Pool	station	repl	station type	sampl method	sampl area m2	Nemertea	Nematoda	*Eteone longa*	*Hediste diversicolor*	*Scoloplos armiger*	*Polydora cornuta*	*Pygospio elegans*	*Tharyx "species A"*	*Capitella capitata*	*Arenicola marina*	*Paranais litoralis*	*Tubificidae*	*Heterochaeta costata*	*Tubificoides benedii*	Enchytraeidae	Ostracoda	*Allomelita pellucida*	*Cheirocratus*	Aoridae	*Microdeutopus gryllotalpa*	*Monocorophium insidiosum*	*Sphaeroma*	*Idotea*	*Idotea chelipes*	Decapoda	*Palaemon varians*	Insecta	Dolichopodidae	Chironomidae "Species 1"	Chironomidae "Species 2"	Corixidae	Psychodidae	Ephydridae	*Coelambus*	Isotomidae	*Symphypleona*	Gastropoda	*Peringia ulvae*	*Potamopyrgus antipodarum*	*Littorina*	*Diaphana minuta*	*Kurtiella bidentata*	*Cerastoderma*	*Cerastoderma glaucum*	*Mya arenaria*	ACTINIARIA	*Conopeum seurati*	*Flustra foliacea*	**Total number of species (quantitative)**	**Total number of species (all)**	**Total abundance**
6	6-1	rep 3	margin	corer	0.01	0	0	0	2	0	0	0	0	0	0	0	0	2	0	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**13**
6	6-1	rep 4	margin	corer	0.01	0	0	0	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4				**4**	**4**	**22**
6	6-1	rep 5	margin	corer	0.01	0	1	0	7	0	2	5	0	0	0	0	2	3	0	1	1	0	0	1	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7				**11**	**11**	**61**
6	6-3	rep 1	margin	corer	0.01	0	0	0	7	0	3	0	0	1	0	5	81	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3				**7**	**7**	**113**
6	6-3	rep 2	margin	corer	0.01	1	0	0	2	0	5	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2				**7**	**7**	**14**
6	6-3	rep 3	margin	corer	0.01	0	0	0	7	0	9	0	1	0	0	0	1	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4				**8**	**8**	**36**
6	6-3	rep 4	margin	corer	0.01	0	0	0	5	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3				**6**	**6**	**20**
6	6-3	rep 5	margin	corer	0.01	0	0	0	5	0	1	1	0	0	0	0	15	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7				**6**	**6**	**31**
6	6PM1	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**0**	**1**	**0**
6	6PM1	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**1**	**1**	**1**
6	6PM2	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**2**	**3**	**6**
6	6PM2	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**0**	**1**	**0**
7	7-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
7	7-1	rep 2	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
7	7-1	rep 3	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	5	0	8	0	0	4	0	0	0	0	5	0	0	0	0	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**6**	**6**	**31**
7	7-1	rep 4	margin	corer	0.01	0	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0				**3**	**3**	**6**
7	7-1	rep 5	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	3	0	21	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0				**5**	**5**	**39**
8	8-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0	0	0				**2**	**2**	**170**
8	8-1	rep 2	margin	corer	0.01	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	105	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0	56	0	0	0	0	0	0				**6**	**6**	**228**
8	8-1	rep 3	margin	corer	0.01	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	104	0	0	0	0	0	0	0	0	0	0	0	0	59	0	0	0	0	0	0	0	0	0	81	0	0	0	0	0	0				**4**	**4**	**245**
8	8-1	rep 4	margin	corer	0.01	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	119	0	0	0	0	0	0	0	0	0	0	0	0	116	0	0	0	0	0	0	0	0	1	62	0	0	0	0	0	0				**7**	**7**	**301**
8	8-1	rep 5	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	171	0	0	0	0	0	0	0	0	0	0	0	0	61	1	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0				**4**	**4**	**273**
9	9-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**3**	**3**	**48**
9	9-1	rep 2	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			P	**2**	**3**	**28**
9	9-1	rep 3	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**3**	**3**	**37**
9	9-1	rep 4	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	27	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**3**	**3**	**29**
9	9-1	rep 5	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	21	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**26**
10	10PM3	rep 1	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		P		**0**	**1**	**0**
10	10PM3	rep 2	deep	grab	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**0**	**0**	**0**
11	11-1	rep 1	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0				**2**	**2**	**4**
11	11-1	rep 2	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0				**5**	**5**	**12**
11	11-1	rep 3	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				**1**	**1**	**3**
11	11-1	rep 4	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**9**
11	11-1	rep 5	margin	corer	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0				**4**	**4**	**5**
					Total N	**28**	**53**	**1**	**85**	**1**	**142**	**19**	**20**	**5211**	**3**	**49**	**371**	**160**	**1**	**69**	**650**	**1**	**1**	**61**	**6**	**2473**	**1**	**18**	**10**	**1**	**2**	**2**	**3**	**477**	**9**	**7**	**7**	**3**	**1**	**1**	**1**	**1**	**81**	**293**	**1**	**1**	**2**	**1**	**1**	**74**						**10403**

Sampling method and area used in shallow marginal stations (0.01m^2 corer) and in deeper stations (0.025m^2 Ekman grab) is also reported. Taxa sampled qualitatively are indicated as P (presence).

Appendix VII. Epifaunal species abundance in samples collected amongst algal vegetation (ind./0.5L weed).

MCS	Code	Species	Qualifier	Notes	EpiFauna 1.4 r1	EpiFauna 1.4 r2	EpiFauna 1.4 r3	EpiFauna 4.1 r1	EpiFauna 4.1 r2	EpiFauna 4.1 r3	EpiFauna 4.2 r1	EpiFauna 4.2 r2	EpiFauna 4.2 r3	EpiFauna 5.1 r1	EpiFauna 5.1 r2	EpiFauna 5.1 r3	EpiFauna 9.1 r1	EpiFauna 9.1 r2	EpiFauna 9.1 r3
P	752	Polydora ciliata	sp. agg.	Bristleworm	1		1												
P	907	Capitella capitata	sp. agg.	Bristleworm			3												
P	1415	Nais elinguis		Oligochaete					1		1								
P	1420	Paranais litoralis		Oligochaete					1		1		1						
Q	53	ACARINA	spp.	Mite														1	
S	82	Praunus flexuosus		Mysid/Opossum shrimp								1	1			1			
S	411	Nototropis guttatus		Amphipod shrimp								1							
S	474	Gammarus duebeni		Amphipod/Gammarus shrimp													1		3
S	481	Gammarus salinus		Amphipod/Gammarus shrimp				33	33	21	1	1	1			2			
S	525	Melita palmata		Amphipod shrimp						1	1								
S	596	Microdeutopus gryllotalpa		Amphipod shrimp		1	1	2		1	48	47	47	1		3			
S	612	Monocorophium insidiosum		Amphipod shrimp	121	64	70	5			56	90	96	12	31	11			
S	936	Idotea chelipes		Isopod shrimp	740	712	488	66	10	20	53	60	53	80	72	73			
W	385	Peringia ulvae		Mud snail								1		1					
W	1067	Haminoea		Bubble shell	5	3	15												
		COLLEMBOLA		Springtail							1								
		DIPTERA - Chironomidae	Larvae	Non-biting midge larvae			2	7	3	2	11	1	5			1	31	16	14
		DIPTERA - Chironomidae	Pupae	Non-biting midge pupae							1								
		COLEOPTERA	Larvae	Beetle larvae		1					1			1					

Appendix VIII. Species abundance in samples collected with push net (ind./1.25m²).

MCS	Code	Species	Qualifier	Notes	Nekton 1.3 r1	Nekton 1.3 r2	Nekton 1.3 r3	Nekton 1.4 r1	Nekton 2.1 r1	Nekton 2.1 r2	Nekton 2.1 r3	Nekton 3.1 r1	Nekton 3.1 r2	Nekton 3.1 r3	Nekton 4.1 r1	Nekton 4.1 r2	Nekton 4.1 r3	Nekton 4.2 r1	Nekton 4.2 r2	Nekton 4.2 r3	Nekton 4.3 r1	Nekton 4.3 r2	Nekton 4.3 r3	Nekton 5.1 r1	Nekton 5.1 r2	Nekton 5.1 r3	Nekton 5.2 r1	Nekton 5.2 r2	Nekton 5.2 r3	Nekton 6.1 r1	Nekton 6.1 r2	Nekton 6.1 r3	Nekton 6.2 r1	Nekton 6.2 r2	Nekton 6.2 r3	Nekton 6.3 r1	Nekton 6.3 r2	Nekton 6.3 r3	Nekton 7.1 r1	Nekton 7.1 r2	Nekton 7.1 r3	Nekton 7.2 r1	Nekton 7.2 r2	Nekton 7.2 r3	Nekton 7.3 r1	Nekton 7.3 r2	Nekton 7.3 r3	Nekton 8.1 r1	Nekton 8.1 r2	Nekton 8.1 r3	Nekton 9.1 r1	Nekton 9.1 r2	Nekton 9.1 r3	Nekton 10.1 r1	Nekton 10.1 r2	Nekton 10.1 r3	Nekton 11.1 r1	Nekton 11.1 r2	Nekton 11.1 r3
P	752	Polydora ciliata	sp. agg.	Bristleworm	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	1420	Paranais litoralis		Oligochaete	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Q	53	ACARINA	spp.	Mite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	0	0	0	0
R	142	COPEPODA	spp.	Cyclops/Water flea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	0	0	0	66	46	52
S		Daphniidae		Daphnia/Water flea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	205	107	0	0	0	5	3	1
S		Macrothricidae		Daphnia/Water flea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	13	4
R		Heterocypris incongruens		Ostracod/Seed shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	67	100
R	2471	Heterocypris salina		Ostracod/Seed shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	18	2
R	2511	Cyprideis torosa		Ostracod/Seed shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
R	2692	Cypridopsis aculeata		Ostracod/Seed shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	60	39
S	74	Mesopodopsis slabberi		Mysid/Opossum shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	76	Neomysis integer		Mysid/Opossum shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	7	0	0	0
S	82	Praunus flexuosus		Mysid/Opossum shrimp	0	3	2	4	1	0	0	0	9	0	0	0	0	21	6	2	0	0	1	0	1	1	2	1	0	6	8	0	6	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	234	Orchestia gammarellus		Amphipod shrimp	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	474	Gammarus duebeni		Amphipod/Gammarus shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	0
S	481	Gammarus salinus		Amphipod/Gammarus shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	495	Melitidae	juv.	Amphipod shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S	596	Microdeutopus gryllotalpa		Amphipod shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	612	Monocorophium insidiosum		Amphipod shrimp	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	0	24	0	0	0	0	0	0	0	0	1	3	1	0	0	0	0	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
S	936	Idotea chelipes		Isopod shrimp	0	0	1	74	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	1293	CARIDEA	juv.	Prawn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	18	39	0	0	0	0	0	0
S	1321	Palaemon varians		Atlantic ditch shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	306	Littorina saxatilis		Rough periwinkle	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	387	Ecrobia ventrosa		Spire snail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	1067	Haminoea		Bubble shell	0	0	7	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	2149	Mya arenaria		Sand gaper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZG	478	Pomatoschistus microps	(juv.)	Common goby	1	4	1	14	0	0	0	5	4	2	0	3	0	6	0	5	2	0	1	4	3	0	0	6	5	0	3	0	5	0	1	1	1	0	0	0	0	1	0	1	0	0	0	8	8	28	0	0	0	0	0	0	0	0	0
		COLLEMBOLA		Springtail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
		HEMIPTERA - Corixidae		Lesser waterboatmen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	43	74	0	0	0	2	4	4
		HEMIPTERA - Notonectidae		Greater waterboatmen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		DIPTERA - Ceratopogonidae	Larvae	Biting midge larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	2
		DIPTERA - Chironomidae	Larvae	Non-biting midge larvae	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	21	0	0	0	2	4	2
		DIPTERA - Chironomidae	Pupae	Non-biting midge pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		DIPTERA - Dolichopodidae	Larvae	Long legged fly larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		DIPTERA - Ephydridae	Pupae	Shore fly larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
		DIPTERA - Limoniidae	Larvae	Limonid crane fly larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		DIPTERA - Muscidae	Larvae	House fly larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
		DIPTERA - Psychodidae	Larvae	Moth fly larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1
		COLEOPTERA	Larvae	Beetle larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
		COLEOPTERA - Dytiscidae		Diving beetle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
				Total number of individuals in the sample	1	9	18	107	1	1	0	5	13	2	0	3	0	31	7	7	33	0	3	4	5	1	2	7	6	9	20	2	11	3	3	7	2	6	3	0	0	1	0	1	0	0	0	8	8	28	180	270	250	1	3	9	161	253	210
				Total number of species in the sample	1	3	5	6	1	1	0	1	2	1	0	1	0	4	2	2	4	0	3	1	3	1	1	2	2	3	5	2	2	2	2	2	2	2	3	0	0	1	0	1	0	0	0	1	1	1	7	6	9	1	2	2	12	16	13

Appendix IX. List of faunal species found in South Walney lagoons in 2013 (August).

Presence id denoted with 1. Lagoon specialist species are highlighted in grey.

				Sampling			
MCS	Code	Species	Qualifier	Grab/Core	Push net	Epifauna (veg.)	Qual. Obs.
D	662	ACTINIARIA	juv.	1			1
G	1	Nemertea		1			
HD	1	Nematoda		1			
P	118	*Eteone longa*	agg	1			
P	462	*Hediste diversicolor*		1			
P	672	*Scoloplos armiger*		1			
P	752	*Polydora ciliata*	sp. agg.		1	1	
P	753	*Polydora cornuta*		1			
P	776	*Pygospio elegans*		1			
P	847	*Tharyx "species A"*		1			
P	907	*Capitella capitata*	sp. agg.	1		1	
P	931	*Arenicola marina*		1			
P	1415	*Nais elinguis*				1	
P	1420	*Paranais litoralis*		1	1	1	
P	1425	Tubificidae		1			
P	1479	*Heterochaeta costata*		1			
P	1490	*Tubificoides benedii*		1			
P	1501	Enchytraeidae		1			
Q	53	ACARINA	spp.		1	1	
R	142	COPEPODA	spp.		1		
S		Daphniidae			1		
S		Macrothricidae			1		
R	2412	OSTRACODA		1			
R		*Heterocypris incongruens*			1		
R	2471	*Heterocypris salina*			1		
R	2511	*Cyprideis torosa*			1		
R	2692	*Cypridopsis aculeata*			1		
S	74	*Mesopodopsis slabberi*			1		
S	76	*Neomysis integer*			1		
S	82	*Praunus flexuosus*			1	1	
S	234	*Orchestia gammarellus*			1		
S	411	*Nototropis guttatus*				1	
S	474	*Gammarus duebeni*			1	1	1
S	481	*Gammarus salinus*			1	1	
S	495	Melitidae	juv.		1		
S	500	Allomelita pellucida	juv.	1			
S	503	*Cheirocratus*		1			
S	525	*Melita palmata*				1	
S	577	Aoridae		1			
S	596	*Microdeutopus gryllotalpa*		1	1	1	1
S	612	*Monocorophium insidiosum*		1	1	1	1
S	868	*Sphaeroma*	juv.	1			
S	884	*Jaera*	sp. indet.				1
S	934	*Idotea*	juv.	1			
S	936	*Idotea chelipes*		1	1	1	
S	1276	DECAPODA	Zoea	1			
S	1293	CARIDEA	juv.		1		
S	1321	*Palaemon varians*		1	1		
W	88	Gastropoda		1			
W	294	*Littorina*	juv.	1			
W	306	*Littorina saxatilis*			1		1
W	385	*Peringia ulvae*		1		1	
W	387	*Ecrobia ventrosa*			1		
W	393	*Potamopyrgus antipodarum*		1			
W	1059	*Diaphana minuta*		1			
W	1067	*Haminoea*	sp.		1	1	
W	1560	*Pelecypoda*		1			
W	1906	*Kurtiella bidentata*		1			
W	1960	*Cerastoderma*	juv.	1			
W	1962	*Cerastoderma glaucum*		1			1
W	2149	*Mya arenaria*	(juv.)	1	1		
Y	173	*Conopeum seurati*		1			1
Y	187	*Flustra foliacea*		1			
ZG	478	*Pomatoschistus microps*			1		
		COLLEMBOLA		1	1	1	
		INSECTA	Larvae	1			
		HEMIPTERA - Corixidae		1	1		
		HEMIPTERA - Notonectidae			1		
		DIPTERA - Ceratopogonidae	Larvae		1		
		DIPTERA - Chironomidae	Larvae	1	1	1	
		DIPTERA - Chironomidae	Pupae		1	1	
		DIPTERA - Dolichopodidae	Larvae	1	1		
		DIPTERA - Ephydridae	Pupae/Larvae	1	1		
		DIPTERA - Limoniidae	Larvae		1		
		DIPTERA - Muscidae	Larvae		1		
		DIPTERA - Psychodidae	Larvae	1	1		
		COLEOPTERA	Larvae		1	1	
		COLEOPTERA - Dytiscidae	Larvae	1	1		

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ISBN 978-1-78354-887-3

Catalogue code: NECR398