BASELINE SURVEYS OF THE HAYLE ESTUARY COMPLEX

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EXECUTIVE SUMMARY

This report presents the results of the baseline surveys of algae (seaweeds), lower saltmarsh plants (*Salicornia europaea* & *Salicornia anglica*), invertebrates and fish at various locations in the Hayle estuary complex.

The baseline surveys were carried out to fulfil the Section 106 requirements for the proposed developments at Hayle. Fish populations have been reassessed in September 2011, during the construction of the temporary causeway in Copperhouse Pool. Further surveys to assess the impacts of various developments are planned for 2012 and 2014. Initially the intention was to carry out a wide range of development activities at the start of the construction programme, but the only developments that are currently underway are:

- Construction of a temporary causeway at the seaward end of Copperhouse Pool
- Works along North Quay, including upgrading the road access

In the near future the bridge access to North Quay will also be constructed,

The only other developments currently being considered are:

- Developments on South Quay (housing and commercial)
- Re-introduction of sluicing at Carnsew, including re-instatement of the mitre gate sluice.

There were seven distinct components to the baseline surveys; each is described in detail in the following Appendices:

Appendix 1.	Biotope mapping of *Salicornia*, *Spartina* & filamentous green algae at Copperhouse and Carnsew, Hayle.
Appendix 2.	Invertebrates & algae on and under hard substrates.
Appendix 3.	Counts of casts of lugworm, *Arenicola marina.*
Appendix 4.	Metals in sediments.
Appendix 5.	Invertebrates in sediments.
Appendix 6.	Metals in selected biota.
Appendix 7.	Fish population survey of Copperhouse Pool, Hayle.

A brief summary of methods and results is provided below.

In total 118 taxa were recorded during the July and August 2010 surveys. Eight species of fish, 78 invertebrates, 28 seaweeds (algae) and 4 higher plants were recorded. As expected, the diversity of invertebrates and algae compared to an unpolluted estuary was very low, largely due to high concentrations of metals (e.g. copper, zinc and arsenic) in the sediments and water. Several species were recorded that are new records for the Hayle estuary complex and the total number of taxa recorded in all our surveys of the Hayle estuary is now 280.

The results provide a suitable baseline for monitoring changes in plant and animal communities in the Hayle estuary complex.

1. Biotope mapping of *Salicornia, Spartina* & filamentous green algae at Copperhouse and Carnsew.

We plotted the boundaries of the main areas of filamentous green algae (mainly *Enteromorpha* spp. now in the genus *Ulva*), *Spartina anglica* and selected areas of *Salicornia europaea* in Copperhouse Pool and Carnsew Pool. We used Real Time Kinematic GPS at all sites and added in data from terrestrial laser scanning at Copperhouse Pool. The RTK GPS provided very accurate (± 10 cm reproducibility) plan and height data on the boundaries.

The boundaries of ten biotopes were mapped. Biotopes were numbered B1 to B10. B1 to B3 were in Lower Copperhouse Pool, B4 to B6 were in Upper Copperhouse Pool and B7 to B10 were in Carnsew.

The filamentous green algal flora of Copperhouse Pool and Carnsew is more diverse than expected, with 11 species recorded. The only unusual filamentous green alga was *Percursaria percursa*, which is probably a new record for the Hayle estuary. Other species may also be new records for Hayle as filamentous green algae are difficult to identify and therefore often grouped together as either filamentous green algae or *Enteromorpha* spp. This was the case for many earlier surveys by Aquatic Environmental Consultants (AEC, 1989 & 2000) which recorded areas of filamentous green algae as *Enteromorpha* spp. The survey of the Hayle estuary complex by the Field Studies Council (Gill, 1989) only listed 6 filamentous greens, of which only two were identified to species level.

2. Invertebrates and algae on and under hard substrates.

We examined the invertebrates and algae (seaweeds) associated with hard substrates at nine locations (3 in each of Copperhouse Pool, Carnsew and Lelant Water). At each location we estimated densities using the SACFOR scale. Most taxa were identified in the field, but we also brought some groups, for example amphipod crustaceans, back to the laboratory for accurate identification.

In total 51 invertebrate taxa and 23 algal taxa were recorded at the nine locations. The most species-rich site was Site 4, in Carnsew near the sluice (26 invertebrate taxa and 19 algal taxa). The area near the sluice in Carnsew has previously been found to be the most diverse site studied, and these results confirm the importance of this location.

The only unusual record was a tentative identification of the nemertean worm *Oxypolia beaumontiana.* This species has only been recorded from the British Isles, where it has been recorded from the Plymouth area, the NE coast of Scotland and the northern North Sea. Unfortunately there are very few nemertean worm specialists in the world, so it hasn't been sent to a specialist for confirmation.

3. Counts of casts of lugworm, *Arenicola marina.*

We examined the density of lugworm casts in quadrats at 11 locations in Copperhouse Pool (4 sites), Carnsew (4 sites) and Lelant Water (3 sites). At each location 5 replicate 1 square metre counts were made of lugworm casts. Mean densities of casts per square metre in each location were:

Copperhouse Pool	Minimum	11. 2	Maximum	29.8
Carnsew	Minimum	5.4	Maximum	82.6
Lelant	Minimum	6.8	Maximum	16.6

4. Metals in sediments

Forty sites were sampled for metals in sediments. The metals analysed were:

- Aluminium (Al)
- Arsenic (As)
- Barium (Ba)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Lithium (Li)
- Manganese (Mn)
- Mercury (Hg)
- Nickel (Ni)
- Tin (Sn)
- Vanadium (V)
- Zinc (Zn)

Aluminium and Lithium were included as the concentration of these metals can be used to normalise the data for toxic metals such as copper, arsenic and zinc (Din, 1992; Loring, 1991).

Each of the 40 sites was the same as used for the benthic core samples, and we were therefore able to statistically assess the impact of metals on the invertebrate fauna (see Section 5).

Several metals exceeded the Canadian Sediment Standards for Probable Effects Levels (PELs) on marine invertebrates. The ratio between mean and maximum concentrations of the metal and PELs was used to assess the relative importance of each metal. In decreasing order of likely severity of impacts the metals were:

- Arsenic
- Copper
- Zinc
- Cadmium and Lead
- Chromium
- Mercury

5. Invertebrates in sediments.

A total of 40 sampling sites were agreed with consultees. These were distributed as follows:

Copperhouse Pool	15
Carnsew Pool	10 (lower number required due to the smaller intertidal area)
Lelant Water	15

Lelant Water was included as a Reference/Control area to ensure that if populations change due to natural causes (such as cold winters, high predation levels, diseases etc) we can hopefully distinguish this from fluctuations due to the sluicing regime.

At each site we took 5 replicate core samples, each of approximately 0.01 square metre. The total number of core samples was therefore 200 (5 x 40). The data set for separate cores is available from Aquatonics Ltd, if required.

Specimens were identified to species level where possible, and then counted. The combined weight (biomass) of all specimens in a taxon was obtained using an analytical balance.

We undertook statistical analyses of the biological and abiotic data (particle size, organic content and metals in sediments). The statistical analyses included cluster analysis, Multi Dimensional Scaling (MDS) and 'BEST' using the Primer® software package.

Comparison of results from 4 surveys of Copperhouse Pool between 1988 and 2010 shows similar densities of ragworm (*Nereis diversicolor*) and shore crabs (*Carcinus maenas*). Bearing in mind seasonal differences in expected densities of *Corophium volutator*, the mean density of this species was broadly similar between surveys.

There were consistent absences of common estuarine species in all four surveys of Copperhouse Pool from 1988 to 2010, e.g. *Hydrobia ulvae* (mud snail), *Cerastoderma edule* (common cockle) and *Scrobicularia plana* (peppery furrow shell) were mot recorded in any survey. It is likely that the high copper concentrations in Copperhouse Pool are the main reason why the molluscan fauna is so restricted, but other metals may also play a role.

The fauna of Copperhouse Pool is changing over time, with more taxa recorded per site in recent surveys than in 1988 and 1989. The lugworm (*Arenicola marina*) has been present in reasonable densities in lower Copperhouse Pool since at least February 2000. Densities of the small spionid polychaete worm *Pygospio elegans* also appear to be increasing.

The invertebrate fauna in Copperhouse Pool and Lelant Water showed many similarities, with similar numbers of taxa and individuals in the 5 combined replicates. The number of taxa in cores from Copperhouse Pool ranged from 4 – 15 per site (mean 8.53; total 29 taxa). In Lelant Water, the number of taxa in core samples ranged from 4 – 16 per site (mean 8.67; total 26 taxa). Samples from Carnsew Pool had 6 – 14 taxa per site (mean 10.2; total 28 taxa).

Several taxa were recorded at high densities at many of the 40 sites. Several of the widespread taxa are important as prey for wading birds, for example *Corophium volutator* (max 61,800 m^{-2}), *Nereis diversicolor* (max 8,900 m^{-2}), enchytraeid worms (max 46, 200 m^{-2}) and various tubificid worms (e.g. *Heterochaeta costata* and *Tubificoides pseudogaster* both with maximum densities of approximately 25,000 m^{-2}). Other taxa that may be important wader prey include shore crabs, *Carcinus maenas* (max 165 m^{-2}) and peppery furrow shells, *Scrobicularia plana* (max 330 m^{-2}, but not recorded in Copperhouse Pool and only occasionally in Lelant Water).

The biomass data and previous surveys of extent of biotopes were used to assess the estimated biomass of common taxa in Copperhouse Pool. These data were then combined with published estimates of productivity to estimate annual production of common taxa in Copperhouse Pool.

Four unusual species were recorded from the sediment cores:

- The carabid beetle *Cillenus lateralis* was found in low numbers at some of the more elevated sites (Sites 9, 14 & 20) where there was a dense cover of filamentous green algae and in some cases *Salicornia*. This species is restricted to saltmarsh habitats and is classified as Nationally Scarce B (i.e. it has been recorded in 16 – 100 10 km squares in the UK).

- Eleven specimens (adults and juveniles) of the intertidal centipede *Geophilus seurati* were recorded at Site 25 (Lelant Water), from an area of firm muddy sand, overlaid with filamentous green algae (approximately 65% cover). This species has been recorded from a number of intertidal sites in the southern and western coasts of the British Isles and in the Channel Isles, Brittany and Algeria. The records from Hayle are interesting because nearly all records for this species are from under rocks in the intertidal, but at Site 25 there were no rocks. Specimens were not seen on the surface during the survey, suggesting that it hunts below the dense layer of filamentous green algae found at this site.

- The bivalve *Lasaea adansoni* was recorded from five of the ten sites sampled in Carnsew. All of the sites were firm sediments on the mid to upper shore. This is an unusual micro-habitat for *Lasaea adansoni*, which is normally recorded from crevices, algal holdfasts and from the intertidal lichen *Lichinia pygmaea*.

- *Limnodriloides agnes* (identification to be confirmed), an oligochaete worm (family Tubificidae) found at some sites in Carnsew and one in lower Copperhouse Pool. This appears to be the first record for the UK, and it may be an introduced species. The maximum density recorded was 18,000 at Site 36 in Carnsew. Identification was by Prof Christer Erseus, an oligochaete worm taxonomist based at the University of Gothenburg, Sweden. This species was first recorded from the Adriatic, but Prof Erseus has also recorded it from the Atlantic coast of France. We expect to send further specimens to him so that he can compare the genetics of the Hayle specimens with those of *Limnodriloides agnes*.

The cluster analysis and MDS produced groupings that were mainly related to height on the shore. Copperhouse Pool and Lelant Water had generally similar communities to each other, but several sites in Carnsew formed a separate group.

The 'BEST' statistical analysis showed that height on the shore was the single most important factor structuring invertebrate communities in the Hayle estuary complex. The 'BEST' analysis of the three separate areas showed that the two most important variables structuring the benthic invertebrate communities were:

Copperhouse Pool	Height + Manganese concentration
Lelant Water	Gravel content (%) + Organic Carbon (%)
Carnsew	Height + Organic Carbon (%)

6. Metals in selected biota.

Some metal concentrations in wader prey in parts of the Hayle estuary complex may be sufficiently high to cause adverse impacts on wading birds, for example reduced number of eggs or poorer breeding success. We therefore assessed the metal concentrations of six important species of wader prey at 20 locations:

Ragworm	*Nereis diversicolor*	6 sites (2 each in Copperhouse, Lelant & Carnsew)
Lugworm	*Arenicola marina*	3 sites (1 each in Copperhouse, Lelant & Carnsew)
Brown shrimp	*Crangon crangon*	2 sites (Copperhouse & Lelant)
Shore crab	*Carcinus maenas*	3 sites (1 each in Copperhouse, Lelant & Carnsew)
Amphipod	*Corophium volutator*	3 sites (1 each in Copperhouse, Lelant & Carnsew)
Periwinkle	*Littorina saxatilis*	3 sites (1 each in Copperhouse, Lelant & Carnsew)

In many cases these appear to be the first data collected on metals in wader prey in Hayle and will form a useful baseline for future studies. Specimens were sent to the Environment Agency Laboratories for analysis of the following metals:

- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Manganese (Mn)
- Mercury (Hg)
- Nickel (Ni)
- Strontium (Sr)
- Zinc (Zn)

Compared to other European estuaries, concentrations of arsenic, copper, iron and manganese were elevated in Hayle. Chromium, lead and zinc concentrations in biota were often elevated. Cadmium, mercury, nickel and strontium did not appear to be unusually high in biota from Hayle.

7. Fish population survey of Copperhouse Pool, Hayle

Fish in Copperhouse Pool were surveyed using seine nets. Most of the survey effort was on the low water pool, but some seine netting was also done in the upper part of Copperhouse Pool.

A total of eight species of fish represented by 4,491 individuals were recorded.

Sand Smelt, *Atherina presbyter* and Golden Grey Mullet *Liza aurata* dominated the community, representing 57.9 % and 35.8 % of the catch respectively. Gobies (*Pomatoschistus* spp.) accounted for most of the remaining catch (5.7 %) and were mainly common gobies (*Pomatoschistus microps*). A small number of Sand Goby were also identified and a few Sea Bass, Pilchard, two Flounder and a single Lesser Weever were recorded.

The species mix was compared with results for the previous survey of fish in Copperhouse Pool (2001). In terms of biomass, Golden Grey Mullet was the dominant species in both surveys. Sand Smelt, the dominant species in terms of numbers in 2010, was also present in reasonable numbers in 2001. Less common species varied between surveys: Pilchard and Lesser Weever were not recorded in 2001; Gilthead Sea Bream was not recorded in 2010.

The age distribution of fish caught in the survey was determined by classification of fish into size groupings and length measurement of a sample of each species. Most fish were in the 0+ age class (young-of-year, 2010).

The results demonstrate that Copperhouse Pool is an important nursery area for several fish species, particularly Golden Grey Mullet, Sand Smelt and gobies. Lower numbers of juvenile Sea Bass were also present.

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Environment Agency
Hayle Harbour Authority
Natural England
RSPB

Staff at the RSPB, Natural England and the Environment Agency also provided feedback on the survey design and sampling methods.

REFERENCES (not including those in appendices)

Aquatic Environmental Consultants (1989). Survey of the Benthic Macro-invertebrate Communities at Estuarine Sites at Hayle, Cornwall, January 1989. Prepared for David Bellamy Associates.

Aquatic Environmental Consultants (2000). Intertidal and Subtidal Surveys of the Hayle estuary Complex, February 2000. Report prepared for The Environment Practice and Hayle Harbour Company.

Din, ZB (1992). Use of aluminium to normalize heavy-metal data from estuarine and coastal sediments of Straits of Melaka. Marine Pollution Bulletin, Volume 24, 484-491.

Gill, C (1989). Surveys of Harbours, Rias and Estuaries in Southern Britain. OPRU, Field Studies Council report for Nature Conservancy Council, August 1989.

Loring, DH (1991). Normalization of heavy-metal data from estuarine and coastal sediments. ICES Journal of Marine Science, Volume 48, 101-115.

APPENDIX 1. BIOTOPE MAPPING OF *SALICORNIA*, *SPARTINA* & FILAMENTOUS GREEN ALGAE AT COPPERHOUSE AND CARNSEW, HAYLE.

1. SUMMARY

The biotope survey was carried out by Aquatonics Ltd on 16 & 17 August 2010. The aim of the survey was to map approximately ten areas of *Salicornia*, *Spartina* and filamentous green algae and *Vaucheria* in Copperhouse Pool and Carnsew Pool.

In total 12 biotope boundaries were mapped to an accuracy of a few cms in plan view and height, using Real Time Kinematic (RTK) GPS. The results will form a baseline against which to measure any changes that may be caused by developments at Hayle.

2. METHODS

The biotope boundaries to be mapped were largely chosen in advance of the survey, using data obtained from our biotope mapping exercise in August & September 2008. This survey used a hand-held GPS and Google Earth imagery to map most of the significant areas of biotopes present in the Hayle estuary complex. In Copperhouse Pool, this biotope information was augmented by detailed boundaries obtained during an Aquatonics staff training exercise in August 2009, where Real Time Kinematic (RTK) and laser scanning methods were demonstrated by Merrett Survey Partnership. The results from the 2009 survey at Copperhouse Pool have not been presented in any formal report, but results that are relevant to the current report are included.

In the August 2010 survey, the biotope boundaries were accurately surveyed (to within a few cms in plan view and height) using RTK GPS. Decisions were made at each biotope on which boundary to map, i.e. the main extent of the biotope or the full extent. In most cases the extreme limit of the biotope was mapped, for example, the *Salicornia* plant furthest into the mudflat. We expect this will reduce the variability between years, as it is easier to spot the furthest plant than be consistent on where to map a boundary based on density of plants.

Filamentous green algae and *Vaucheria* spp. were an important component of most of the biotopes that were mapped in August 2010. We made extensive field notes and took photographs of dominant species. Algal samples were taken from all biotopes and brought back to the laboratory for identification. Many of the algae were in the genus *Ulva*, but note that all members of the genus *Enteromorpha* are now included in *Ulva*. For example, the species known as gutweed was previously called *Enteromorpha intestinalis* but is now *Ulva intestinalis*.

Biotopes were numbered B1 to B10. B1 to B3 were in Lower Copperhouse Pool, B4 to B6 were in Upper Copperhouse Pool and B7 to B10 were in Carnsew. At B4 we mapped two boundaries, an inner boundary that was the limit of the filamentous green algae (mainly *Ulva prolifera*) and an outer boundary that was the limit of *Salicornia europaea*. B5 had two sub-units. B5A was a small island of *Spartina anglica*. B5B was the main bed of *Spartina*. Other small islands of *Spartina* that were mapped by laser scanner in August 2009 have been added to the biotope map (see Figure 2) but were not numbered or examined during the recent field survey.

Large numbers of photographs were taken of each biotope and notes were made on any features of interest, for example where the low water creek was adjacent to the boundary. This information may help determine if future changes are due to natural changes (eg erosion of a bed of *Salicornia* by a low water channel that migrates) or due to the developments at Hayle. It should be noted, however, that distinguishing natural change from changes brought about by the development and other changes in management is likely to be difficult. For example, the maximum inundation height of Copperhouse Pool has been decreased as a flood control measure and this may affect some biotope boundaries.

3. RESULTS

Results are summarised in Table 1.1. Digital maps showing the boundaries are available from Aquatonics Ltd in dxf format. Figures 1.1-1.2 show the boundaries of the biotopes mapped. Photographs 1.1-1.30 show features from each of the biotopes that were mapped.

3.1 Algae Recorded

The list of algae recorded in the biotopes is included below. Some, such as *Percursaria percursa,* may be new records for the Hayle complex. All difficult specimens were sent to an algal expert (Ian Tittley) for confirmation or identification.

Green filamentous algae & *Vaucheria*:

Blidingia marginata
Blidingia minima
Percursaria percursa
Rhizoclonium riparium
Ulva compressa
Ulva intestinalis (gutweed)
Ulva lactuca
Ulva linza
Ulva prolifera
Ulva torta
Vaucheria spp.

Brown algae

Ascophyllum nodosum (knotted wrack)
Fucus vesiculosus (bladder wrack)

4. ACKNOWLEDGEMENTS

Merrett Survey Partnerships (MSP) provided training on the use of the RTK GPS and also provided CAD & GIS expertise and mapped data obtained onto existing aerial photography.

Table 1.1 Summary of Biotopes Mapped in August 2010
Rhizoclonium = *Rhizoclonium riparium; Salicornia* = *Salicornia europaea; Spartina* = *Spartina anglica*
Nereis = *Nereis diversicolor* (also known as *Hediste diversicolor*) Harbour ragworm.
"Points" mentioned in the final column refer to specific GPS fixes where notes were made of information that will be needed for comparative purposes in future surveys. Not all this information is shown in Table 1.1.
Algal species identified in core samples within the biotope are included in the list of algae present.

BIOTOPE & LOCATION	DOMINANT PLANT & ALGAL SPECIES	OTHER PLANT & ALGAL SPECIES	COMMENTS
B1 Lower Copperhouse Pool	*Ulva prolifera*	<10% of area has some *Salicornia* *Rhizoclonium* (minor) *Ulva torta* (minor) *Ulva intestinalis* (minor) *Blidingia minima* (minor)	Raised bed of filamentous green algae with patches of *Salicornia*. Firm muddy sand. Occasional *Carcinus* (shore crab) holes, especially at eastern end.
B2 Lower Copperhouse Pool	*Ulva prolifera*	*Salicornia* *Ulva compressa* (occasional) *Ulva torta* (minor) *Ulva intestinalis* (minor) *Rhizoclonium* (minor) *Blidingia minima* (minor)	Raised bed of filamentous green algae with patches of *Salicornia* (more than B1). At upstream end ~ 20 – 30% of the biotope had *Salicornia* present. Occasional *Carcinus* holes on edge, plus *Nereis* and *Corophium*.
B3 Lower Copperhouse Pool	*Salicornia* *Ulva prolifera* *Ulva torta* co-dominant or dominant on densest region of filamentous greens on eastern edge of the biotope	*Ulva torta* (occasional) *Ulva intestinalis* (minor) *Rhizoclonium* (minor) *Ulva linza* (minor)	Raised bed with filamentous green algae and dense *Salicornia* (approx 80% of the area). On eastern side of the biotope, filamentous green algae dominant with few *Salicornia*. Firm sandy mud. *Nereis* holes on the edge. An area of bare mud within the boundary was not mapped. We walked boundary of the lowest of either *Salicornia* or *Ulva* sp.

BIOTOPE & LOCATION	DOMINANT PLANT & ALGAL SPECIES	OTHER PLANT & ALGAL SPECIES	COMMENTS
B4 Upper Copperhouse Pool	*Salicornia* *Ulva prolifera*	*Suaeda maritima* (occasional, especially on higher parts) *Rhizoclonium* (minor) *Ulva torta* (minor)	Raised area of filamentous green algae dominated by *Salicornia*. Anaerobic sandy clayey mud. *Salicornia* extends beyond boundary of the filamentous green algae. Two boundaries mapped: inner boundary = lower limit of filamentous greens outer boundary = limit of *Salicornia*. Point 540 – some scattered *Spartina* nearby. Point 525 - *Salicornia* continues beyond boundary towards Black Bridge.
B5 (B5A small island & B5B main bed) Upper Copperhouse Pool	*Spartina*	No filamentous greens present	*Spartina* with occasional muddy pools. Anaerobic sandy mud. *Fucus vesiculosus* common on southern boundary. Mapped lower boundary of the *Spartina*. Upper boundary, a complex inlet into the Spartina and boundaries of small islands of *Spartina* were mapped in August 2009 by laser scanning and have been added to the RTK boundary.
B6 Upper Copperhouse Pool	*Salicornia* in parts co-dominant with *Rhizoclonium* or *Ulva prolifera* and *Ulva torta*	*Suaeda maritima* (common in central higher part) Sea aster occasional (eastern edge). *Ulva prolifera* (occasional) *Ulva torta* (occasional) *Blidingia marginata* (minor)	Firm but wet (at time of survey) slightly sandy mud. We mapped the lowest point where *Salicornia* was present, at times just occasional isolated plants.

BIOTOPE & LOCATION	DOMINANT PLANT & ALGAL SPECIES	OTHER PLANT & ALGAL SPECIES	COMMENTS
B7 Carnsew	*Salicornia* *Ulva prolifera* *Vaucheria* spp	*Suaeda maritima* (occasional to common on higher parts) *Fucus vesiculosus* on scattered cobbles & boulders *Ulva intestinalis* (minor) *Ulva torta* (minor) *Rhizoclonium* (minor) *Ascophyllum nodosum* (minor) *Blidingia minima* (minor) *Blidingia marginata* previously recorded at Core Site C32.	*Salicornia* on firm mud, extending to base of revetment. *Suaeda maritima* dominant in higher parts. Mapped upper and lower limits of *Salicornia.* Firm mud with scattered cobbles and boulders in upper parts. *Corophium* and *Nereis* holes. *Anurida maritima* on surface. Point 1052 - lower boundary terminated at creek where narrow band of *Salicornia* extended at < 1 per sq metre.
B8 Carnsew	*Ulva torta* and *Vaucheria* co-dominant (data from Core C37)	*Percursaria percursa* (minor) *Rhizoclonium* (minor) *Ulva intestinalis* (minor)	Large area of filamentous green algae & *Vaucheria*. Moderately firm mud with *Nereis* and *Corophium* holes. Mapping did not include algae on SE end at base of revetment or algae on edge of the creek on west/south west boundary: photo taken at 19:17, 07/0910.
B9 Carnsew	*Ulva prolifera* on lower parts but *Rhizoclonium* dominant in some higher parts (eg Core C39)	*Blidingia minima* (minor) *Ulva torta* (minor) *Ulva intestinalis* (minor) *Percursaria percursa* (rare: core C39) *Vaucheria* approx 5% cover at Core C39 and 5-10% cover in patches (with *Rhizoclonium*)	Sub-lobe of whole biotope mapped. Raised area of firm mud extending almost to low water. Possible *Nereis* holes. *Ascophyllum nodosum* on some cobbles.
B10 Carnsew	*Vaucheria* with *Rhizoclonium* co-dominant in patches	*Blidingia minima* (minor) *Ulva prolifera* (minor) *Ulva torta* (minor) *Ulva intestinalis* (minor) *Percursaria percursa* (rare) core 31	Area of *Vaucheria* dominated mud on upper shore with occasional scattered cobbles and boulders. Firm sandy mud.

PHOTOGRAPHS OF BIOTOPES

Photo 1.1 Biotope 1 – general view.

Photo 1.2 Biotope 2 – general view.

Photo 1.3 Biotope 2, boundary along edge of low water channel.

Photo 1.4 Biotope 2 showing *Salicornia* and green filamentous algae (mainly *Ulva prolifera*).

Photo 1.5 Biotope 2 showing substrate and filamentous green algae (*Ulva prolifera* and some *Ulva compressa*).

Photo 1.6 Biotope 3 surveying boundary nearest to the seawall. Dense *Salicornia* present.

Photo 1.7 Biotope 3 surveying the seaward end.

Photo 1.8 Biotope 3 - appearance on 8 September 2010 on ebb tide showing limit of biotope.

Photo 1.9 Biotope 4 – general view looking towards Black Bridge.

Photo 1.10 Biotope 4 showing substrate with *Salicornia* and filamentous green algae (mainly *Ulva prolifera*).

Photo 1.11 Biotope 5A - a small area of *Spartina anglica*.

Photo 1.12 Biotope 5B - main area of *Spartina* in upper Copperhouse Pool.

Photo 1.13 Biotope 5B - area of creek in *Spartina* bed that was mapped by laser scanner in August 2009.

Photo 1.14 Biotope 5B – looking towards mouth of Copperhouse Pool.

Photo 1.15 Biotope 6 – general view of *Salicornia*.

Photo 1.16 Biotope 6 - surveying the lower shore boundary of *Salicornia* along the low water channel.

Photo 1.17 Biotope 6 –boundary of *Salicornia* with mudflat (shown by footprints). Biotope 5A (small island of *Spartina anglica*) in the right foreground.

Photo 1.18 Biotope 6 – surveying boundary between *Salicornia* and *Suaeda maritima*.

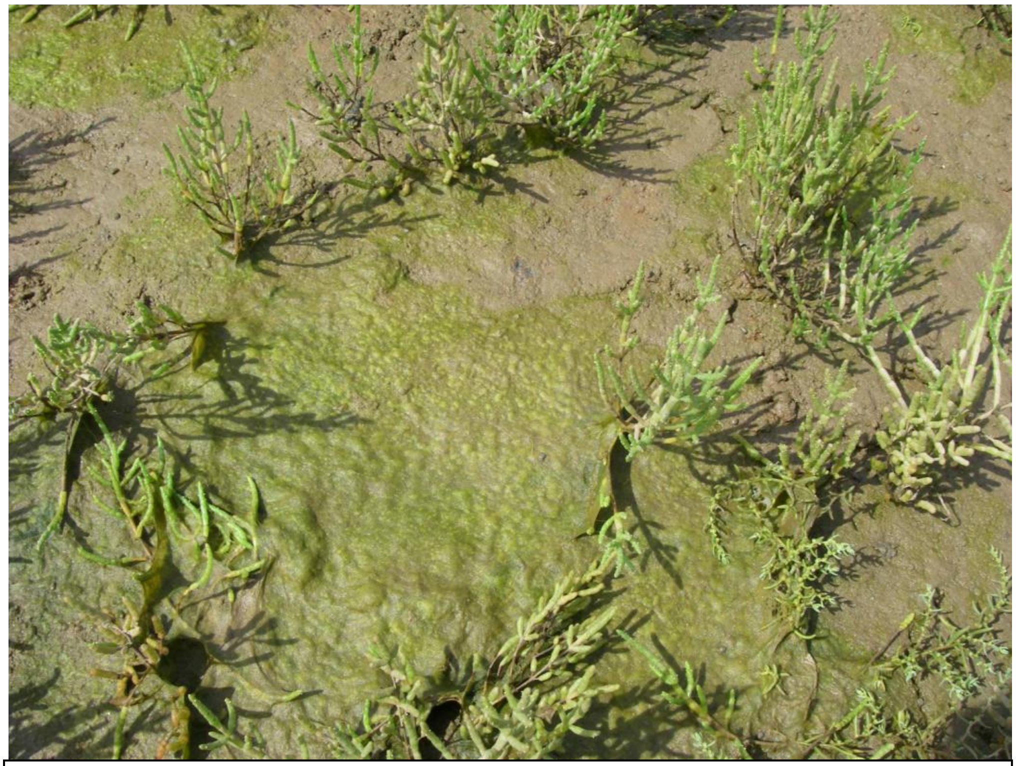


Photo 1.19 Biotope 6 - detail of substrate with *Salicornia* and filamentous green algae (mainly *Ulva prolifera*).

Photo 1.20 Biotope 6 – Area of the filamentous green alga *Rhizoclonium riparium* surrounded by *Salicornia*.

Photo 1.21 Biotope 7 – general view towards the entrance to Carnsew.

Photo 1.22 Biotope 7 – surveying lower edge of *Salicornia*.

Photo 1.23 Biotope 7 – surveying upper edge of *Salicornia*.

Photo 1.24 Biotope 7 - *Salicornia* with filamentous green algae (mainly *Ulva prolifera*) and scattered *Fucus vesiculosus* (bladder wrack).

Photo 1.25 Biotope 8 – general view of dense growths of filamentous algae (mainly *Ulva torta* and *Vaucheria* spp).

Photo 1.26 Biotope 8 – very shallow creek marks the left boundary of the area mapped.

Photo 1.27 Biotope 9 - blue dots indicate limit of area surveyed. Photo taken on 7 September 2010.

Photo 1.28 Biotope 9 - lower edge with dense population of lugworms (*Arenicola marina)* below boundary on right of photo.

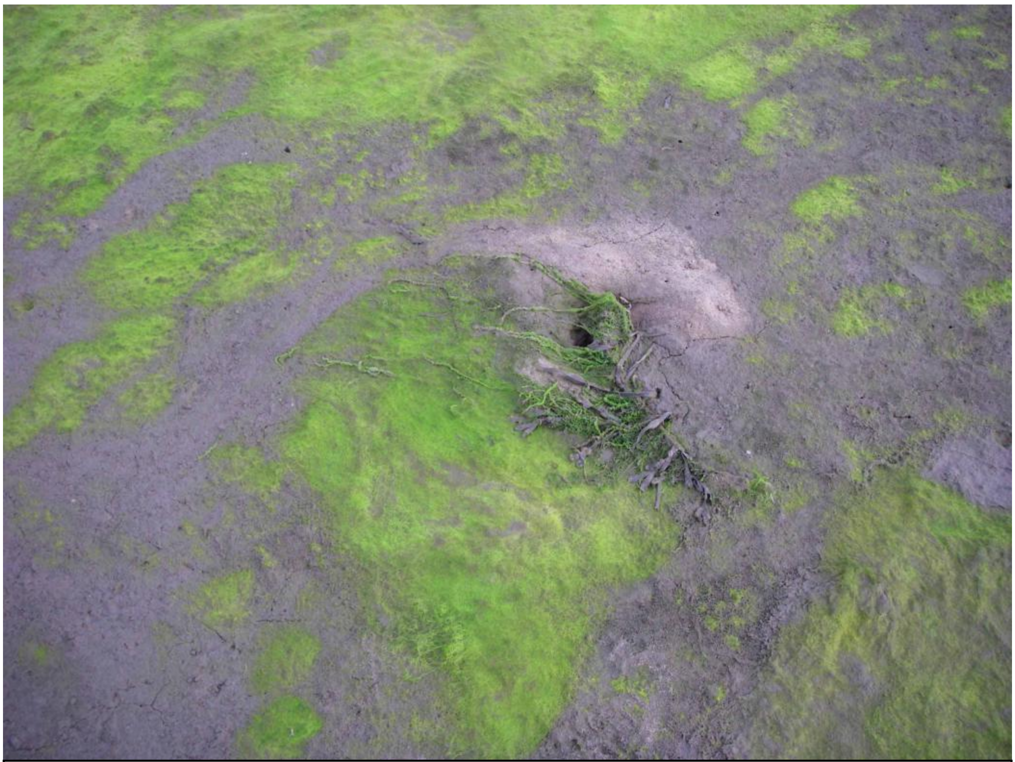


Photo 1.29 Biotope 9 - substrate with dense filamentous algae (mainly *Ulva prolifera*).

Photo 1.30 Biotope 10 – surveying upper limit of area of filamentous algae (mainly *Vaucheria* spp.).

Figure 1.1 Biotopes in lower Copperhouse Pool. Green line = boundary mapped in August 2010 by RTK GPS. Core sites for benthic invertebrates are also shown. Grid lines at 250 m intervals. Aerial image obtained in autumn 2007 and reproduced courtesy of the Channel Coastal Observatory (www.channelcoast.org).

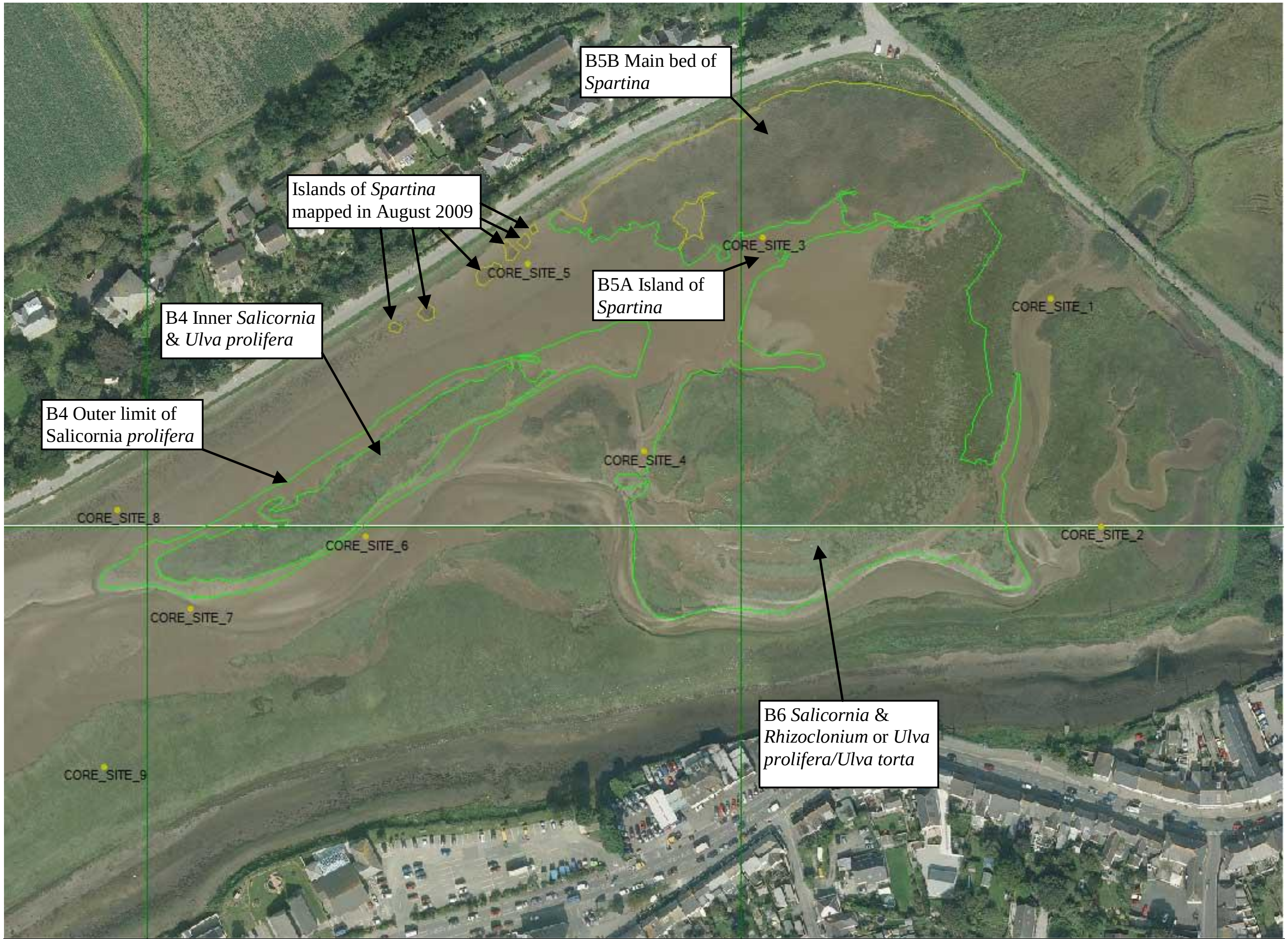


Figure 1.2 Biotopes in upper Copperhouse Pool. Green line = boundary mapped in August 2010 by RTK GPS. Yellow line = boundary mapped in August 2009 by laser scanner. Core sites for benthic invertebrates are also shown. Grid lines at 250 m intervals. Aerial image obtained in autumn 2007 and reproduced courtesy of the Channel Coastal Observatory (www.channelcoast.org).

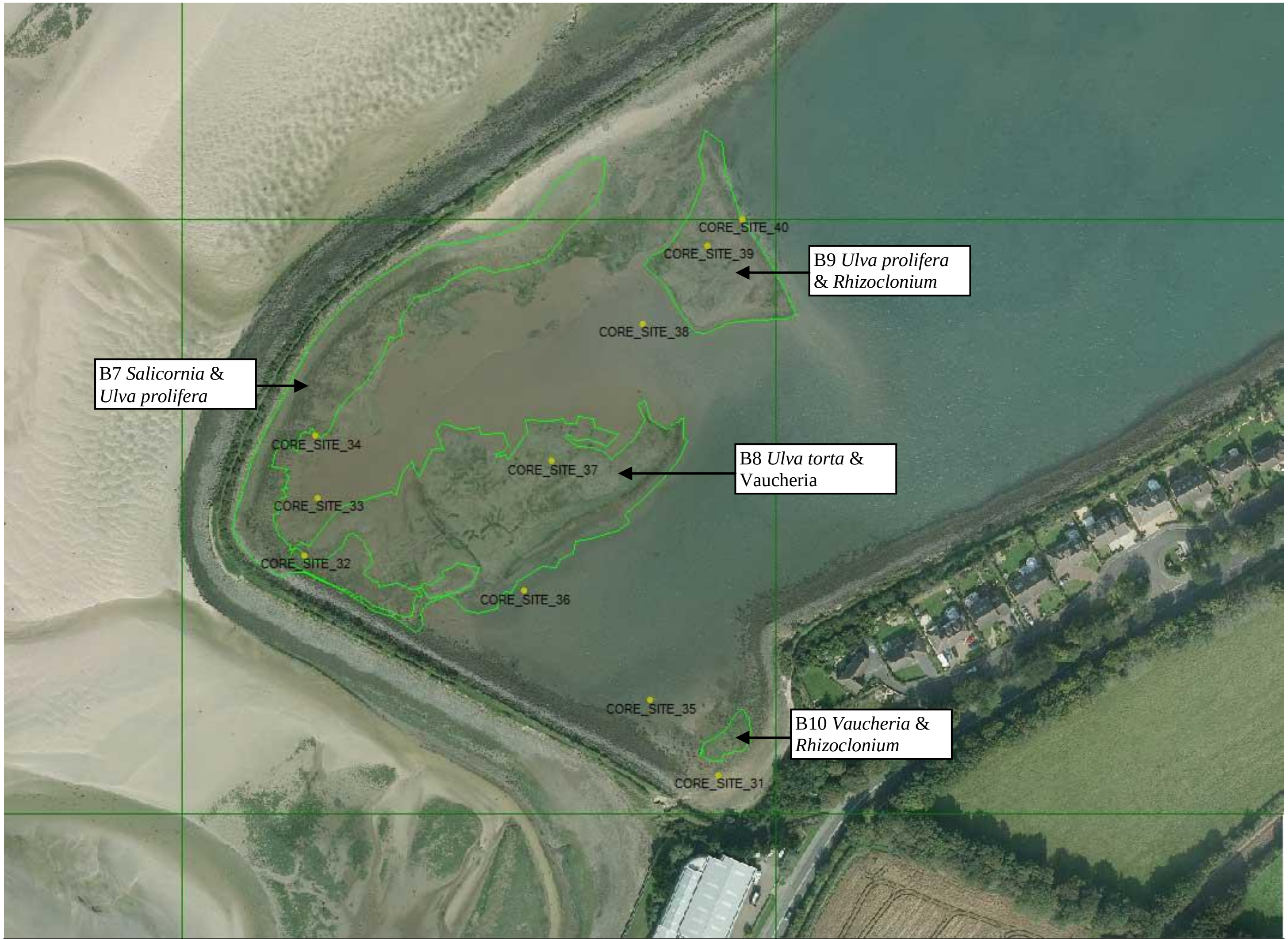


Figure 1.3 Biotopes in Carnsew Pool. Green line = boundary mapped in August 2010 by RTK GPS. Core sites for benthic invertebrates are also shown. Grid lines at 250 m intervals. Aerial Image obtained in autumn 2007 and reproduced courtesy of the Channel Coastal Observatory (www.channelcoast.org).

APPENDIX 2. INVERTEBRATES & ALGAE ON AND UNDER HARD SUBSTRATES.

1. INTRODUCTION

Most estuarine systems contain appreciable areas of hard substrate, either naturally occurring or man-made features such as seawalls and slipways. These hard substrate areas can be very rich in seaweeds and invertebrates. Some of the invertebrates (e.g. barnacles and tubeworms) are permanently attached to the substrate, whilst others are mobile (e.g. periwinkles and limpets) or are found at low water under cobbles and boulders, where it is relatively damp and protected from desiccation. Others, e.g. amphipod crustaceans, are often associated with the seaweeds.

2. METHODS

We examined the invertebrates and algae (seaweeds) associated with hard substrates at nine locations (3 in each of Copperhouse Pool, Carnsew and Lelant Water). The surveys were carried out on 8-9 July 2010. It is not possible to provide quantitative data for all groups of organisms associated with hard substrates, we therefore used a 10 minute timed search and recorded using a combination of actual counts (which may be useful for comparison with future surveys) and the SACFOR scale:

S= Superabundant,
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

The density required for each of these abundance categories depends on the size of the organism. We therefore used the Joint Nature Conservancy Council (JNCC) SACFOR scale descriptors available at: www.jncc.gov.uk/marine/biotopes/downloads/intro_habclass.pdf

Most taxa were identified in the field, but we also brought some groups, for example amphipod crustaceans, back to the laboratory for accurate identification.

3. RESULTS

Sampling sites are shown in Figures 2.1 to 2.3. Counts for each of the species identified in the hard substrate surveys are shown in Table 2.1 and the SACFOR equivalent values for all taxa are shown in Table 2.2.

In total 51 invertebrate taxa and 23 algal taxa were recorded at the nine locations. The most species-rich site was Site 4, in Carnsew near the sluice, where we recorded 26 invertebrate taxa and 19 algal taxa. The area near the sluice in Carnsew has previously been found to be the most diverse site studied, and these results confirm the importance of this location. The invertebrate fauna at most of the hard substrate sites was very restricted, probably due mainly to metal concentrations in water, underlying sediments and the substrate itself, which was often slag material from the copper works and other industrial sites.

The only unusual record was the tentative identification of the nemertean worm *Oxypolia beaumontiana*. This species has been recorded from north-east Scotland, the northern North Sea and the Plymouth area. It is known only from the British Isles. Unfortunately there are very few nemertean worm specialists in the world, so it hasn't been sent to a specialist for confirmation.

Figure 2.1 Hard substrate sampling sites in Copperhouse Pool.

Figure 2.2 Hard substrate sampling sites in Carnsew and Lower Lelant Water.

Figure 2.3 Hard substrate sampling sites in Upper Lelant Water.

Table 2.1 Counts for species identified in hard substrate surveys, 8-9 July 2010

TAXON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Hymeniacidon perleve (no of colonies)				2					
Dynamena pumila				O					
Ventromma halecioides?				R					
Actinia equine					11				
Nemerteans (2 species present at site 6)				1		8			
Lineus ruber				1					
Oxypolia beaumontiana?					1				
Enchytraeid oligochaetes							3		
Nereis diversicolor	3	2	16					12	
Perinereis cultrifera				1					
Pholoe synophthalmica				1					
Harmothoe sp.				1					
Autolytus prolifer				1					
Sphaerosyllis taylori				1					
Fabricia sabella				3					
Janua pagenstecheri				460	70				
Spirorbis spirorbis				>100					
Eupolymnia nesidensis				1					
Littorina saxatilis	15	240	210	23	18	179	79	17	279
Littorina littorea									3
Littorina mariae				1					
Gibbula umbilicalis				1					
Osilinus lineatus				3					
Leucophytia bidentata				4					
Heteranomia squamula				14					
Kellia suborbicularis						50			
Mytilus edulis	1			31					
Patella vulgata				8					
Ondina divisa				1					

TAXON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ligia oceanica		3	48		5	17	17		77
Paragnathia formica					6				
Carcinus maenas	38	3	33	3	15	10	28	18	18
Orchestia gammarellus			11	22					
Orchestia mediterranea		>1000			40	171	31		
Orchestia sp.	2								8
Hyale prevostii					1				
Melita palmata	6								
Echinogammarus marinus		5			2				
Gammaridae (not collected or identified)				2					
Dexamine sp. (juv)				1					
Ischryoceridae (indeterminate)				2					
Elminius modestus				1		30			
Chthamalus montagui				3180		27			
Chthamalus stellatus									227
Red mites							1		
Anurida maritima	74	83	28	3	20	81	>1900	148	>1000
Petrobius maritimus				5	5	2			
Alcyonidium hirsutum				O					
Cryptosula pallasiana				O					
Celleporella hyalina				R					

Table 2.2 SACFOR scale recordings during invertebrate surveys at Copperhouse Pool (sites 1-3), Carnsew (sites 4-6) and Lelant (sites 7-9).

	Copperhouse Pool			Carnsew			Lelant		
TAXON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Hymeniacidon perleve				O					
Dynamena pumila				O					
Ventromma halecioides?				R					
Actinia equina					O				
Nemerteans (indeterminate)						O			
Lineus ruber				R					
Oxypolia beaumontiana?					R				
Enchytraeid oligochaetes							R		
Nereis diversicolor	O	F	F					O	
Perinereis cultrifera				R					
Pholoe synophthalmica				R					
Janua pagenstecheri				C	O				
Spirorbis spirorbis				O					
Eupolymnia nesidensis									
Littorina saxatilis	O	C	C	F	O	C	C	O	C
Littorina littorea									R
Littorina mariae				R					
Gibbula umbilicalis				R					
Osilinus lineatus				O					
Auriculinella bidentata				R					
Heteranomia squamula				O					
Kellia suborbicularis						O			
Mytilus edulis	R			F					
Patella vulgata				O					
Ligia oceanica		O	F		O	F	O		F
Paragnathia formica					O				
Carcinus maenas	C	O	C	O	C	F	C	O	F
Orchestia gammarellus			O	O					
Orchestia mediterranea		A			O	C	F		
Orchestia sp.	R								O
Hyale prevostii					R				
Melita palmata	O								
Echinogammarus marinus		O			R				
Gammaridae (not collected or identified)				R					
Elminius modestus				R		O			
Chthamalus montagui				C		O			
Chthamalus stellatus									F

Table 2.2 (cont) SACFOR scale recordings during invertebrate surveys at Copperhouse Pool (sites 1-3), Carnsew (sites 4-6) and Lelant (sites 7-9).

	Copperhouse Pool			**Carnsew**			**Lelant**		
TAXON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Red mites							R		
Anurida maritima	F	F	O	R	O	F	A	F	A
Petrobius maritimus				O	O	R			
Alcyonidium hirsutum				O					
Cryptosula pallasiana				O					
Celleporella hyalina				R					
Vaucheria sp.								O	
Rhizoclonium riparium	O						O		
Blidingia marginata		A	A		F	O	C		R
Blidingia minima	A	O		O		O	C	O	
Ulva lactuca				C					
Ulva intestinalis				C				O	
Cladophora rupestris				O					
Pelvetia canaliculata				C		F			O
Fucus serratus				C					
Fucus spiralis	C	F			C	C		O	C
Fucus vesiculosus	C	F	F	A	C				R
Ascophyllum nodosum				C	C	C			
Laminaria digitata				O					
Chorda filum				O					
Sargassum muticum				O					
Chondrus crispus				O					
Mastocarpus stellatus				C					
Ceramium virgatum				F					
Ceramium secundatum				O					
Porphyra cf *purpurea*				O					
Lomentaria articulata				R					
Gelidium pusillum				R					
Polysiphonia lanosa				O					
Salicornia europaea		A	A				C		

APPENDIX 3. COUNTS OF CASTS OF LUGWORM, *ARENICOLA MARINA*

1. INTRODUCTION

The lugworm (*Arenicola marina*) feeds on sediment and produces characteristic sediment casts on the surface when it defecates. Counting these casts is the best way to monitor lugworms, which live deep in the sediment and are therefore under-recorded in core samples.

2. METHODS

We examined the density of lugworm casts in quadrats at 11 locations in Copperhouse Pool (4 sites), Carnsew (4 sites) and Lelant Water (3 sites). At each location counts of lugworm casts were made in five separate square metre quadrats. The locations of the sampling sites are shown in Figure 3.1.

3. RESULTS

Results are summarised in Table 3.1. The mean densities of casts per square metre in each location were:

Copperhouse Pool	Minimum	11.2	Maximum	29.8
Carnsew	Minimum	5.4	Maximum	82.6
Lelant	Minimum	6.8	Maximum	16.6

It appears that lugworms are now much more common in the Hayle estuary complex than in the late 1980s. For example, a survey by the Field Studies Council in June 1988 (Gill, 1989) did not record any lugworm (*Arenicola marina*) in cores, but some were recorded at one site described as Hayle Street, opposite Works. The NGR given is SW 557 373 which is closest to Penpol, but there is no Hayle Street near that location. We did not record any lugworm casts in Copperhouse Pool during a survey in 1988 (Appendix 5, Table 5.3).

Figure 3.1 Quadrat sites for Lugworm (*Arenicola marina*) cast counts. Scale bar = 300 m.

Table 3.1 Data for *Arenicola* quadrat counts in Copperhouse Pool, Carnsew and Lelant Water, July 2010.

SITE	DESCRIPTION	SUBSTRATE & NOTES	AREA	NGR	DATE	TIME	1	2	3	4	5	MEAN COUNT	ST DEV
A1	Copperhouse Pool, just u/s from LW pool	Muddy sand. Avoided bait digging areas	8 m x 8 m	SW 55889 37722	08/07/2010	19:05	31	37	32	30	19	29.80	6.61
A2	Copperhouse Pool, just u/s from A1	Muddy sand	10 m x 10 m	SW 55956 37767	08/07/2010	19:14	12	20	14	23	25	18.80	5.63
A3	Copperhouse Pool, just u/s from A2 in wet area	Muddy sand. Central part of large lobe mud, all dense with *Arenicola*		SW 56003 37791	08/07/2010	19:25	6	20	5	15	10	11.20	6.30
A4	Copperhouse Pool, north side of *Ulva* bed	Hummocky muddy sand with leaf litter in hollows		SW 56003 37791	08/07/2010	19:30	19	28	15	16	22	20.00	5.24
A5	Carnsew	Very muddy sand		SW 55218 37050	08/07/2010	20:30	38	64	127	125	59	82.60	40.81
A6	Carnsew, downshore from rusting metal box	Soft, hummocky wet sandy mud		SW 55145 37080	08/07/2010	20:50	17	16	40	16	33	24.40	11.33
A7	Carnsew central near the edge of the LW pool	Soft sandy mud, hummocky with water pools		SW 55181 37210	08/07/2010	21:00	3	2	9	10	3	5.40	3.78
A8	Lelant along LW channel adjacent to Carnsew	Firm muddy sand, slightly hummocky but no standing water	4 m x 50 m	SW 55026 37072	08/07/2010	21:20	13	4	3	4	10	6.80	4.44
A9	Lelant Water, in line with centre of wooden boat wrecks	Muddy, very hummocky sand		SW 54945 37324	09/07/2010	10:00	14	16	10	11	9	12.00	2.92
A10	Lelant upstream of A9 in flat wet area	Wet sand with small amount of mud	20 m x 6 m	SW 54954 37309	09/07/2010	10:05	17	20	17	10	19	16.60	3.91
A11	Carnsew, close to LW pool	Soft, sticky sandy mud, hummocky. Minor drainage channel	30 m x 7 m	SW 55214 37286	09/07/2010	10:27	57	51	74	91	58	66.20	16.27

APPENDIX 4. METALS IN SEDIMENTS

1. INTRODUCTION

The aim of the study was to determine the baseline levels of selected metals in the upper 10 cm of sediment at the three main locations in the Hayle estuary complex (Copperhouse Pool, Lelant Water and Carnsew Pool). The data will be used to determine if construction activities, for example the new road bridge to North Quay, have affected metal concentrations in sediments.

In addition to the metal content the particle size of the sediments and the organic carbon content was also assessed.

2. METHODS

Samples were collected using a plastic corer, which was pushed into the sediment to a depth of 10 cm. The corer was removed from the sediment by digging underneath the base. The sediment in the corer was removed either by allowing it to fall into a labelled plastic bag, or, more usually by pushing it out using a wooden plunger. The corer and plunger were washed at every opportunity.

Locations of the sampling sites are shown in Appendix 5 (Figures 5.3 to 5.5).

Samples were processed and analysed by the Environment Agency Laboratory at Llanelli. Sediment samples were digested with hydrofluoric acid then analysed for the following metals:

- Aluminium (Al)
- Arsenic (As)
- Barium (Ba)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Lithium (Li)
- Manganese (Mn)
- Mercury (Hg)
- Nickel (Ni)
- Tin (Sn)
- Vanadium (V)
- Zinc (Zn)

Most of the metals were included due to their potential toxicity to aquatic organisms. Others (Al, Fe, Li & Mn) were included to aid interpretation of concentrations of toxic metals. Oxides of iron and manganese often co-precipitate more toxic metals and there are often strong positive correlations between the concentrations of iron and manganese and toxic metals such as nickel, copper and zinc (Jenne, 1968).

Aluminium was included so that the metal content of samples could be normalised to the aluminium content (Din, 1992). In most cases, the trace metal content of a sediment increases as the particle size decreases. It is possible to use the particle size data to normalise for the effect of particle size (or even analyse different fractions of the sediment separately) but it is usually more convenient to use the Aluminium content as a surrogate for the silt and clay content. This is due to the fact that aluminium is a major component of the aluminosilicates found in clays and silts.

Lithium can have advantages over aluminium for normalising metal data in some data sets, especially if there are significant contributions from glacial marine sediments derived from igneous as well as sedimentary sources (Loring, 1991).

Particle size analyses were carried out by Ambios Ltd and organic content was analysed by the Environment Agency Laboratory.

3. RESULTS

Table 4.1 shows the metal data and particle size data for Copperhouse Pool, Table 4.2 for Lelant Water and Table 4.3 for Carnsew.

3.1 Comparison with Probable Effects Levels (PELs)

Table 4.4 shows the ratio between minimum, mean and maximum metal concentrations and the Probable Effects Level (PEL) developed in Canada to protect estuarine and marine organisms. Of the metals analysed, the most important in determining the toxicological effect on sediment-dwelling organisms were (in order of ratio of mean concentration to PEL):

- Arsenic 14.4
- Copper 9.3
- Zinc 3.4
- Cadmium and Lead 1.5
- Chromium 0.6
- Mercury 0.2

There are no PELs for the remaining metals that we analysed.

Table 4.5 shows mean concentrations of each metal in the three areas studied. The highest mean concentrations of each metal were in Copperhouse Pool.

3.2 Correlations between Metals

Correlations between metals, and between metals and height on the shore are shown in Table 4.6. Although many metals are positively correlated with each other (e.g. copper and zinc, arsenic and iron) it is apparent that chromium only has a strong positive correlation with nickel. These correlations may be useful in determining links between metals. For example the high correlation between nickel and chromium (neither of which are normally associated with mining in Cornwall) may be due to a discharge containing chromium and nickel, perhaps from small scale chromium-nickel plating.

Figure 4.1 shows the MDS plot of metals. Metals which are closest to each other are most similar in their distribution. The close relationship between nickel and chromium and iron and manganese is apparent.

3.3 Differences between the three Main Areas

Figure 4.2 shows the MDS plot of sites based on data on metals in sediments. The sites are colour coded to show the clear distinction between the three main areas. Sites in Carnsew were intermediate between Copperhouse Pool and Lelant Water.

Gill (1989) mentioned a discharge of lead from British Ethyl (lead) factory that may have affected Copperhouse Pool. This discharge ceased in the early 1970s (Gill, 1989). We examined mean values of lead in sediments from Copperhouse Pool compared to Lelant Water and Carnsew. There was little evidence of very high lead levels in Copperhouse Pool (mean 190 mg/kg) compared to Lelant Water (159 mg/kg) and Carnsew (145 mg/kg).

4. REFERENCES

Din, ZB (1992). Use of aluminium to normalize heavy-metal data from estuarine and coastal sediments of Straits of Melaka. Marine Pollution Bulletin, Volume 24, 484-491.

Gill, C (1989). Surveys of Harbours, Rias and Estuaries in Southern Britain. OPRU, Field Studies Council report for Nature Conservancy Council, August 1989.

Jenne, EA (1967). Controls on Mn, Fe, Co, Ni, Cu and Zn concentrations in soils and water: the significant role of hydrous Mn and Fe oxides. Trace Inorganics in Water, p. 337−387. American Chemical Society, Washington DC.

Loring, DH (1991). Normalization of heavy-metal data from estuarine and coastal sediments. ICES Journal of Marine Science, Volume 48, 101-115.

Table 4.1. Metals in Sediments in Copperhouse Pool.

COPPERHOUSE POOL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aluminium	67800	61200	76100	70800	76500	55800	60500	56800	62500	57200	60600	61200	55600	63100	52300
Arsenic	643	842	1300	879	1300	814	991	538	862	801	866	1670	505	523	567
Barium	217	252	184	227	167	226	208	277	363	226	201	243	181	216	211
Cadmium	4.51	11.3	12.1	10.7	9.28	11.6	11.3	10.9	10.3	13.7	10.8	7.97	9.94	6.38	10.6
Chromium	86.3	74.8	70.5	89.8	62.2	83.3	90.5	161	84.5	90.6	104	62.6	208	91.3	87.9
Copper	1020	1290	1630	1280	1160	1080	1100	677	1020	1040	1010	1870	1150	833	887
Iron	73500	79900	92200	82200	94600	76800	78700	67600	90400	72000	74700	91900	64100	66700	63400
Lead	224	178	171	200	171	161	232	170	229	174	199	180	169	208	186
Lithium	127	140	138	145	130	125	127	122	128	120	116	170	105	111	94.3
Manganese	918	945	1090	983	1120	918	958	821	1140	898	979	1100	749	846	740
Mercury	0.163	0.208	0.193	0.18	0.188	0.108	0.099	0.108	0.367	0.199	0.083	0.126	0.351	0.173	0.102
Nickel	60.7	58.1	46.9	63.6	46.9	64.1	63.6	114	62.6	73.2	76.7	46.5	157	63.8	69.5
Tin	175	212	218	225	215	209	226	191	205	243	211	153	177	149	188
Vanadium	80.4	79.6	74.9	92.9	71.6	77.1	81.7	65.7	96.4	78.5	71.3	70.3	69.9	85.7	95.2
Zinc	1340	1410	1320	1390	1290	1200	1230	862	1190	1410	1210	1520	1070	1030	1090
Height (m ODN)	1.550	1.575	1.795	1.429	1.686	1.336	1.155	1.326	2.020	1.091	0.985	1.670	0.966	1.369	0.734
Gravel (%)	1.82	0.13	0.29	0.52	1.15	0.10	0.10	1.39	0.15	0.09	0.84	1.22	0.61	0.06	0.40
Sand (%)	61.15	36.86	15.48	68.72	25.35	64.51	79.92	53.83	74.32	92.00	95.30	29.03	96.41	81.97	98.19
Silt and clay (%)	37.03	63.01	84.23	30.77	73.50	35.40	19.98	44.78	25.52	7.91	3.86	69.75	2.98	17.97	1.41
Mean phi (Folk and Ward)	3.06	5.45	6.13	3.12	5.19	3.89	3.84	3.75	4.74	2.47	2.13	5.22	1.96	2.71	1.91
Organic carbon (% in <63 um)	1.90	1.10	0.90	1.10	0.59	1.20	1.20	0.78	1.20	1.10	0.65	1.20	0.78	0.88	0.78

Table 4.2. Metals in Sediments in Lelant Water.

LELANT WATER	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Aluminium	60000	59000	47500	47600	49500	47500	47000	42300	43300	50100	47600	54500	53300	53100	24100
Arsenic	270	1350	675	366	502	298	431	478	216	517	342	325	446	338	110
Barium	134	166	137	142	149	139	146	161	145	142	151	149	135	124	69.1
Cadmium	4.48	6.38	10.1	2.84	4.74	2.06	2.53	5.1	1.72	5.36	0.217	3.73	4.14	5.36	0.584
Chromium	70.7	105	106	85.1	93.5	74.1	84.9	77.7	76.5	133	74.4	70.8	65.8	111	16.1
Copper	614	2100	3380	1170	1220	590	699	973	515	1140	596	671	1040	760	98.4
Iron	68300	97100	79700	70600	78200	57400	68000	67100	53000	75700	63700	66200	61100	58000	22300
Lead	150	224	236	176	207	128	145	162	161	194	129	147	154	135	35.7
Lithium	121	184	168	147	147	111	130	126	108	129	122	111	108	102	53.3
Manganese	798	1370	850	812	1040	698	743	823	656	1400	761	837	756	749	302
Mercury	0.042	0.036	0.026	0.094	0.099	0.03	0.045	0.56	0.067	0.126	0.054	0.03	0.036	0.033	0.002
Nickel	52.6	84	97.7	71.2	73.6	52.3	63.3	55.7	48.3	108	51.8	48.2	46.7	80.4	10.1
Tin	92.7	136	164	192	121	135	150	96.7	125	113	199	90	81.1	100	42.8
Vanadium	55.8	84.3	73.4	61.8	65.7	57.6	64	65.8	58.2	66.3	63.4	54.7	60.8	54.7	24.6
Zinc	613	1360	2590	807	620	597	635	684	543	677	576	489	892	847	253
Height (m ODN)	1.372	1.781	1.507	1.816	1.796	1.399	1.755	0.966	1.332	1.523	1.588	1.287	0.798	0.779	0.504
Gravel (%)	0.11	0.37	0.24	10.10	0.23	0.34	0.26	0.02	0.55	7.08	0.34	0.18	0.01	0.00	0.13
Sand (%)	92.63	19.63	24.13	36.46	49.78	67.68	16.72	79.50	50.43	85.64	29.52	61.12	63.79	95.07	99.55
Silt and clay (%)	7.26	80.00	75.63	53.44	49.99	31.98	83.02	20.48	49.02	7.28	70.13	38.70	36.2	4.93	0.32
Mean phi (Folk and Ward)	2.36	6.01	5.38	4.13	4.46	3.81	5.70	3.27	4.61	1.69	5.26	3.99	3.96	2.54	2.13
Organic carbon (% in <63 um)	0.20	0.56	0.36	0.42	0.23	0.81	0.43	0.21	1.50	0.10	1.10	0.60	1.34	0.86	<0.80

Table 4.3. Metals in Sediments in Carnsew.

CARNSEW	31	32	33	34	35	36	37	38	39	40
Aluminium	57500	44800	65900	61600	55100	44900	59800	56200	56600	55300
Arsenic	349	446	596	579	334	308	525	417	442	211
Barium	233	211	159	191	194	170	195	173	198	162
Cadmium	4.58	2.32	9.48	5.65	3.37	1.79	6.05	3.88	3.24	3.28
Chromium	167	72.8	80.4	67.9	70.7	78.7	83.6	70.1	92.3	83
Copper	548	559	1510	912	581	538	968	760	504	535
Iron	55300	70400	89200	80800	62200	58700	74600	68800	71300	47500
Lead	149	141	214	179	113	105	198	123	148	82.7
Lithium	103	116	148	136	118	110	124	119	120	103
Manganese	733	830	1060	1010	750	762	1020	823	763	619
Mercury	0.106	0.125	0.162	0.165	0.099	0.099	0.156	0.147	0.15	0.099
Nickel	107	45.8	67.2	54.3	46.9	47	63.4	49.5	63.2	48.8
Tin	83.7	158	166	115	79.7	124	124	130	141	69.6
Vanadium	86.6	68.8	67.1	72.5	59.3	61.1	73.6	63.3	69.8	63.4
Zinc	581	491	911	635	467	425	664	531	491	386
Height (m ODN)	1.625	1.429	1.095	1.287	0.292	0.346	1.132	0.449	0.812	0.333
Gravel (%)	19.36	0.25	1.12	0.05	0.12	0.55	0.84	0.52	0.10	0.01
Sand (%)	79.07	9.33	3.89	9.48	34.80	27.65	35.29	25.57	44.81	98.87
Silt and clay (%)	1.57	90.42	94.99	90.48	65.08	71.79	63.87	73.91	55.09	1.12
Mean phi (Folk and Ward)	0.50	5.81	6.21	6.17	4.64	4.72	4.80	5.30	4.45	1.66
Organic carbon (% in <63 um)	1.00	0.78	0.77	0.91	1.10	1.10	0.70	1.10	0.50	1.10

Table 4.4 Ratios between Metal Concentrations and Probable Effects Levels (PELs)

Metal	Minimum mg/kg	Mean mg/kg	Maximum mg/kg	Canadian ISQL mg/kg	Canadian PEL mg/kg	Ratio Min:PEL	Ratio Mean:PEL	Ratio Max:PEL
Aluminium	24100	55553	76500					
Arsenic	110	599	1670	7.2	41.6	2.6	14.4	40.1
Barium	69.1	184.4	363					
Cadmium	0.217	6.359	13.7	0.7	4.2	0.05	1.51	3.26
Chromium	16.1	89.0	208	52.3	160	0.10	0.56	1.3
Copper	98.4	1000.7	3380	18.7	108	0.91	9.27	31.3
Iron	22300	70848	97100					
Lead	35.7	167.2	236	30.2	112	0.32	1.49	2.11
Lithium	53.3	124.1	184					
Manganese	302	879	1400					
Mercury	0.002	0.131	0.56	0.130	0.700	0.003	0.19	0.80
Nickel	10.1	65.1	157					
Tin	42.8	150.7	243					
Vanadium	24.6	69.7	96.4					
Zinc	253	908	2590	124	271	0.93	3.35	9.56

Table 4.5 Mean Concentrations of Metals in Three Main Areas Studied. Red shows the highest mean concentrations – all in Copperhouse Pool.

	Copperhouse	Lelant	Carnsew	Canadian PEL
	Mean mg/kg	Mean mg/kg	Mean mg/kg	mg/kg
Aluminium	62533	48427	55770	
Arsenic	873	444	421	41.6
Barium	227	139	189	
Cadmium	10.1	4.0	4.4	4.2
Chromium	96	83	87	160
Copper	1136	1038	742	108
Iron	77913	65760	67880	
Lead	190	159	145	112
Lithium	127	124	120	
Manganese	947	840	837	
Mercury	0.18	0.09	0.13	0.7
Nickel	71	63	59	
Tin	200	123	119	
Vanadium	79	61	69	
Zinc	1237	812	558	271

Table 4.6 Correlations between Metals and between Metals and Height

	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Sn	V	Zn
Aluminium													
Arsenic	0.635												
Cadmium	0.598	0.660											
Chromium	0.139	-0.023	0.296										
Copper	0.308	0.618	0.520	0.140									
Iron	0.724	0.810	0.584	0.061	0.656								
Lead	0.541	0.557	0.599	0.301	0.660	0.763							
Manganese	0.599	0.707	0.466	0.152	0.549	0.884	0.722						
Mercury	0.237	0.210	0.342	0.197	0.057	0.287	0.255	0.233					
Nickel	0.136	0.051	0.384	0.965	0.315	0.174	0.425	0.257	0.193				
Tin	0.505	0.589	0.712	0.150	0.351	0.593	0.552	0.396	0.245	0.219			
Vanadium	0.624	0.533	0.620	0.329	0.380	0.615	0.720	0.538	0.378	0.344	0.604		
Zinc	0.441	0.690	0.735	0.161	0.863	0.600	0.682	0.433	0.119	0.304	0.615	0.549	
Height (m ODN)	0.317	0.469	0.221	0.122	0.409	0.595	0.585	0.548	0.072	0.195	0.439	0.398	0.402

Figure 4.1. MDS plot of metal data, showing which metals are most similar in their distribution. Site 30 excluded as it was an outlier

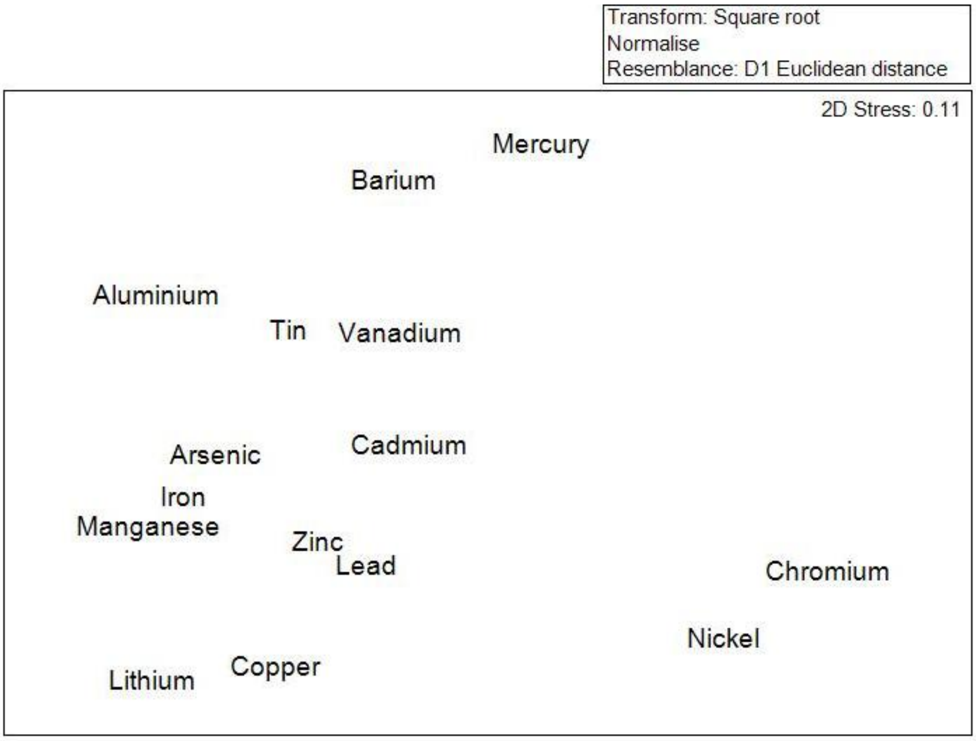
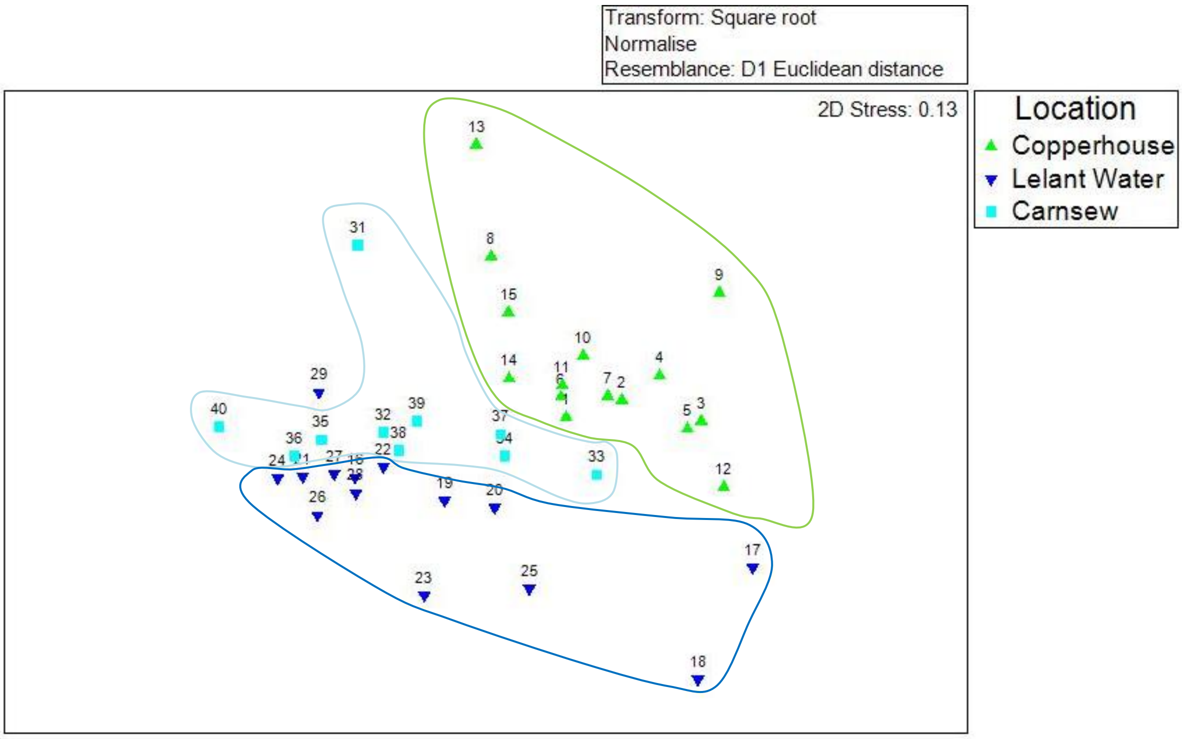


Figure 4.2. MDS plot of metal data, showing which similarities between sites. Site 30 excluded as it was an outlier.



APPENDIX 5. INVERTEBRATES IN SEDIMENTS

1. INTRODUCTION

The invertebrate species that live in the sediment (benthic infauna) and on the sediment (benthic epifauna) are continually exposed to any disturbance or contamination and are therefore very useful monitors of environmental conditions. Samples of sediment are obtained with cores and sieved in the laboratory to remove any invertebrates present. Use of replicate cores at a site enables an estimate of population densities and biomass. In the Hayle estuary complex the number of invertebrates present is lower than in most estuaries in the UK, due to the high concentrations of metals, such as copper, arsenic and zinc. At most locations in the Hayle estuary complex this results in a very small number of taxa present in a core.

The most important natural factors that affect which species are found in a core are salinity regime at the site, particle size distribution and height on the shore. Anthropogenic (human) effects such as mobilisation of metal by mining or smelting, or the input of organic matter from sewage treatment works can also affect the distribution and abundance of benthic organisms.

2. METHODS

2.1 Field Survey

Forty locations were chosen for sampling; of which 15 were in Copperhouse Pool, 15 in Lelant Water and 10 in Carnsew Pool. The lower number in Carnsew Pool was due to the smaller area of intertidal habitat there compared to the other two locations.

Sampling sites were chosen to cover the full range of intertidal heights where sediment occurred and all the major intertidal sedimentary biotopes (with the exception of the dense bed of *Spartina* at Copperhouse Pool). The final choice of sampling sites was made in the field.

At each of the 40 locations, five replicate cores were obtained for invertebrates, one core was taken for particle size and organic content and a further core for metal analysis. The site was marked with a labelled cane and a GPS position was taken with a hand held GPS. The GPS used was a WAAS (Wide Area Augmentation System) capable receiver. WAAS is a system of satellites and ground stations that provide GPS signal corrections, giving a position accuracy of < 3 m, 95 percent of the time. Readings were displayed on the GPS unit in GRB36 datum. These files were later converted to Google Earth files (KML format) in latitude and longitude and loaded directly onto a Google Earth image. At a later date all 40 sites markers were re-visited using a Real Time Kinematic GPS (RTK GPS). This enabled accurate position fixing (to within a few cms) and an accurate height to be obtained (again to within a few cms).

The following information was recorded at each site on a proforma:

- Date and time
- Weather including cloud cover
- GPS location (and height at a later date)
- Operators
- Photograph times and subject matter (photos available on CD from Aquatonics Ltd)
- Any relevant human usage, e.g. nearby discharges

- Depth to the anaerobic layer (estimated to nearest cm)
- Sediment description
- Presence of: mounds/casts; burrows; algal mats (with samples taken for later identification if present); drainage channels or creeks; standing water; subsurface coarse layer; subsurface clay or mud; surface silt or flocculent material
- The following sediment characteristics were assessed on a scale of 1-5:
  - Surface relief (even – uneven)
  - Firmness (firm to soft)
  - Stability (stable to mobile)
  - Sorting of sediment (well-poor). Well sorted means that most particles belong to a narrow range of particle size
  - Depth to anaerobic layer (deep to shallow).

Core samples were taken to a depth of 15 cm for the five replicate invertebrate samples. The corer had an area of 0.0085 square metres and was inserted into the sediment by hand. The estimated density per square metre was later calculated by multiplying the combined count from the five replicate cores by 23.6.

For the sediment particle size and metal analyses a smaller core was obtained to a depth of 10 cm (see Appendix 5 for details of methods for particle size, organic content and metal analyses).

A deeper core was used for the invertebrate samples to increase the chance of sampling more deeply burrowing species such as lugworm (*Arenicola marina*). However, nearly all specimens in intertidal sediments live in the upper few cms, so it is better to analyse particle size and metals in a 10 cm core as this is more representative of the conditions that most invertebrates in the sample experience.

Each invertebrate sample was placed in a separate, pre-labelled plastic bag, which was then tied securely to prevent any material escaping. In the laboratory each of the five replicate cores was sieved through a 0.5 mm mesh to remove the macroinvertebrates. The 0.5 mm sieve also retained larger particles of sediment and larger pieces of decaying vegetation (detritus). All the material on the sieve was transferred using the minimum amount of water to a labelled, lidded and air-tight container and 10% buffered formalin was added to fix and preserve the specimens.

2.2 Laboratory Analysis

2.2.1 Sample preparation

Immediately prior to sample analysis the sample was re-sieved through a 0.5 mm mesh to remove all the formalin. It was split into a less dense fraction (mainly detritus and invertebrates) and a denser fraction by repeated elutriation. In some cases additional sieving was necessary to remove sand particles that were slightly smaller than 0.5 mm but had not been removed in the initial sieving of the core.

For those sites where there was a range of sand and gravel size particles in the dense fraction a nest of sieves (4 mm, 2 mm, 1 mm and 0.5 mm) was used to separate out the various fractions. This made sorting easier.

2.2.2 Sample sorting and identifications

The 4 mm fraction could be sorted in a white tray by eye. All other material was sorted under stereo zoom microscopes at a minimum magnification of x7.

Samples were sorted and identified in the Aquatonics Laboratory. All data were entered onto a paper proforma and the main results (numbers of specimens and biomass) were then transferred to a spreadsheet. Ancillary information recorded during the sample processing included the following:

- Description of the relative amount of light and dense fractions (e.g. small, moderate or large)
- Estimated percentage of various materials found in the light and dense fractions. These materials included mineral sands and gravels, coal and slag, shell and detritus
- Counts of the number of paint particles, pieces of plastic and pieces of glass etc.

Sample sorting and identifications were led by Dr Phil Smith, who has over 30 years of experience in sorting and identifying estuarine invertebrates. Dr Smith provided training and internal Quality Assurance (QA) for the samples sorted by Professor Anne Smith and Dr Jo Rabineau.

Although the 0.5 mm mesh retained macroinvertebrates, including most juveniles macroinvertebrates, it only retained a few larger specimens of the meiofauna (for example nematodes and copepods). Any nematodes or copepods retained by the sieve were therefore ignored when the sample was sorted later in the laboratory.

In this report we often refer to taxa (singular taxon) rather than species, as not all specimens were identified to species level. The word taxa is used to refer to all distinct taxonomic groups present in a sample. For example enchytraeid oligochaete worms are not identifiable to species level in this type of survey, so if enchytraeid worms are present in a sample they are counted as one taxon, even though more than one species of enchytraeid may be present.

Due to the low number of species at most sites and the similarity in the invertebrate fauna between most sites, it was relatively straightforward to identify most specimens during the sorting. These identified specimens were counted during the sorting process, using tally counters or by recording on the proforma for the sample.

2.2.3 External Quality Assurance (QA)

External QA of identifications of some difficult or unusual groups was provided by the following specialists:

Dr Peter Garwood	Cirratulid & syllid polychaetes; unusual tubificid and damaged or unusual bivalve molluscs
Prof Christer Erseus	*Limnodriloides agnes*, a tubificid oligochaete worm
Ian Killeen	Confirmation of *Lasaea adansoni*
David Gibbs	Coleopteran larvae and adults; dipteran larvae and pupae
Tony Barber	Centipede
Ian Tittley	Filamentous green algae collected in the field

2.2.4 Biomass

Each taxon was put into a small petri dish containing some tap water. At the end of sample sorting all the specimens belonging to a single taxon were put onto filter paper to remove excess moisture. They were then weighed to the nearest 0.0001 g on a balance. The only exception were enchytraeid worms, which were often very small and very numerous. For these the weight was calculated on a pro-rata basis from a large number weighed from one site. In a few cases the weight of a single specimen was less than could be accurately weighed on the balance. In these cases a figure of 0.0001 g was recorded.

2.3 Statistical analysis

Statistical analyses were carried out using Version 6 of Primer®, the most commonly used statistical package for assessing benthic data. Two main types of analyses (univariate and multivariate) were done for the pooled replicates from each of the 40 sampling sites.

Univariate analyses in the Primer® package were carried out to calculate the following statistics for pooled replicates from each of the 40 sampling sites:

- Number of taxa
- Number of individuals
- Margalef's Species Richness
- Pielou's Evenness
- Shannon diversity index (log e)
- Rarefaction (ES) calculated on randomly selected 40 individuals. This method calculates the number of taxa present in the first 40 (or other chosen number) of specimens.

Multivariate analyses were used to assess the similarities between the invertebrate fauna at the 40 sampling sites. Two techniques (Cluster analysis and Multi-Dimensional Scaling, or MDS) were used. In Primer® the data were square root transformed to reduce the importance of the species that were numerous. A similarity matrix was calculated Primer® using the Bray-Curtis method. This similarity matrix was then used for Cluster Analysis and MDS.

Cluster analysis links sites that are most similar to each other in a dendrogram. However, this can be difficult to interpret and the method we prefer is MDS, which produces a two dimensional plot in which the sites most similar to each other occur closest together. However, this cannot be done without loss of some information. The plot shows one of the optimal solutions, but as the final plot depends on the order in which the samples were considered it is normal for slightly different plots to occur for each analytical run. For this reason it is common practice to carry out the MDS analysis a number of times (we chose 25) and allow the Primer® software to plot the best overall distribution.

To determine which abiotic variables (metal concentrations, height on shore and particle size) best "explained" the distribution of invertebrates we used the BEST (Bio-Env + Stepwise) routine in Primer® software. The biotic data was square root transformed and the resemblance matrix was calculated using the Bray Curtis method. The abiotic data was carefully examined to determine whether any of the variables needed to be transformed. Only percentage gravel showed a skewed distribution, so this was square root transformed. Chromium and nickel were so highly correlated (Figure 5.15) that one could be removed, we chose nickel. To reduce the number of variables we assessed which others were probably not required. The variables removed were:

- Percentage sand (this was redundant as we included % silt and clay and % gravel)
- Vanadium (only varied from 50 – 100 mg/kg at most sites)
- Barium (concentrations not likely to affect invertebrates)
- Lithium (included in chemical analyses as a way to normalise other metal data – unlikely to be at toxic concentrations)

Particle size data for sites 28, 29 and 30 were not available (the samples were mislaid but have now been analysed) and so the BEST analysis was carried out on 37 sites. Initially we examined all 37 sites together, but we also examined the three areas (Copperhouse Pool, Lelant and Carnsew) separately, as examination of the datasets suggested that different abiotic factors may be important in each area.

We also used BEST for all 40 sites, but with particle size data excluded, so that Sites 28-30 could be included in the assessment of the importance of metal concentrations and height on the shore.

3. RESULTS

The 40 sampling sites are shown in Figures 5.3 to 5.5. Sites 1 -15 were in Copperhouse Pool, sites 16 – 30 were in Lelant Water and sites 31 – 40 were in Carnsew Pool.

3.1 Number of Individuals

Lelant Water samples had the highest mean number of individuals per site (Table 5.1; 1976, range 66 – 3264). The minimum of 66 individuals was recorded at Site 30 in Lelant Water, which was in the low water channel. The sediment at the site was clean sand with almost no detritus; this probably reduced the number of species that the site could support. Site 28 in Lelant Water had the highest number of specimens of all 40 sites (3624 in 5 cores, equivalent to approximately 85,500 per square metre. Most (2620, or 72%) of the individuals at Site 28 were the amphipod crustacean *Corophium volutator*. This was the highest recorded density for *Corophium volutator* at any of the 40 sites, equivalent to 61,800 per square metre.

Copperhouse Pool had a mean of 1541 individuals per site (Table 5.1; range 855 – 2484). At most sites the numerically dominant species were either the amphipod *Corophium volutator* or enchytraeid worms. The only exception was Site 15, which was close to the edge of the low water pool and had a relatively diverse invertebrate fauna. Here the numerically dominant species was the polychaete worm *Capitella capitata*. This species is usually considered to be indicative of organic enrichment. In the five replicates we examined in the laboratory the highest densities appeared to be associated with the cores that had the largest amount of detritus (mainly dark pieces of decaying leaves). Unfortunately the relatively large amount of organic matter present at Site 15 is not clear from the organic carbon analyses, which were done on the <63 µm fraction.

Carnsew Pool had the lowest mean number of individuals (Table 5.1; mean 849, range 52 – 1845). Carnsew Pool had generally lower concentrations of metals and no areas of sediment that were suitable for the amphipod *Corophium volutator*, the dominant species at many sites in Copperhouse Pool and Lelant Water. Only 2 specimens of *Corophium volutator* were recorded from the 10 sites in Carnsew Pool. There was no consistent pattern in the dominant taxa in

Carnsew, with 7 different taxa dominant at the 10 sites.

3.2 Number of taxa

In total 40 invertebrate taxa were recorded in the 200 core samples. We excluded a single record of an unidentified hydroid from one site before undertaking the statistical analyses. The total number of invertebrate taxa (40) is unusually low considering the sampling effort and variety of substrates and tidal heights sampled. The low number of taxa is probably mainly due to the concentrations of metals in the sediments, which ranged from high to very high (see Appendix 5).

Most of the taxa recorded live in the sediment, with most concentrated in the upper few cms. The only epifaunal species recorded in the cores were:

Carcinus maenas (shore crab)	Juveniles widespread but at low densities, mainly on the mid to upper shore.
Geophilus seurati (a centipede)	Only recorded at Site 25. Unusual habitat for this species.
Cillenus lateralis (a carabid beetle)	Only recorded at "saltmarsh" sites (Sites 9, 14 & 20).

Some benthic invertebrates were absent from the cores but were recorded in the field. Catworm (*Nephtys hombergii*) was recorded at Site 35 and cockles (*Cerastoderma edule*) were recorded from Site 38.

Table 5.1 Number of Taxa and Number of Individuals Recorded in Three Locations

Location	Mean number of taxa in 5 replicates combined	Total number of taxa recorded from all sites at this location	Mean number of individuals in 5 replicates combined
Copperhouse Pool	8.53	30 (15 sites)	1541
Lelant Water	8.67	26 (15 sites)	1976
Carnsew Pool	10.20	28 (10 sites)	849

The invertebrate fauna in Copperhouse Pool and Lelant Water showed many similarities, with similar numbers of taxa and individuals (see Table 5.1) in the 5 combined replicates. The number of taxa in Copperhouse Pool ranged from 4 – 15 per site (mean 8.53; total 29 taxa). In Lelant Water the number of taxa ranged from 4 – 16 (mean 8.67; total 26 taxa). Samples from Carnsew Pool had 6 – 14 taxa per site (mean 10.2; total 28 taxa) and this higher number of taxa per site was probably at least partly due to the lower concentrations of metals in sediments in Carnsew Pool.

3.3 Ubiquitous taxa

Table 5.2 shows the taxa that were recorded at the most sites. Four taxa were present at ≥ 75% of the 40 sites. These were enchytraeid oligochaetes, *Nereis diversicolor* (ragworm), *Corophium volutator* (a gammarid amphipod crustacean) and *Pygospio elegans* (a spionid polychaete worm).

Although enchytraeid oligochaetes appear to be the most ubiquitous, this may be misleading as different species of enchytraeid may have been present in different biotopes.

Table 5.2 Ubiquitous and widespread taxa

Widespread taxa in descending order	Percentage of sites where taxon recorded (those at ≤ 10% omitted)
Enchytraeidae	97.5
Nereis diversicolor (ragworm)	80.0
Corophium volutator	75.0
Pygospio elegans	75.0
Heterochaeta costata	60.0
Dolichopodidae larvae	55.0
Tubificoides pseudogaster	55.0
Carcinus maenas (shore crab)	50.0
Anurida maritima	47.5
Capitella capitata	35.0
Nemertea (indeterminate)	30.0
Lineus viridis	22.5
Tubificoides benedii	20.0
Chironomidae larvae	17.5
Streblospio shrubsolii	17.5
Arenicola marina (lugworm)	12.5
Paragnathia formica	12.5
Tharyx sp. A	12.5

3.4 Unusual Records

Most of the species recorded are common in surveys of estuarine sediments. There were four exceptions:

The carabid beetle *Cillenus lateralis* (Photo 5.1) was found in low numbers at some of the more elevated sites (Sites 9, 14 & 20) with a dense cover of filamentous green algae and in some cases *Salicornia*. This species is restricted to saltmarsh habitats and is classified as Nationally Scarce B (i.e. it has been recorded in 16 – 100 10 km squares in the UK). This species was until recently called *Bembidion laterale*.

Eleven specimens (adults and juveniles) of the intertidal centipede *Geophilus seurati* (Photo 5.2) were recorded at Site 25 (Lelant Water), from an area of firm muddy sand, overlaid with filamentous green algae (approximately 65% cover). This species has been recorded from a number of intertidal sites in the southern and western coasts of the British Isles and in the Channel Isles, Brittany and Algeria (Barber, 2009). The records from Hayle are interesting because nearly all records for this species are from under rocks in the intertidal, but at Site 25 there were no rocks. It wasn't seen during the survey, suggesting that it hunts below the dense layer of filamentous green algae found at this site. The dominant alga at Site 25 was *Ulva torta*, with some *Ulva prolifera* and *Ulva intestinalis* (about 1%) and very small amounts of *Ulva compressa* & *Rhizoclonium riparium* (all the species of *Ulva* were previously placed in *Enteromorpha*). *Geophilus seurati* may feed on enchytraeid worms (the only other macrofaunal species at this location) which live under the algae and in the top layers of sediment. Presumably the centipedes remain on this site throughout the tidal cycle as the nearest terrestrial habitat is 25 m away.

The bivalve *Lasaea adansoni* (Photo 5.3) was recorded from five of the ten sites sampled in Carnsew. All of the sites were firm sediments on the mid to upper shore. This is an unusual micro-habitat for *Lasaea adansoni*, which is normally recorded from crevices, algal holdfasts and from the intertidal lichen *Lichinia pygmaea* (information from MarLIN website at www.marlin.ac.uk/speciesinformation.php?speciesID=3638.).

Limnodriloides agnes (identification to be confirmed), an oligochaete worm (family Tubificidae) found at some sites in Carnsew and one in lower Copperhouse Pool. This appears to be the first record for the UK, and it may be an introduced species. The maximum density recorded was 18,000 at Site 36 in Carnsew. Identification was by Prof Christer Erseus, an oligochaete worm taxonomist based at the University of Gothenburg, Sweden. This species was first recorded from the Adriatic, but Prof Erseus has also recorded it from the Atlantic coast of France. We expect to send further specimens to him so that he can compare the genetics of the Hayle specimens with those of *Limnodriloides agnes.*

3.5 Missing Taxa

Many benthic infaunal taxa would probably be present if the sediments at Hayle were not so contaminated with metals. They following taxa were either absent from the core samples and not seen in the field survey, or had a very restricted distribution.

- *Nephtys* spp, *Nereis virens* & several species of spionid, terebellid & ampharetid polychaetes
- *Corophium arenarium* & *Haustorius arenarius* (both amphipod crustaceans)
- *Cyathura carinata* and *Eurydice pulchra* (both isopod crustaceans)
- *Hydrobia ulvae* (mudsnail). Only recorded at 4 sites in Carnsew (Sites 31, 35, 37 & 39). None of these sites had the high densities of *Hydrobia ulvae* that usually occur in estuarine waters.
- *Cerastoderma edule* (common cockle). Not found in any of the 200 cores, but seen near Site 38 (Carnsew) during the survey.

3.6 Dominant Taxa in the Three Main Areas

Table 5.3 shows the taxa recorded in each area in descending order from the most numerous (on average across all sites) to the least numerous. Values are rounded to the nearest integer. It is clear from Table 5.3 that the fauna in Copperhouse Pool is similar to that in Lelant Water, with *Corophium volutator* and enchytraeid oligochaetes the most common taxa at both locations. Other common species were the oligochaete worms *Heterochaeta costata*, *Tubificoides pseudogaster* and the polychaete worms *Pygospio elegans* and *Nereis diversicolor* (ragworm).

The dominant taxa in Carnsew were enchytraeid oligochaete worms, *Tharyx* sp. A (a cirratulid polychaete worm), *Heterochaeta costata*, *Limnodriloides agnes* (a tubificid oligochaete worm, first record for the UK), *Pygospio elegans* (a spionid polychaete worm), *Tubificoides pseudogaster* (a tubificid worm) and the small bivalve mollusc *Lasaea adansoni* (Table 5.3)

3.7 Comparisons with Previous Surveys

The baseline survey of invertebrates in July 2010 was the most comprehensive to date for the Hayle complex. However, the number of taxa recorded (40) is low considering the sampling effort. This is primarily due to taxa that are missing, due to pollution from metals. In the June 1988 survey by Gill (1989) cores of a similar size to those we used were taken at 5 various locations around the Hayle estuary complex. The number of cores per site ranged from 2-4. Only 14 taxa were recorded from the cores. There were many similarities with the July 2010 survey, for example the most numerous taxa in the 1988 core survey were (in order of maximum density recorded):

- *Corophium volutator*
- *Pygospio elegans*
- Oligochaeta (indeterminate) Note: we identified most oligochaetes further than this
- *Nereis diversicolor* (ragworm)
- *Capitella capitata* (& *Capitella* sp. recorded)
- *Bathyporeia pilosa*
- *Scrobicularia plana* (peppery furrow shell)
- *Malacoceros fuliginosus*
- *Eurydice pulchra*
- *Cerebratulus* sp. (a nemertean worm)
- *Carcinus maenas* (shore crab)
- Cirratulidae (we identified these to species level)
- *Crangon crangon* (brown shrimp)

The mean density of taxa in Copperhouse Pool from various surveys between 1988 and 2010 (present survey) is shown in Table 5.4. Direct comparisons are difficult, as different surveys used different size cores, number of replicates and locations for samples. However, it is apparent that densities of ragworm (*Nereis diversicolor*) and shore crabs (*Carcinus maenas*) and are similar in most surveys. Bearing in mind seasonal differences in expected densities of *Corophium volutator*, the mean density of this species is broadly similar between surveys. The exception is February 2000, where the zero density is due to the fact that only two sites in lower Copperhouse Pool were sampled and neither were suitable habitat for *Corophium*.

There are consistent absences of common estuarine species in all four surveys of Copperhouse Pool from 1988 to 2010, e.g. *Hydrobia ulvae* (mud snail), *Cerastoderma edule* (common cockle) and *Scrobicularia plana* (peppery furrow shell). It is likely that the high copper concentrations in Copperhouse Pool is the main reason why the molluscan fauna is so restricted, but other metals may also play a role.

The fauna of Copperhouse Pool has changed slowly over time, with more taxa recorded per site in recent surveys than in 1988 and 1989. The lugworm (*Arenicola marina*) has been present in reasonable densities in lower Copperhouse Pool since at least February 2000. Densities of the small spionid polychaete worm *Pygospio elegans* appear to be increasing (Table 5.4).

Table 5.4 Taxa in Order of Abundance at the Three Main Areas. Indet = indeterminate

Copperhouse Pool			Lelant			Carnsew	
Corophium volutator	16599		*Corophium volutator*	24245		Enchytraeidae	4056
Enchytraeidae	9451		Enchytraeidae	8515		*Tharyx* sp. A	2295
Heterochaeta costata	2767		*Tubificoides pseudogaster*	2324		*Heterochaeta costata*	1735
Nereis diversicolor	1945		*Pygospio elegans*	2105		*Limnodriloides agnes*	1665
Tubificoides pseudogaster	1874		*Heterochaeta costata*	2000		*Pygospio elegans*	1458
Capitella capitata	1510		*Nereis diversicolor*	1715		*Tubificoides pseudogaster*	806
Pygospio elegans	1103		*Tubificoides benedii*	824		*Lasaea adansoni*	285
Anurida maritima	340		*Capitella capitata*	566		*Capitella capitata*	228
Chironomidae larvae	250		Tubificidae (juv, indet)	455		*Nereis diversicolor*	227
Littorina saxatilis	110		*Anurida maritima*	373		*Streblospio shrubsolii*	201
Dolichopodidae larvae	96		*Malacoceros fuliginosus*	88		Dolichopodidae larvae	79
Malacoceros tetracerus	90		*Carcinus maenas*	36		*Tubificoides benedii*	61
Streblospio shrubsolii	60		*Streblospio shrubsolii*	30		Chironomidae larvae	47
Nemertea (indet)	41		Dolichopodidae larvae	28		*Scrobicularia plana*	39
Tharyx sp. A	33		*Geophilus seurati*	19		*Malacoceros fuliginosus*	30
Carcinus maenas	20		*Littorina saxatilis*	9		*Anurida maritima*	27
Ceratopogonidae pupae	16		Nemertea (indet)	9		*Arenicola marina*	22
Paragnathia formica	14		*Scrobicularia plana*	8		*Lineus viridis*	22
Coleopteran larvae (prob Carabidae)	8		*Bathyporeia pilosa*	6		*Hydrobia ulvae*	19
Lineus viridis	8		*Cillenus lateralis*	3		*Paranais litoralis*	17
Arenicola marina	6		*Paragnathia formica*	3		Nemertea (indet)	14
Limonidae – Chioneinae	6		Coleopteran larvae (prob Carabidae)	2		Coleopteran larvae (prob Carabidae)	5
Tubificoides benedii	6		*Crangon crangon*	2		*Paragnathia formica*	5
Cillenus lateralis	3		Hemiptera juvenile	2		*Carcinus maenas*	3
Crangon crangon	3		*Machaerium maritimae*	2		*Machaerium maritimae*	3
Limnodriloides agnes	3		*Mya* sp.? Damaged or juv	2		*Corophium volutator*	2
Microphthalmus sp. (indet)	2					*Crangon crangon*	2
Hemiptera juvenile	2					*Magelona filiformis*	2
Mya sp.? Damaged or juv	2						
Phyllodocidae (indet)	1						
Total mean density	36371			43371			13354

Table 5.4 Densities of Common Taxa Recorded in Copperhouse Pool from 1988 - 2010

TAXA	**June 1988**	**Oct 1988**	**Feb 2000**	**July 2010**
Reference	**Gill, 1989**	**AEC, 1989**	**AEC, 2000**	**Aquatonics This report**
Corophium volutator	6,830	12,152	0**	16,600
Oligochaete worms	2,040	10,685*	17,250*	14,102*
Nereis diversicolor	1,125	1,367	450**	1,945
Capitella capitata	0	0	450	1,510
Pygospio elegans	15	33	150	1,103
Carcinus maenas	25	33	0	21
Arenicola marina	0	0	Present	6
Tharyx sp. A	0	0	5,100**	33
Streblospio shrubsolii	0	0	900	60
Other taxa (number of taxa)	0	0	0	15
MISSING TAXA INCLUDE				
Bathyporeia pilosa	0	0	0	0
Hydrobia ulvae	0	0	0	0
Cerastoderma edule	0	0	0	0
Scrobicularia plana	0	0	0	0

* We combined counts for all oligochaete taxa.

** Only 2 sites in lower Copperhouse Pool sampled, therefore no *Corophium* present and low density of *Nereis*, but higher than typical densities of *Tharyx* sp A.

3.8 Wader Prey

Wading birds feed on a wide variety of intertidal invertebrates and small fish. Each species has diet preferences and different abilities to obtain food. We have only examined the overall wader prey available from the sedimentary areas of Copperhouse Pool and have not yet extended the analysis to include Carnsew or Lelant Water. This could be done if future repeat surveys suggest any decline in wader prey in Copperhouse Pool.

We have not included prey available from permanent water courses through Copperhouse Pool or from under seaweeds and the hard substrates which are mainly confined to the areas immediately below the sea walls.

We have estimated the standing stock of wader prey in Copperhouse Pool from the biomass measurements for each of the 40 sites. Each site was grouped with others that appear to belong to the same biotope and the total area of the biotope was estimated from Google Earth imagery. The mean biomass per square metre at all the sites in the biotope was then multiplied by the total area (in square metres) of the biotope. The estimated standing stocks are summarised in Table 5.5.

Table 5.5 Estimated Standing Stock of Invertebrate Prey in Sedimentary Areas of Copperhouse Pool in July 2010.

Taxon	Biomass (kg)
Littorina saxatilis (rough periwinkle). Includes shell	1694
Nereis diversicolor (ragworm)	1502
Corophium volutator (an amphipod crustacean)	1037
Enchytraeid oligochaete worms	377
Carcinus maenas (shore crab)	223
Tubificid oligochaete worms	111
Pygospio elegans (a small spionid polychaete worm)	64
Insect larvae and adults (all species combined)	44
Arenicola marina (lugworm). Underestimate due to burrowing depth of adults	39
Nemertean worms	25
Bivalves (damaged or juvenile) probably mainly *Mya* sp.	21
Capitella capitata (a small capitellid polychaete worm)	7
Malacoceros tetracerus (a spionid polychaete worm)	4
Crangon crangon (brown shrimp). From sediments only - many more in channels	3
Streblospio shrubsolii (a small spionid polychaete worm)	1
Paragnathia formica (a small isopod crustacean)	1
Total biomass in sedimentary habitats in July 2011	5153

Littorina saxatilis had the highest biomass in Copperhouse Pool, however this figure includes the shell and in terms of available food for birds it is likely that *Nereis diversicolor and Corophium volutator* are the most important species. The relatively low value for *Arenicola marina* (lugworm) is likely to be an accurate reflection of the biomass available to birds but will be an underestimate of the total biomass of this species, as the largest adults are often in burrows beyond the maximum depth of the 15 cm corer.

In ecological studies the production is more relevant than the standing stock, but providing site-specific estimates of production is very time consuming and different methods produce different results. Studies of production usually include the Production to Biomass ratio (or P/B ratio). A review of the international literature on P/B ratios showed consistent differences in production at different latitudes, with temperate latitudes having higher P/B ratios, and also between taxonomic groups (Cusson & Bourget, 2005). In general, small, short-lived species have higher P/B ratios than larger, long-lived species. Most of the invertebrates recorded from Copperhouse Pool are relatively small and short-lived.

Table 5.6 has been compiled from a rapid assessment of P/B ratios in the literature and should be viewed as indicative, rather than definitive. From the available literature the highest P/B ratios of the species recorded in Copperhouse Pool are for *Crangon crangon* and *Corophium volutator* (Table 5.6).

Table 5.6 Estimated production of some key wader prey in Copperhouse Pool, using published P/B values from other studies in Europe and North America. Note that the calculated production figures are based on the assumption that biomass recorded in July 2010 was typical of the whole year, which may not be true.

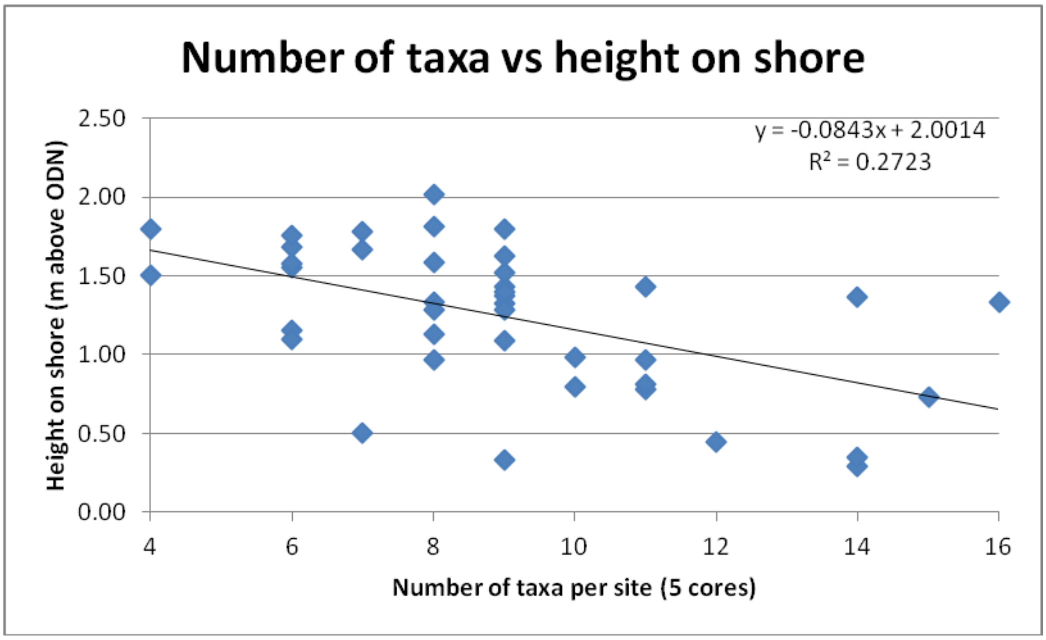
Taxon	P/B ratios (various studies)	"Typical" value used to estimate production in Copperhouse Pool	Estimated Annual Production in Copperhouse Pool (kg)
Littorina saxatilis (incl shell)	4.1	4.1	6945
Nereis diversicolor	1.8 , 2.5, 3.0	2.5	3755
Corophium volutator	3-4, 7.7, 6-11	5.0	5185
Carcinus maenas (shore crab)	1.4, 1.85	1.6	357
Tubificid oligochaete worms	4.2	4.2	466
Arenicola marina	1.0	1.0	39
Bivalves (mainly *Mya* sp?).	0.41 (*Mya arenaria*)	0.4	8
Crangon crangon	9, 8.7 – 10.9	9.0	27

Table 5.7 Number of Individuals, Number of Taxa and Diversity Indices
S = number of species (taxa); N = number of individuals; d = Margalef's Species Richness; J' =Pielou's Evenness; ES (50) = Rarefaction (in this case the number of expected taxa in the first 50 specimens taken from a sample); H'(log_e) = Shannon Diversity Index

Site	S	N	d	J'	ES(50)	H'(loge)
1	6	1408	0.690	0.700	4.75	1.254
2	6	1081	0.716	0.271	3.02	0.486
3	4	855	0.444	0.421	3.04	0.584
4	9	1839	1.064	0.383	3.52	0.842
5	6	862	0.740	0.465	4.24	0.834
6	8	2484	0.895	0.411	3.31	0.855
7	6	1673	0.674	0.684	4.89	1.225
8	9	1886	1.061	0.563	4.93	1.236
9	8	2085	0.916	0.149	2.95	0.310
10	9	2320	1.032	0.631	5.25	1.386
11	10	1138	1.279	0.462	4.54	1.064
12	7	980	0.871	0.465	4.17	0.906
13	11	1206	1.409	0.580	5.93	1.391
14	14	1407	1.793	0.225	3.82	0.594
15	15	1893	1.855	0.504	6.73	1.366
16	9	2622	1.016	0.509	5.51	1.118
17	7	2174	0.781	0.419	3.40	0.815
18	4	1961	0.396	0.473	3.40	0.656
19	8	1649	0.945	0.578	5.05	1.202
20	9	902	1.176	0.089	2.35	0.196
21	9	2819	1.007	0.286	3.31	0.628
22	6	1601	0.678	0.447	4.07	0.801
23	8	1651	0.945	0.387	2.99	0.804
24	16	3045	1.870	0.676	8.16	1.874
25	9	1127	1.138	0.099	2.55	0.218
26	8	1546	0.953	0.212	3.36	0.440
27	9	962	1.165	0.195	3.27	0.428
28	10	3624	1.098	0.447	5.68	1.029
29	11	1817	1.332	0.694	6.33	1.663
30	7	66	1.432	0.631	6.26	1.228
31	9	1788	1.068	0.414	3.97	0.910
32	11	483	1.618	0.292	4.65	0.700
33	6	52	1.265	0.833	6.00	1.492
34	8	115	1.475	0.566	6.32	1.178
35	14	1139	1.847	0.510	6.93	1.346
36	14	1845	1.729	0.561	6.11	1.482
37	8	1253	0.981	0.140	2.67	0.291
38	12	1039	1.584	0.687	7.35	1.708
39	11	339	1.716	0.257	4.85	0.616
40	9	435	1.317	0.434	5.03	0.953
Mean values						
Copperhouse	8.53	1541	1.029	0.461	4.339	0.955
Lelant	8.67	1976	1.013	0.370	4.083	0.785
Carnsew	10.20	849	1.460	0.469	5.388	1.067

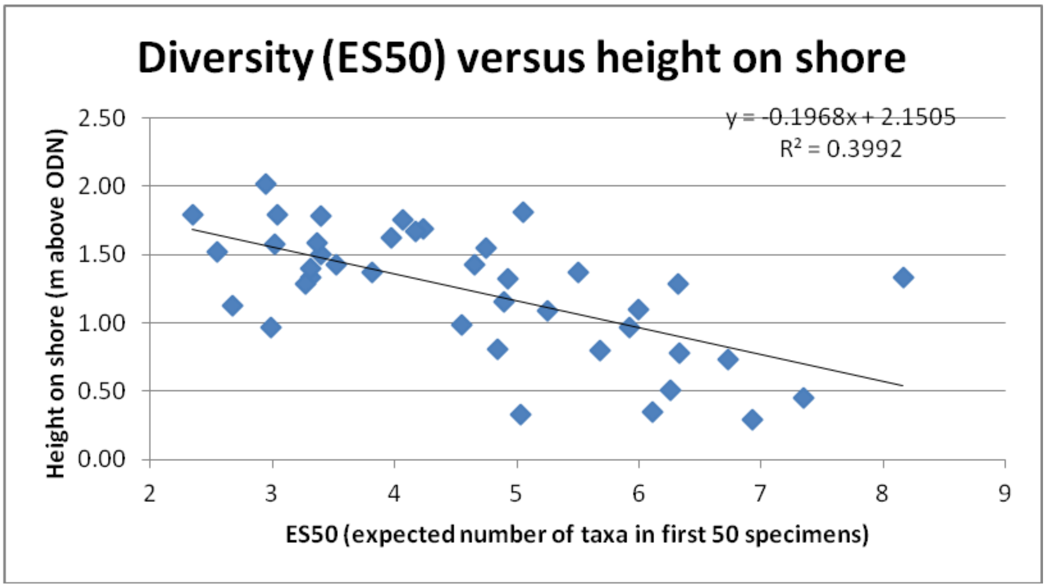
Figure 5.1 shows the inverse correlation between the number of taxa per site and the height on the shore (i.e. sites higher on the shore usually had fewer taxa).

Figure 5.1 Number of taxa vs height on shore.



The diversity (ES50) also showed an inverse correlation with height on the shore (Figure 5.2).

Figure 5.2 Diversity (ES50) vs height on shore.



3.9 Cluster Analysis

The cluster analysis dendrograms for all replicates (densities or biomass) were too complex for easy interpretation and are not included in this report. In general replicate samples clustered with each other at high levels of similarity. We therefore grouped all replicates from a site together and produced a similarity matrix and dendrogram for the 40 sites for densities (counts) (Figure 5.6) and biomass (Figure 5.7).

Interpretation of dendrograms is quite complex. The order of sites from left to right is not of importance, as each group can be rotated around its vertical axis (like a child's mobile hanging from a ceiling), so care is needed in interpretation. We have included the dendrograms for the sake of completeness, but the MDS plots (Figures 5.8 to 5.14) provide an easier interpretation of the main biological communities and groupings of sites.

The biomass dendrogram may be useful in making comparisons with preferred bird feeding area.

3.10 Multi-Dimensional Scaling (MDS)

Figure xx shows the MDS plot of the similarity between sites based on densities of invertebrates. Densities were square root transformed prior to the MDS analysis to reduce the importance of species present at high densities. Figure xx is the MDS plot for the abiotic variables. Note that there is very little agreement between the two MDS plots, suggesting that biology is difficult to predict from the abiotic variables that were measured.

Figures 5.8 and 5.10 to 5.14 show the invertebrate density data (square root transformed) with overlays of proportional circles for height on the shore (Figure 5.10) and densities of key taxa for each of four main groups (Figures 5.11 to 5.14). The 'BEST' analysis (next section) showed that height was the important variable in structuring the benthic community, and the importance of height is also clear from Figure 5.10 showing the height as a proportional circle overlaid on the MDS plot. However, there are two clearly separate groups (Groups 1 & 2) on the MDS plot that have a similar height. The main characteristics of the four groups based on height are summarised below. Note that Group 3 is not well defined, individual sites within Group 3 often have higher similarities with other Groups than with other sites within Group 3.

Group 1

Copperhouse	Sites 9 & 14
Lelant	Sites 20 & 25
Carnsew	Sites 31, 32, 34 & 37

All sites were on the upper part of the intertidal (1.13 – 2.02 m above ODN) and had a firm substrate with a cover of filamentous green algae (mainly *Ulva* spp.). The dominant invertebrates were enchytraeid oligochaetes, dipteran larvae & pupae and coleopteran larvae and adults (e.g. *Cillenus lateralis*).

Group 2

Copperhouse	Sites 1 – 8 & 10 - 13
Lelant	Sites 16 – 19, 21-24, 26 & 27
Carnsew	None

All sites with soft muddy sand to sandy mud sediments on the mid to upper part of the intertidal (0.95 – 1.82 m). Invertebrate fauna dominated (in terms of biomass and densities) by *Corophium volutator* and *Nereis diversicolor*.

Group 3

Copperhouse	Sites 15
Lelant	Sites 28, 29
Carnsew	Sites 33 & 39

Lower intertidal sites (0.95 – 1.1 m), often with higher similarities with other Groups than with other sites within Group 3. For example, Site 15 had lugworm present and was more similar to many sites in Group 4. Site 39 was more similar to sites in Group 1, and Sites 28 & 29 had similarities with Group 2 due to their high densities of *Corophium*.

Group 4

Copperhouse	None
Lelant	Sites 30
Carnsew	Sites 35, 36, 38 & 40

Sites on the lowest part of the intertidal, (0.2 – 0.6 m) mainly sandy mud (Site 30 mainly sand). *Arenicola marina* and *Scrobicularia plana* at all sites in Carnsew, but not at Site 30 (Lelant), which had a very restricted invertebrate fauna due to mobile sands in the low water channel.

Figure 5.3 Core sampling sites in Copperhouse Pool. Sites 1 – 15.

Figure 5.4 Core sampling sites in upper and mid Lelant Water. Sites 16 - 26 and 28 – 30.

Figure 5.5 Core sampling sites in Carnsew (31 – 40) and lower Lelant Water (Site 27).

Figure 5.6. Cluster Analysis Dendrogram (Densities) for 40 Sites (combined replicates).

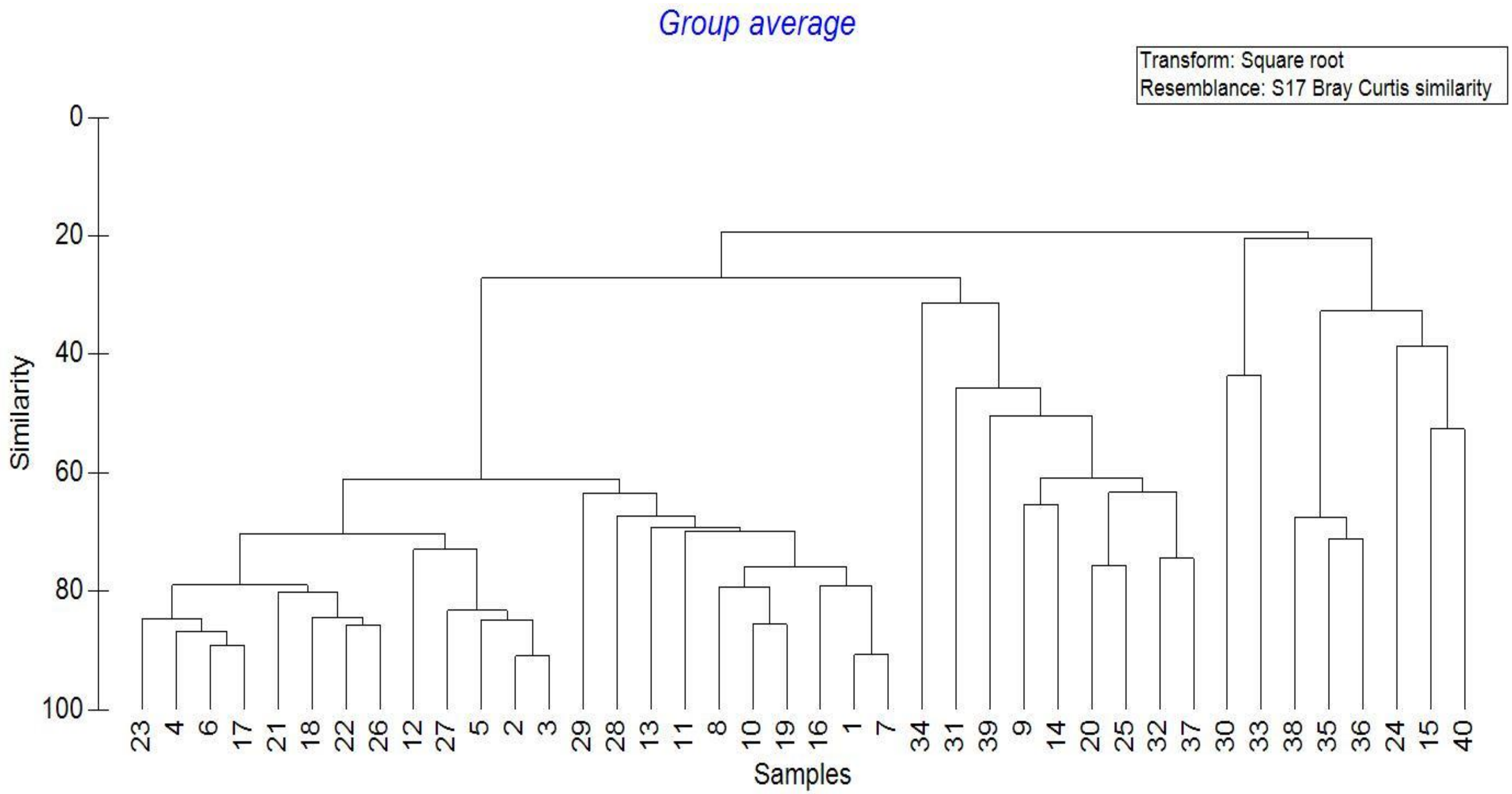


Figure 5.7 Cluster Analysis Dendrogram (Biomass) for 40 Sites (combined replicates).

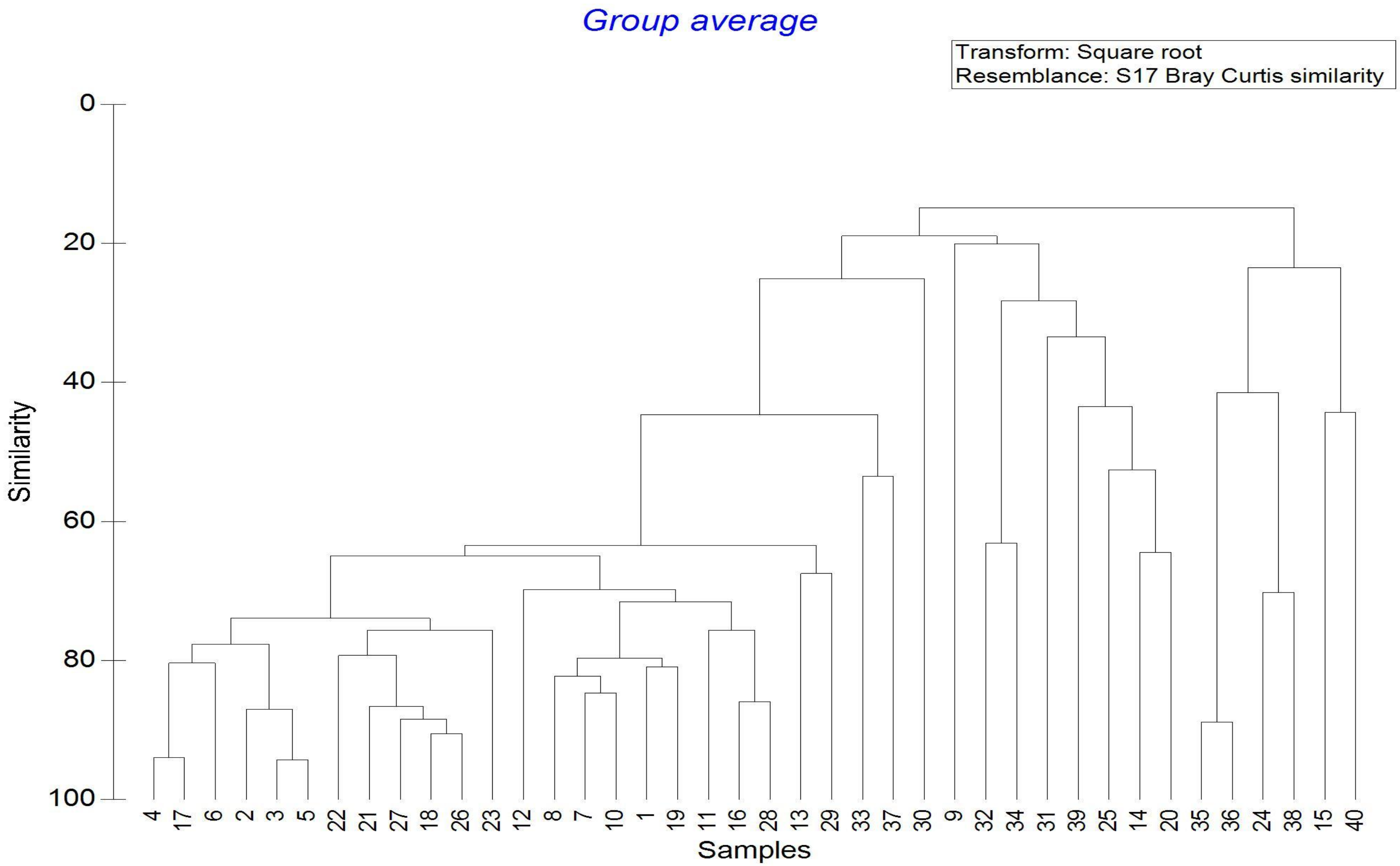


Figure 5.8 MDS Plot Invertebrate Taxa and Densities.

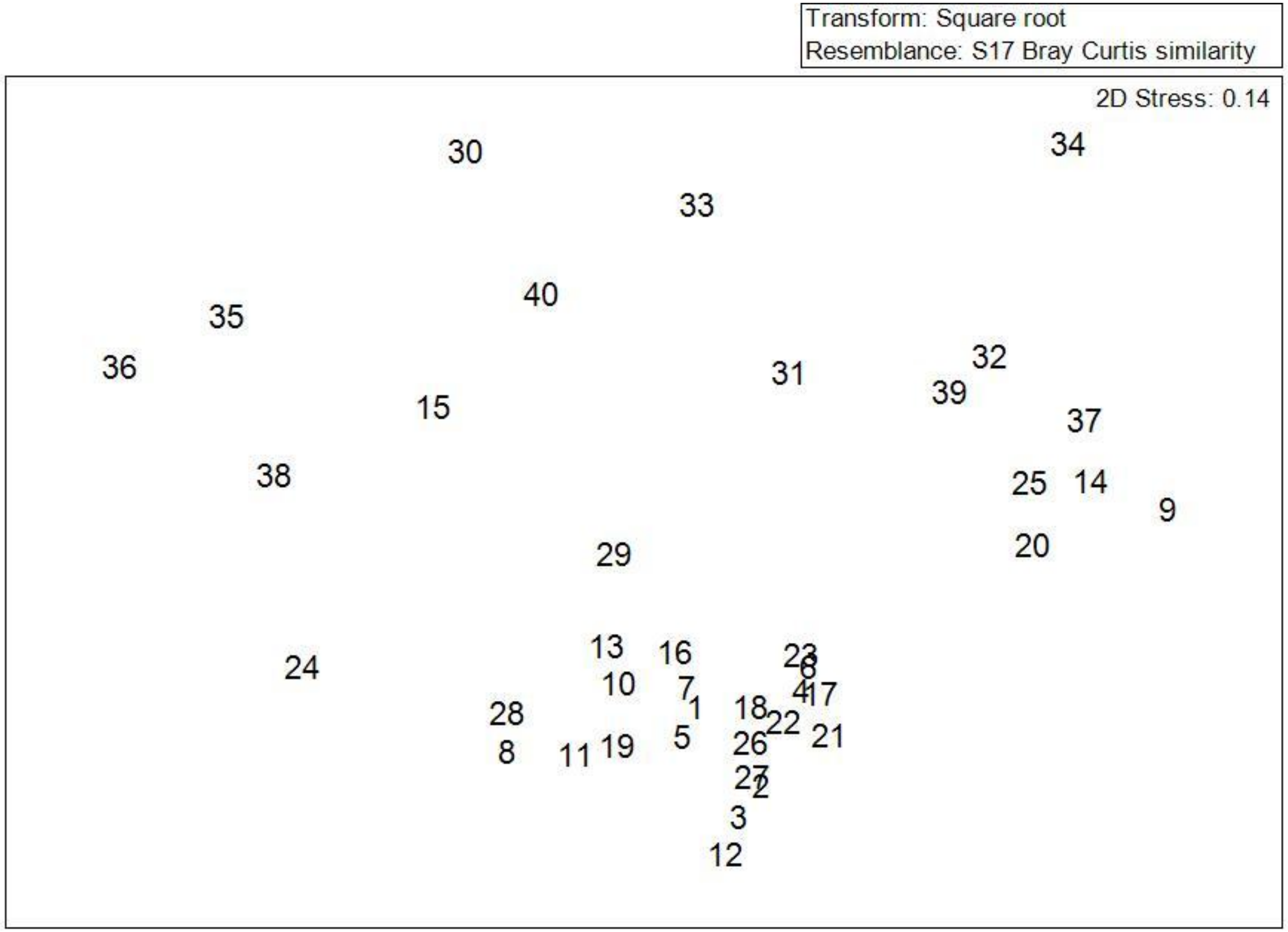


Figure 5.9 MDS Plot Based on Abiotic Data (Height, Metal Concentrations and Particle Size).

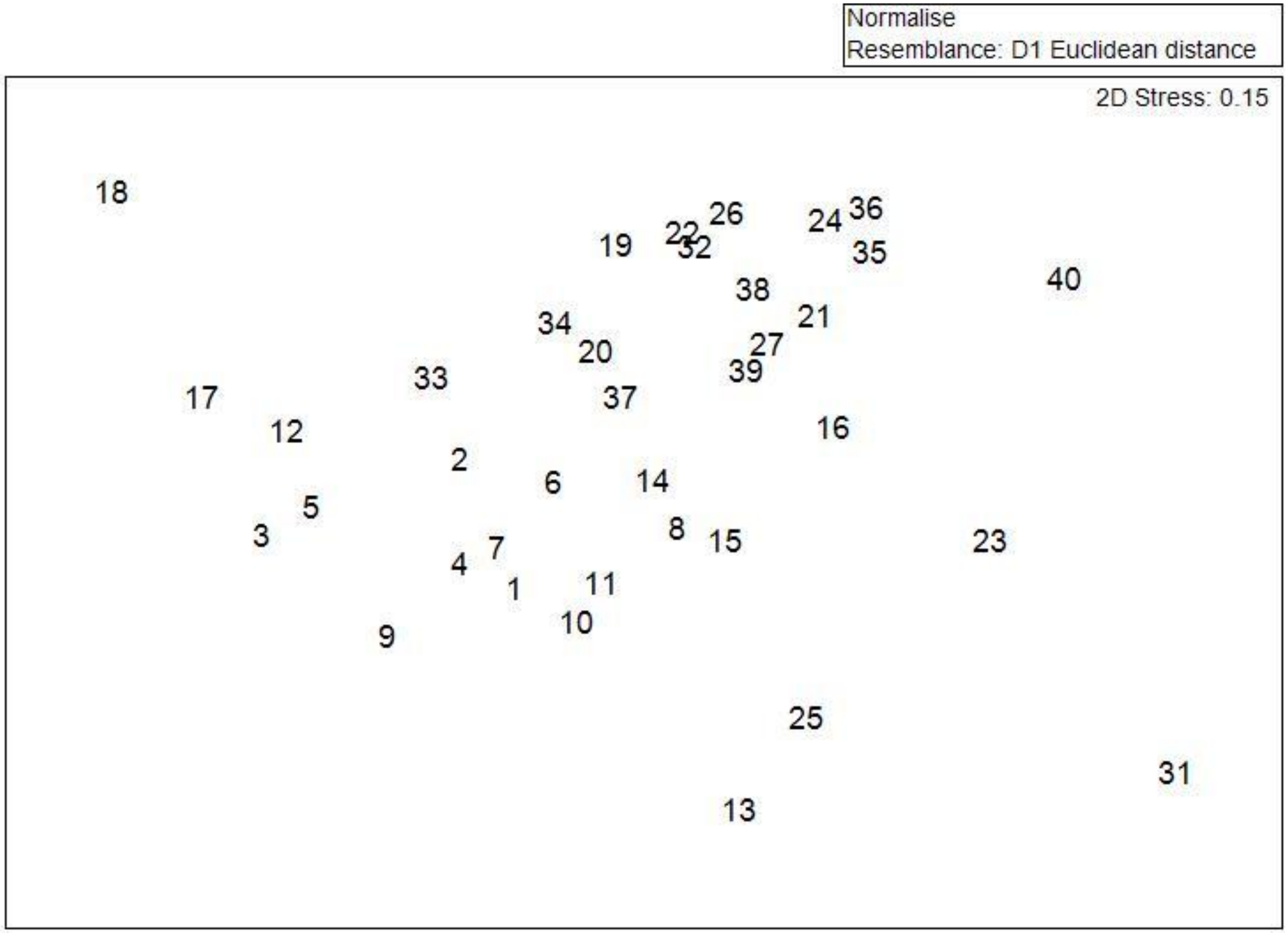


Figure 5.10. MDS Invertebrate Taxa & Density Plot Overlaid with Height on Shore as Proportional Circles.
Note: Outlines of Groups are based on Height and MDS results.

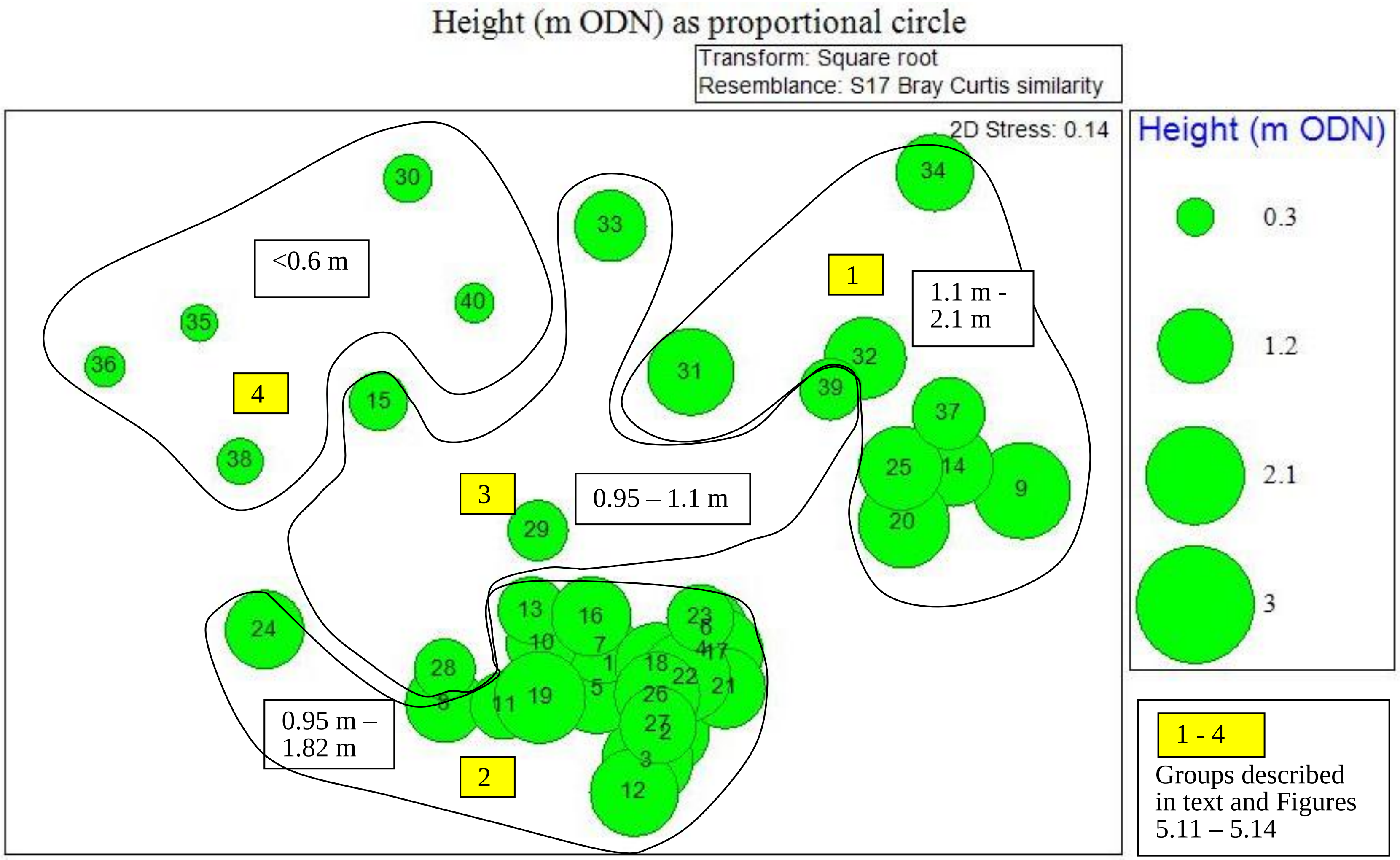
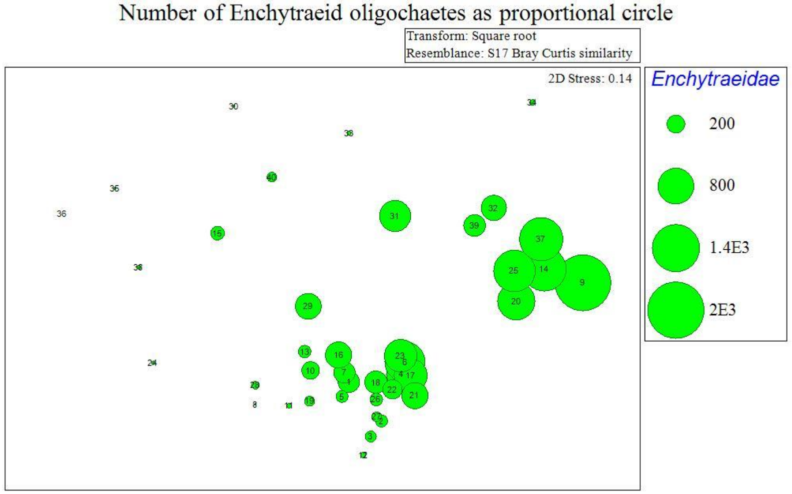
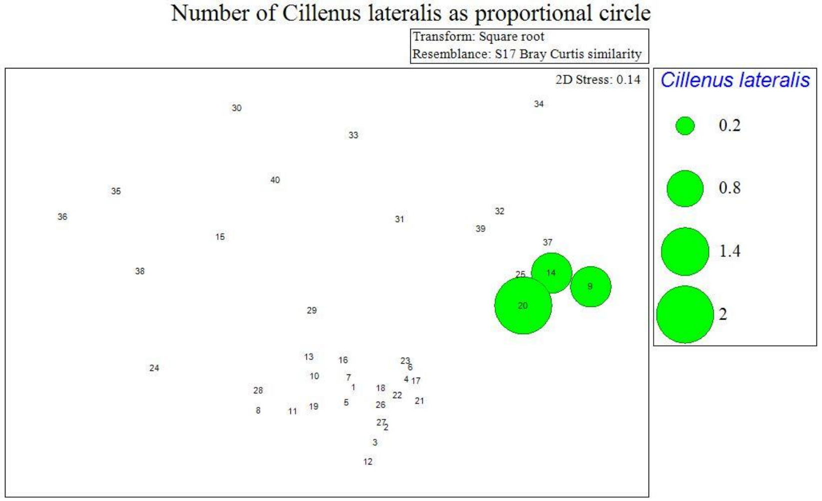


Figure 5.11 Examples of Dominant Taxa in Group 1 (1.1 – 2.1 m, firm sediment with filamentous green algae, enchytraeid oligochaetes and dipteran larvae).





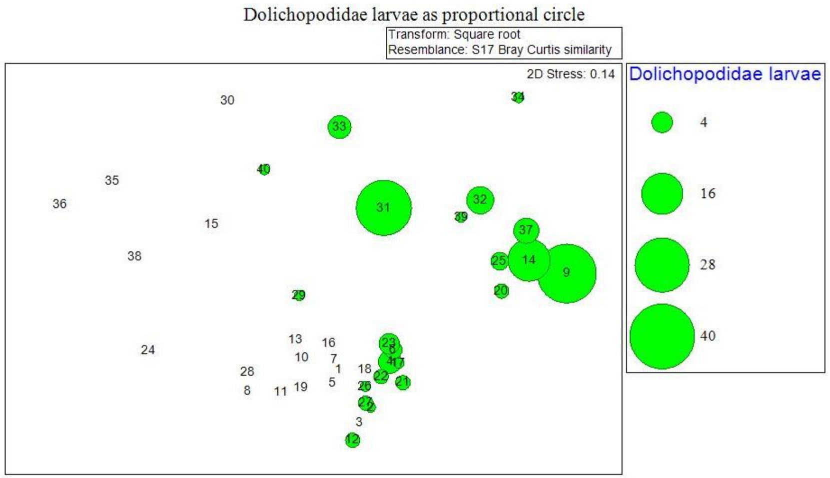
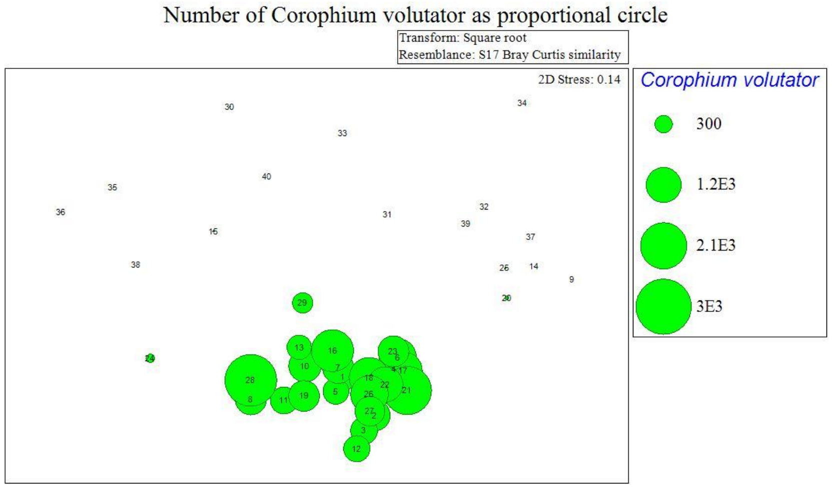
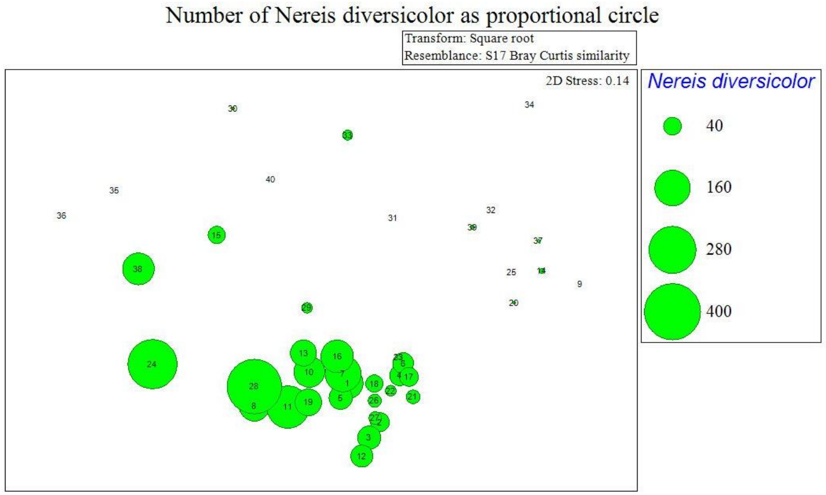


Figure 5.12 Examples of Dominant Taxa in Group 2 (0.95 - 1.82 m, soft sediment with little or no algal cover).





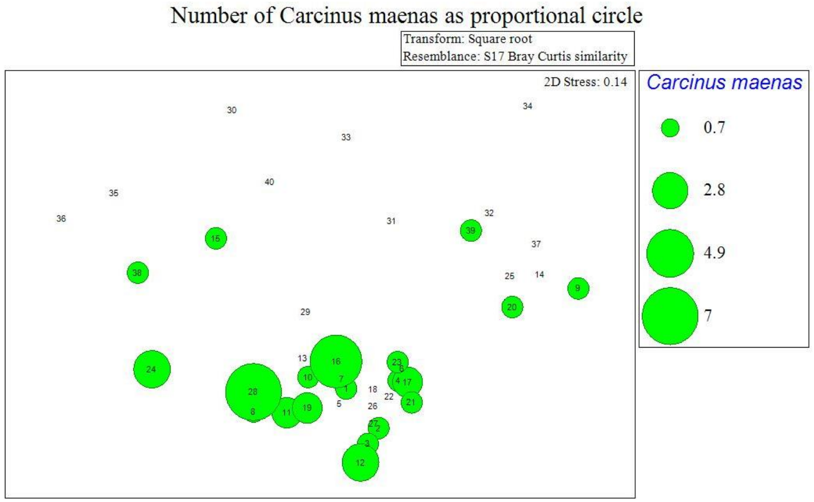
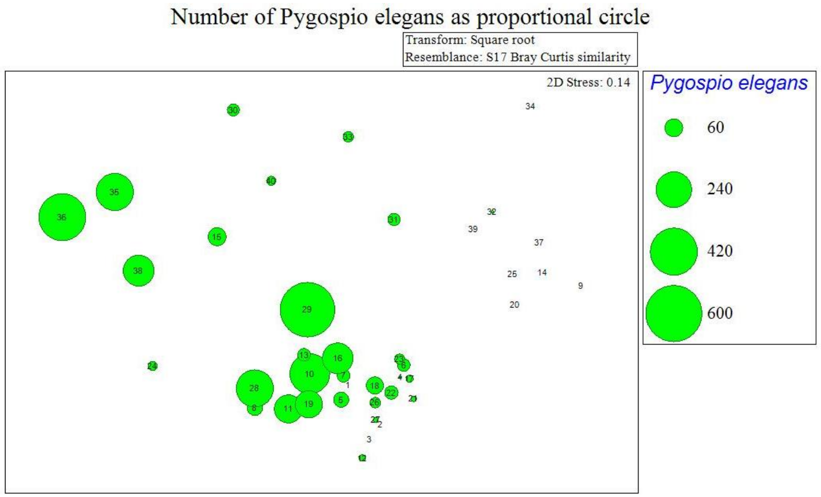
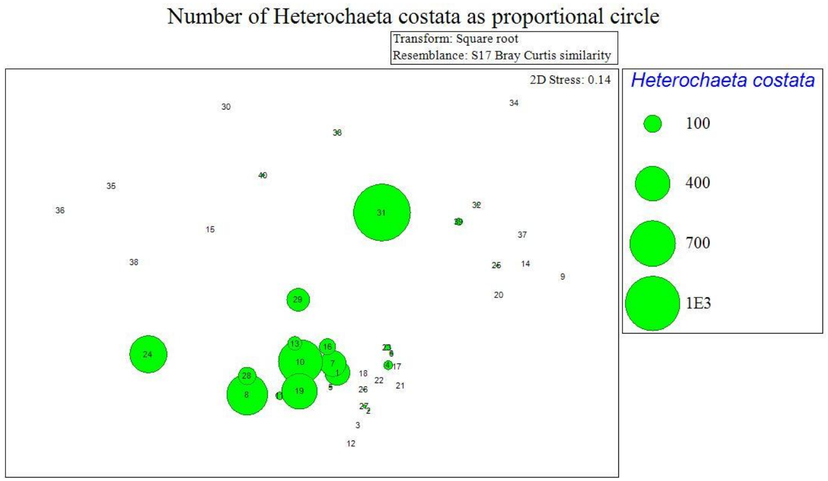


Figure 5.13 Examples of Taxa in Group 3 (0.95 – 1.1 m). None are restricted to Group 3.

A poorly defined grouping, most sites have higher affinities with other Groups than with other members of Group 3.
Enchytraeidae – see Fig 5.11
Nereis diversicolor – see Fig 5.12





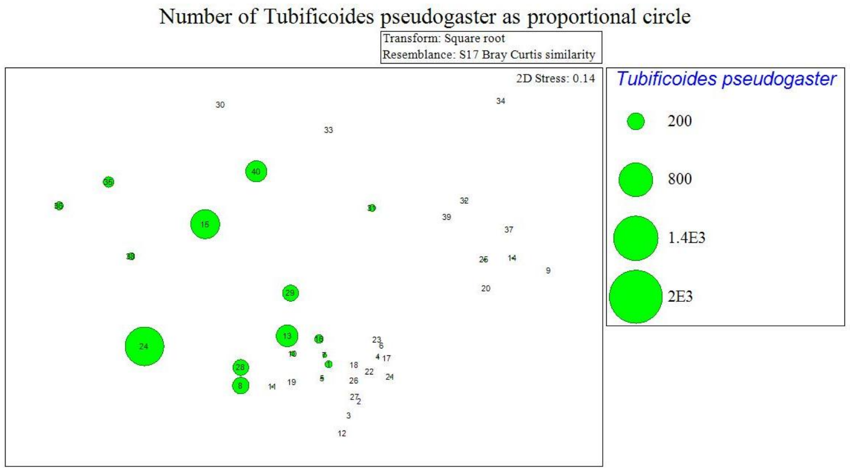
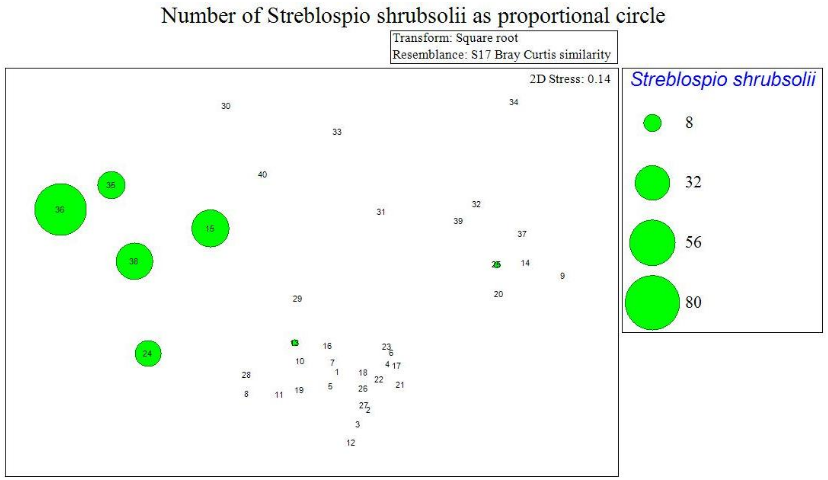
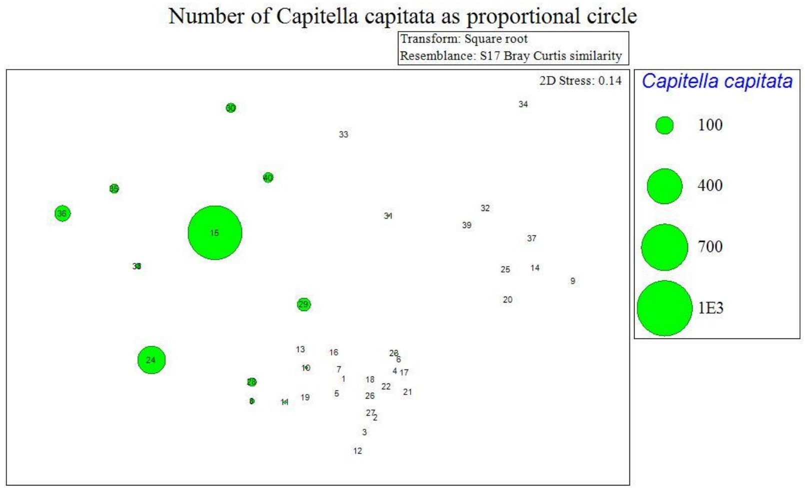
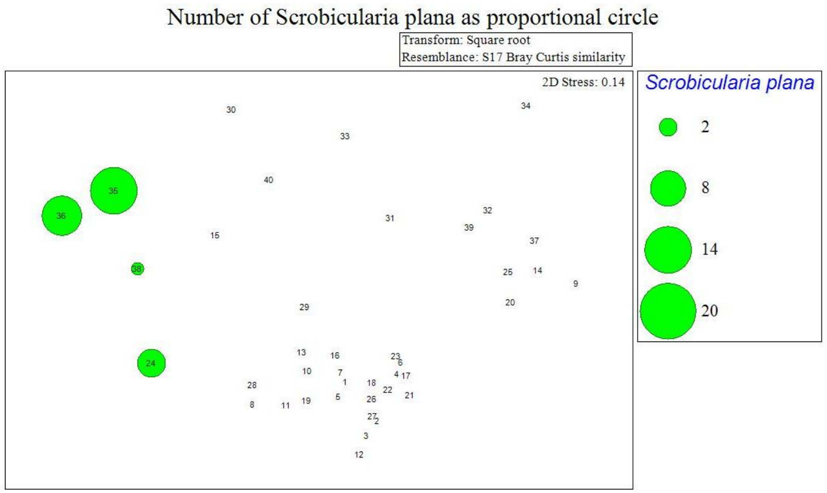
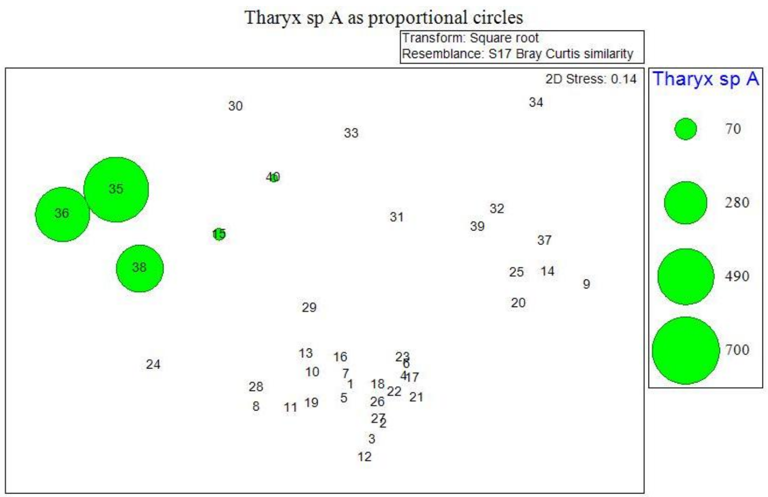


Figure 5.14 Examples of Dominant Taxa in Group 4 (0.2 – 0.6 m, many in lower part of Carnsew, no *Corophium*).







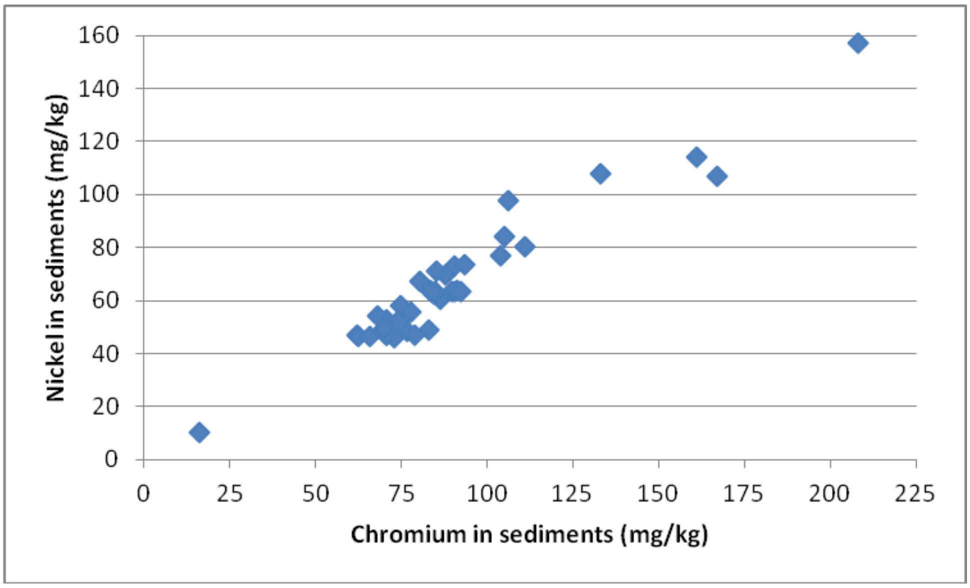


3.11 'Best' Analysis

All three areas combined (Copperhouse, Lelant and Carnsew)

Nickel was not included in the 'BEST' analysis as it was almost perfectly correlated with the chromium content (See Figure 5.15).

Figure 5.15 Correlation between Chromium and Nickel in Sediments.



Three sites in Lelant Water (28, 29 and 30) were excluded from the main analysis as we did not have particle size data for them.

The analysis of 37 sites examined the relative importance of the measured abiotic variables in "structuring" the invertebrate communities at the various sites. Initially the variables included were:

- Aluminium (Al)
- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Manganese (Mn)
- Mercury (Hg)
- Tin (Sn)
- Zinc (Zn)
- Height (m ODN)
- Gravel (%)
- Silt + clay (%)

- Organic carbon (% in <63 um fraction)
- Mean phi (Folk and Ward)

The 'BEST' analysis shows which variable or group of variables is most highly correlated with the biological data. The individual parameters which best "explained" the biological variability were:

	Correlation
Height (metres above ODN)	0.382
Lead	0.171
Iron	0.125

When two or more abiotic variables at a time were included in the analysis the highest correlations were for the following combinations (the order within a group does not always indicate relative importance):

	Correlation
Height & Silt + clay	0.427
Height & Mean phi (particle size)	0.403
Height, Silt+ clay and iron	0.387
Height	0.382
Height, Silt+ clay and manganese	0.376
Height, Silt+ clay and lead	0.370
Height, mean phi & iron	0.366
Height, mean phi & manganese	0.361
Height, mean phi & lead	0.360
Height & iron	0.355

Initially the results seem surprising, as none of the toxic metals (except lead) are important in structuring the community. Perhaps the best explanation is that concentrations of metals such as copper, arsenic and zinc concentrations are so high that the whole of the Hayle estuary has a very restricted fauna, but one that is still structured by important natural variables such as height and particle size. As an analogy, if you examined invertebrate communities in high alpine meadows at similar altitudes, you would probably find that height was not an important variable in structuring the communities.

Another explanation is that metals such as copper and zinc are often highly correlated with the iron and manganese concentrations in the sediment, due to the ability of iron and manganese oxides to co-precipitate metals such as cadmium, zinc, copper and lead. Sediment geochemistry can be an important factor in the bioavailability of metals to estuarine invertebrates (Thomas and Bendell-Young, 1998). Iron and manganese can be considered 'master' variables that are important not because they are toxic metals, but because they are often highly correlated with the concentrations of toxic metals.

Due to the high correlation between mean phi and aluminium content we removed mean phi from the analysis. We removed iron and manganese from the list of variables so that we could examine whether copper, zinc and arsenic became more important. With mean phi, iron and manganese excluded the highest correlations were:

Height & silt + clay	0.427
Height	0.382

Height & silt + clay & lead	0.370

This indicates that if metals such as copper, zinc and arsenic are important, they are much less important in structuring the biological communities (those able to tolerate high Cu, Zn, As etc) across at all 37 sites than natural factors such height and silt and clay content.

The final 'BEST' analysis of all sites combined used the metal and height data for all 40 sites, but excluded the particle size data (as this wasn't available for 3 sites). The results were:

Height & Iron	0.396
Height & Manganese	0.390
Height	0.380
Height, Iron & Manganese	0.374
Height, Iron & Lead	0.359
Height, Lead & Manganese	0.358
Height, Iron & Manganese	0.352
Height & Lead	0.349
Height, Iron & Zinc	0.335
Height, Iron & Chromium	0.331

The results confirmed that height on the shore is likely to be the single most important factor structuring g benthic invertebrate communities throughout the Hayle estuary complex, with iron or manganese as secondary factors. Inclusion of toxic metals (e.g. lead, zinc and chromium) did not improve the ability of the abiotic data set to predict benthic communities throughout the Hayle estuary complex.

'BEST' analysis of three areas separately

The next 'BEST' analyses examined the three areas (Copperhouse, Lelant and Carnsew) separately, to determine if different variables were important in each. The results are summarised in Table 5.8.

The results show that height was the single most important variable in Copperhouse Pool and Carnsew (where organic carbon was also important). In Copperhouse Pool trace metals such as copper, mercury tin and zinc also had some importance. In Lelant Water the most important variables were percentage gravel and organic carbon.

Table 5.8 'BEST' analysis of the most important abiotic variables.
Note that the order of metals in a group isn't necessarily their order of importance.

Copperhouse Pool		Lelant Water		Carnsew	
Variables	Corr	Variables	Corr	Variables	Corr
Height Cu, Mn, Hg & Sn	0.500	Gravel Carbon	0.491	Height Carbon	0.551
Height Cu, Mn, Hg, Sn & Zn	0.496	Gravel Carbon & Mn	0.488	Height Carbon, As & Pb	0.551
Height Mn, Hg & Sn	0.488	Gravel Carbon & Cr	0.459	Height Carbon, Cd & Hg	0.551
Height Mn	0.483	Gravel Carbon, Mn & Cr	0.422	Height Carbon, As & Zn	0.547
Height Cu, Hg & Sn	0.479	Carbon & Mn	0.418	Height Carbon, As, Pb & Zn	0.546
Height Fe, Mn, Hg, Sn & Zn	0.470	Gravel Carbon & Sn	0.399	Height Carbon, Hg & Zn	0.546
Height As, Mn, Hg, Sn &Zn,	0.469	Gravel	0.395	Height Carbon, As, Pb & Hg	0.546
Height Fe, Mn, Hg & Sn	0.469	Gravel Carbon, Cr, Mean phi	0.395	Height, Carbon, As, Pb, Hg & Zn	0.545
Height Cu, Fe, Hg & Sn	0.469	Gravel Carbon, Mean phi	0.393	Height Carbon, Pb, Hg & Zn	0.544
Height Fe, Hg, Sn & Zn	0.468	Gravel Carbon, Mn & Mean phi	0.387	Height Carbon	0.542

4. REFERENCES

Barber, AD (2009). Centipedes. No 58 Synopses of the British Fauna (New Series). The Linnean Society of London.

Cusson, M & Bourget, E (2005). Global patterns of macroinvertebrate production in marine benthic habitats. Marine Ecology Progress Series, Volume 297, 1-14.

Burdige, D (1993). The biogeochemistry of manganese and iron reduction in marine sediments.

Thomas, CA and Bendell-Young, LI (1998). Linking the sediment geochemistry of an intertidal region to metal bioavailability in the deposit feeder *Macoma balthica*. Marine Ecology Progress Series, Volume 173, 197-213.

Photo 5.1 *Cillenus lateralis*. Copyright Roy Anderson roy.anderson@ntlworld.com

Photo 5.2 *Geophilus seurati* head end. Copyright Aquatonics Ltd.

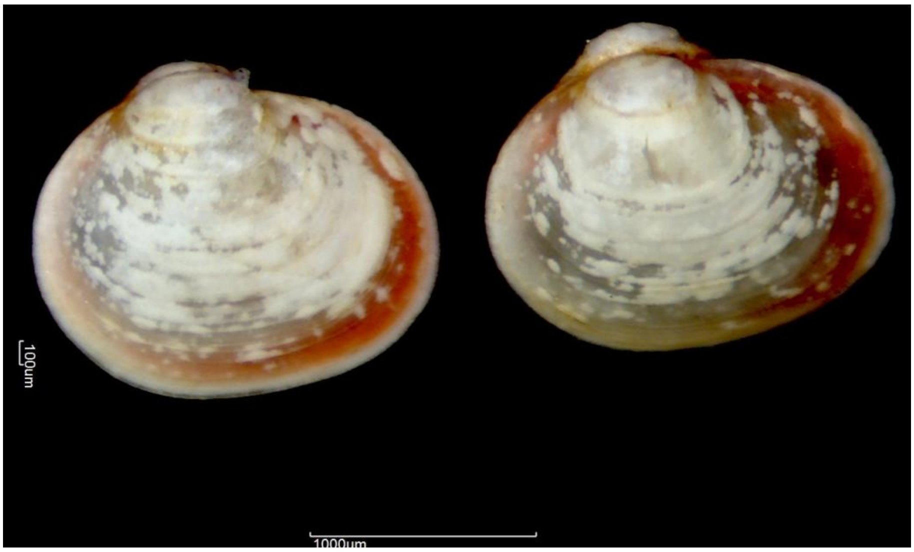


Photo 5.3 *Lasaea adansoni*. Copyright Aquatonics Ltd.

APPENDIX 6. METALS IN SELECTED BIOTA

1. INTRODUCTION

The main aim of the study was to determine whether the construction of the new road bridge to North Quay had any impact on metal concentrations in key invertebrate species, especially those that are important prey items for wading birds and fish. The data should also aid any future calculations of the quantity of each metal consumed by wading birds during their overwintering period on the Hayle estuary complex.

After email correspondence with consultees the following species were selected:

Harbour ragworm	*Nereis diversicolor* (also called *Hediste diversicolor*)
Lugworm	*Arenicola marina*
Brown shrimp	*Crangon crangon*
Shore crab	*Carcinus maenas*
Burrowing amphipod	*Corophium volutator*
Rough periwinkle	*Littorina saxatilis*

2. METHODS

Samples of the selected species of biota were collected by Aquatonics Ltd staff (Dr Phil Smith and Dr Anne Smith) on 24 and 28 August 2010 at 20 locations.

The number of samples collected for each species was as follows:

Nereis diversicolor	6 sites (2 each in Copperhouse, Lelant and Carnsew)
Arenicola marina	3 sites (1 each in Copperhouse, Lelant and Carnsew)
Crangon crangon	2 sites (Copperhouse and Lelant)
Carcinus maenas	3 sites (1 each in Copperhouse, Lelant and Carnsew)
Corophium volutator	3 sites (1 each in Copperhouse, Lelant and Carnsew)
Littorina saxatilis	3 sites (1 each in Copperhouse, Lelant and Carnsew)

Site locations are listed in Table 6.1.

The protocol followed for each species is summarised below.

2.1 General

- Put specimens into 20 ml Nalgene pots.
- Label pots with site number (Mxx) and species.
- Put filled Nalgene pots into cooler packed with plenty of ice packs.
- Wash specimens (except *Crangon*) in pure water (25 psu), taken to Hayle in a carbuoy with tap or in large plastic bottles.

2.2 *Nereis diversicolor*

- Use a fork to dig as deeply as necessary to obtain approximately 50 specimens.

- Don't attempt to remove all mud from specimens in the field.
- Collect specimens in a 4 litre container and return to the car.
- Add saline to 4 l container and swirl gently.
- Pour off liquid and add more saline.
- Repeat until specimens are fairly clean.
- Transfer ragworm to a plastic bowl.
- Move worms onto side of plastic bowl edge – wriggling releases sediment in chaetae
- Some sediment needs removing with forceps when stuck in mucus.
- Transfer one by one to Nalgene pot.
- Count specimens put into Nalgene pots, weigh and record number.

2.3 *Arenicola marina*

- Use a 'garden fork' to dig as deeply as necessary to obtain approximately 8 specimens.
- Don't attempt to remove all sediment in the field.
- Put specimens into a 4 litre container and return specimens to the car for cleaning.
- Add saline and swish gently.
- Pick out specimens.
- Carefully remove sediment and mucus tube surrounding each specimen using fine forceps.
- Wipe gently with gloved finger and tissue to remove any sediment attached to chaetae.
- Swish in saline before transfer to Nalgene pots.
- Measure size range (whole length – approximate).
- Count specimens, put into Nalgene pots, weigh and record.

2.4 *Crangon crangon*

- Collect samples from LW channel using an FBA handnet.
- Put into white tray (or 4 l container) containing few cm water from channel.
- Pick out approximately 30 medium to medium-large specimens, using forceps.
- Place directly in Nalgene pots (no need to wash with 25 psu saline).
- Count number of specimens transferred.
- Weigh Nalgene bottle and record number and weight.

2.5 *Carcinus maenas*

- Collect small specimens (~4 mm to ~18 mm, so that they fit into Nalgene bottles).
- Collect ~ Organic C-20 individuals from under cobbles and boulders.
- Put into white 4 litre container and return to the car.
- Add 25 psu saline water to 4 l container and swish gently to wash the crabs.
- Pour through the nylon sieve.
- Return crabs to 4 litre container and rewash.
- Repeat 2 x so crabs are free of attached sediment.
- Transfer crabs to Nalgene pots using forceps, counting number of specimens.
- Weigh Nalgene bottle and record number and weight.

2.6 *Corophium volutator*

- Use a spade or large white plastic "shovel" to remove upper 5-8 cm of sediment.
- Place on large 1 mm sieve.
- Sieve using water in nearby LW channel.
- Put some of the water into the bottom of a yellow bucket.
- Transfer the *Corophium* by turning the sieve upside down on the bucket and tapping the sieve.
- Repeat the process until several hundred *Corophium* have been collected (~ 8-10 shovels required).
- Return yellow bucket to car.
- Transfer onto 1 mm sieve and wash by pouring saline onto sieve – needs several litres.
- Tip some of contents into white tray or plastic bowl.
- Add saline for further washing.
- Pick out *Corophium* with fine tweezers, ensuring that no detritus is included.
- *Corophium* are not counted.
- Weigh Nalgene bottle and record.
- Aim for 4 - 4.5 g (>150 specimens).

2.7 *Littorina saxatilis*

- Collect 30 – 50 specimens from on and under boulders.
- Place in 4 litre container.
- Return to car for washing.
- Add saline to 4 litre container
- Transfer to white tray.
- Allow specimens to move around tray and detach themselves from most of the attached sediment.
- When shells are covered in sediment/algae, rub them on tissue to remove external debris.
- Measure size range (operculum to top of shell).
- Transfer to Nalgene pots, counting number of specimens, weigh and record details.

3. RESULTS

Results are tabulated for each species in Tables 6.2 to 6.7 and summarised in Table 6.8.

3.1 *Nereis diversicolor* Table 6.2

Nereis diversicolor is known to regulate concentrations of iron, manganese and zinc, making it a poor indicator of availability for these metals (Bryan and Gibbs, 1987). It is a moderate indicator for As, Co, Hg and Pb (and possibly Cr, Ni and Sn) and is a good indicator of cadmium, copper and silver (Bryan and Gibbs, 1987). The cadmium is mainly taken up from solution, but for other metals are accumulated from the sediment.

We obtained six samples of *Nereis diversicolor* at Hayle, more than any other species examined, so it was more likely to show the highest levels of each metal. The following toxic metals had their highest values in *Nereis diversicolor*:

Chromium	11.2 mg/kg at M9 (Copperhouse lower)
Copper	1650 mg/kg at M19 (Lelant mid/upper)
Iron	13100 mg/kg at M19 (Lelant mid/upper)
Lead	33 mg/kg at M19 (Lelant mid/upper)

Compared with other parts of the UK, *Nereis diversicolor* from the Hayle area have high concentrations of arsenic, chromium, copper, iron and manganese. They also have elevated concentrations of lead, nickel and zinc (Table 6.2).

3.2 *Arenicola marina* Table 6.3

Arenicola marina is a poor indicator for manganese, a moderate indicator for cadmium and possibly copper, lead and zinc (Bryan and Gibbs, 1987).

Three samples of *Arenicola marina* were examined at Hayle. The following toxic metals had their highest values in Arenicola *marina*:

Arsenic	277 mg/kg at M7 (Copperhouse lower)
Nickel	8.56 mg/kg at M7 (Copperhouse lower)

Compared with other parts of the UK, *Arenicola marina* from the Hayle area have high concentrations of arsenic, copper and manganese. They also have elevated concentrations of lead and zinc (Table 6.2).

3.3 *Corophium volutator* Table 6.4

Metal concentrations in *Corophium volutator* have not been examined in many studies, which is surprising considering its importance as a prey item for wading birds and fish. It is also a suitable biomonitor as it stays within a relatively small area and is not as mobile as other crustacean species such brown shrimp.

Copper and zinc concentrations in *Corophium volutator* from Hayle are lower than in the same species from Restronguet Creek (Bryan & Gibbs, 1983). The maximum iron concentration in *Corophium volutator* (site M8 Copperhouse lower) was slightly higher than recorded at Restronguet Creek. We have not located any other metal data for *Corophium volutator* obtained from field studies in the UK.

Two samples of *Corophium volutator* were examined at Hayle. None of the toxic metals had maximum values in *Corophium volutator*. This may be due to the low number of samples, but *Corophium* were sampled at M20, within a few metres of a M19 where *Nereis diversicolor* exhibited very high metal concentrations for copper, iron and lead. The following table compares concentrations of these metals at M19 and M20:

	Nereis at M19	*Corophium* at M20
Copper	1650	255

Iron	13100	581
Lead	33	2.93

Cadmium and strontium were higher in *Corophium volutator* at M20 than in *Nereis diversicolor* at M19. The same pattern was noticed at Copperhouse Pool, where the *Corophium* at M8 had a similar concentration of cadmium and a higher concentration of strontium than *Nereis diversicolor* at nearby M9. All other toxic metals were higher in *Nereis diversicolor*.

The relatively low concentrations of metals in *Corophium volutator* may be due to loss of metals during moulting.

It is likely that for a similar weight ingested by wading birds or fish, *Corophium volutator* is a better prey item than *Nereis diversicolor* in terms of metal burden. However, it is possible that the bioavailability of metals in each prey species is not identical.

Compared with other parts of the UK, *Corophium volutator* from the Hayle area have high concentrations of copper and iron. They also have elevated concentrations of zinc (Table 6.2). Comparative data are not available for other metals.

3.4 *Crangon crangon* Table 6.5

As *Crangon crangon* is relatively mobile it has not been viewed as a good indicator of localised contamination. We included this species as it is likely to be an important prey item for some wading birds and fish. Only two samples were obtained, and neither had the maximum value of any of the toxic metals. Metal concentrations in the two samples of *Crangon crango*n were broadly similar to those in the two samples of *Corophium volutator*, suggesting that the brown shrimp at Hayle may spend most of their time in the estuarine parts rather than in nearby St Ives Bay where metal concentrations are expected to be lower.

Concentrations of copper, lead and zinc in brown shrimp at Hayle were relatively high compared to the data we have for other locations in the UK. They also had elevated concentrations of cadmium and copper.

Two samples of *Crangon crangon* were obtained at Hayle. None of the toxic metals had maximum values in *Crangon crangon*. This may be due to the low number of samples, the higher mobility of *Crangon crangon* (specimens could spend some time in nearby St Ives Bay, which is much cleaner) or because *Crangon crangon* is able to shed metals when it moults.

Compared with other parts of the UK, *Crangon crangon* from the Hayle area have high concentrations of copper, lead and zinc. They also have elevated concentrations of cadmium and chromium (Table 6.2).

3.5 *Carcinus maenas* Table 6.6

Three samples of *Carcinus maenas* were examined at Hayle. Most metals in *Carcinus maenas* were lowest in Carnsew; the only exception was strontium.

The following toxic metals had higher values in *Carcinus maenas* than any of the other 5 species analysed:

Manganese	363 mg/kg at M22 (Lelant upper)
Strontium	1690 mg/kg at M12 (Carnsew)

Compared with other parts of the UK, *Carcinus maenas* from the Hayle area have high concentrations of lead. They also have elevated concentrations of cadmium, copper and zinc (Table 6.2).

3.6 *Littorina saxatilis* Table 6.7

The following toxic metals had their highest values in *Littorina saxatilis*:

Cadmium	4.21 mg/kg at M21 (Lelant upper)
Mercury	0.182 mg/kg at M3 (Copperhouse upper)
Zinc	336 mg/kg at M21 (Lelant upper)

Compared with other parts of the UK (data for the closely related *Littorina littorea*), *Littorina saxatilis* from the Hayle area have high concentrations of arsenic, chromium, copper, iron and manganese. They also have elevated concentrations of cadmium, lead and zinc (Table 6.2).

4. REFERENCES

Bat, L and Raffaelli, D (1999). Effect of gut sediment contents on heavy metal levels in the amphipod *Corophium volutator* (Pallas). Turkish Journal of Zoology, Volume 23, 67-71.

Bryan, GW and Gibbs, PE (1983). Heavy metals in the Fal estuary, Cornwall: a study of long-term contamination by mining waste and its effects on estuarine organisms. Marine Biological Association of the UK, Occasional Publication No 2. March 1983.

Bryan, GW and Gibbs, PE (1987). Polychaetes as indicators of heavy-metal availability in marine deposits. In: Oceanic Processes in Marine Pollution. Volume 1 Biological Processes and Wastes in the Ocean. Krieger Publishing, USA.

Bryan, GW and Hummerstone, LG (1973). Adaptation of the polychaete *Nereis diversicolor* to manganese in estuarine sediments. Journal of Marine Biological Association UK, Volume 53, 859-872.

Bryan, GW; Langston, WJ; Hummerstone, LG; Burt, GR and Ho, YB (1985). An assessment of the gastropod, *Littorina littorea*, as an indicator of heavy-metal contamination in United Kingdom estuaries. Journal of the Marine Biological Association, UK Volume 63, 327-345.

Bryan, GW; Langston, WJ; Hummerstone, LG and Burt, GR (1985). A guide to the assessment of heavy-metal contamination in estuaries using biological indicators. Marine Biological Association of the UK, Occasional Publication No 4. March 1985.

Casado-Martinez, C, Smith, BD; Luoma, SN and Rainbow, PS (2010). Metal toxicity in a sediment-dwelling polychaete: threshold body concentrations or overwhelming accumulation rates? Environmental Pollution, Volume 158, 3071-3076.

Culshaw, C., Newton, LC; Weir, I and Bird, DJ (2002). Concentrations of Cd, Zn and Cu in sediments and brown shrimp (*Crangon crangon* L.) from the Severn Estuary and Bristol Channel, UK. Marine Environmental Research, Volume 54, 331-334.

Everaarts, JM; Otter, E and Fischer, CV (1990). Cadmium and polychlorinated biphenyls: different distribution pattern in North Sea benthic biota. Netherlands Journal of Sea Research, Volume 26, 75-82.

Havard, MSC (1991). Temporal changes in trace metal levels in the polychaete *Nereis diversicolor* O.F. Müller from two British estuaries with contrasting sedimentary metal concentrations. In: Estuaries and Coasts: Spatial and Temporal Intercomparisons. ECSA Symposium No 19. Olsen & Olsen.

Ireland, MP (1973). Result of fluvial zinc pollution on the zinc content of littoral and sub-littoral organisms in Cardigan Bay, Wales. Environmental Pollution, Volume 4, 27-35.

Ireland, MP and Wootton, RJ (1977). Distribution of lead, zinc, copper and manganese in the marine gastropods *Thais lapillus* and *Littorina littorea*, around the coast of Wales. Environmental Pollution, Volume12, 27-41.

Mance, G and Yates, J (1984). Proposed Environmental Quality Standards for List II substances in water. Nickel. Technical Report TR 211, August 1984. Water Research Centre, Stevenage.

Packer, DM; Ireland, MP and Wootton, RJ (1980). Cadmium, copper, lead, zinc and manganese in the polychaete *Arenicola marina* from sediments around the coast of Wales. Environmental Pollution (series A), Volume 22, 309-321.

Sahu, AK and Jones, NV (1991). Variation of arsenic and iron concentrations in the intertidal sediment, *Hediste* (*Nereis*) *diversicolor* and *Fucus vesiculosus* from the Humber estuary, UK, during a two-year period. In: Estuaries and Coasts: Spatial and Temporal Intercomparisons. ECSA Symposium No 19. Olsen & Olsen.

Wharfe, JR and Van den Broek, WLF (1977). Heavy metals in macroinvertebrates and fish from the lower Medway estuary, Kent. Marine Pollution Bulletin, Volume 8, 31- 34.

Wright, P and Mason, CF (1999). Spatial and seasonal variation in heavy metals in the sediments and biota of two adjacent estuaries, the Orwell and the Stour, in eastern England. The Science of the Total Environment, Volume 226, 139-156.

Table 6.1 Locations of sampling sites and species collected.

Sample number	Species	Number	Weight (g)	Size (mm)	NGR
M2	*Corophium volutator*	Not counted	4.5		SW 56254 37985
M3	*Littorina saxatilis*	92	31	3.6 - 13.5	SW 56362 38095
M4	*Crangon crangon*	30			SW 56447 38025
M5	*Carcinus maenas*	17	6	5 - 17 carapace width	SW 56437 38151
M6	*Nereis diversicolor*	56	6	2 - 5 cm	SW 56440 38149
M7	*Arenicola marina*	6	15	48 - ~100	SW 55933 37777
M8	*Corophium volutator*	Not counted	4		SW 56056 37843
M9	*Nereis diversicolor*	95	15		SW 55904 37780
M10	*Littorina saxatilis*	80	13	3 - 10	SW 55205 37027
M11	*Arenicola marina*	6	12	59 - 97	SW 55211 37049
M12	*Carcinus maenas*	27	13	6 - 18	SW 55205 37027
M13	*Crangon crangon*	34	8		SW 55024 37086
M15	*Nereis diversicolor*	33	14		SW 55105 37121
M16	*Nereis diversicolor*	33	12	~ 2 - 10	SW 55205 37175
M17	*Arenicola marina*	2	26		SW 54946 37320
M18	*Nereis diversicolor*	52	8		SW 54743 36955
M19	*Nereis diversicolor*	53	12		SW 54678 36770
M20	*Corophium volutator*		7		SW 54687 36770
M21	*Littorina saxatilis*	50	6	4 - 9.5	SW 54664 36368
M22	*Carcinus maenas*	18	12	5 - 23	SW 54659 36368

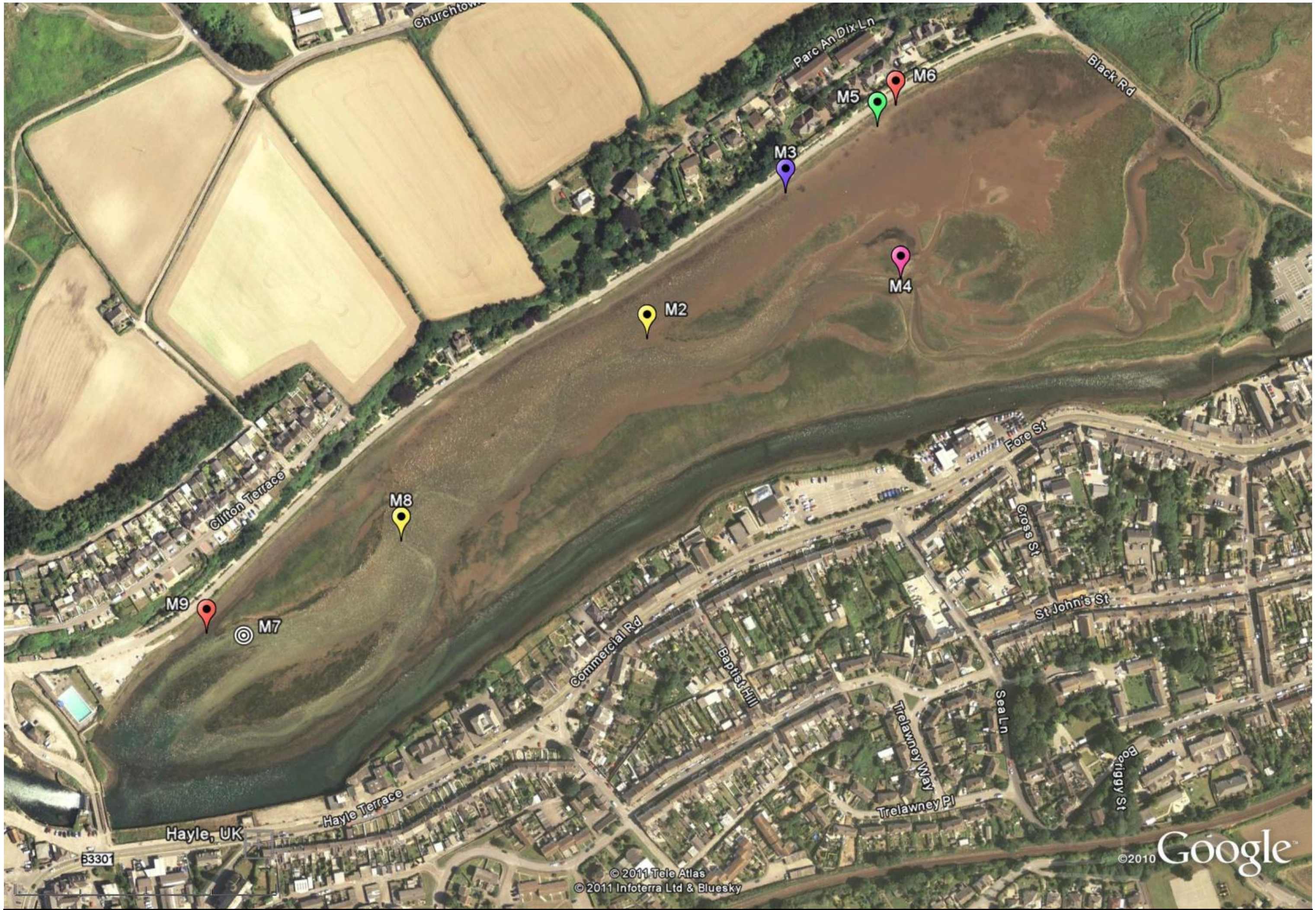


Figure 6.1 Location of sampling sites in Copperhouse Pool. Red = *Nereis*, White = *Arenicola*, Green = *Carcinus*, Yellow = *Corophium*, Pink = *Crangon*, Purple = *Littorina*

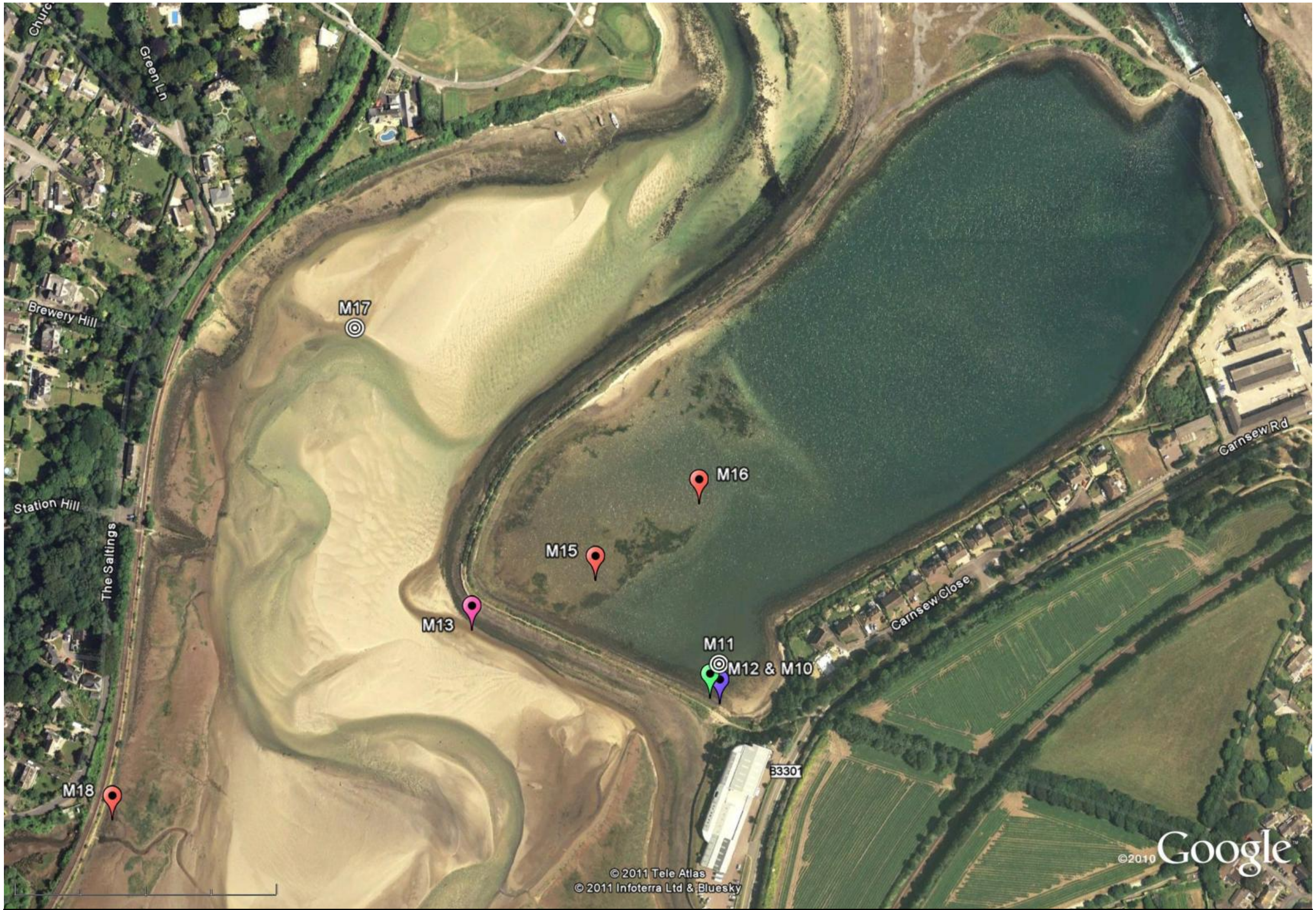


Figure 6.2 Location of sampling sites in Carnsew and Lower Lelant. Red = *Nereis*, White = *Arenicola*, Green = *Carcinus*, Yellow = *Corophium*, Pink = *Crangon*, Purple = *Littorina*

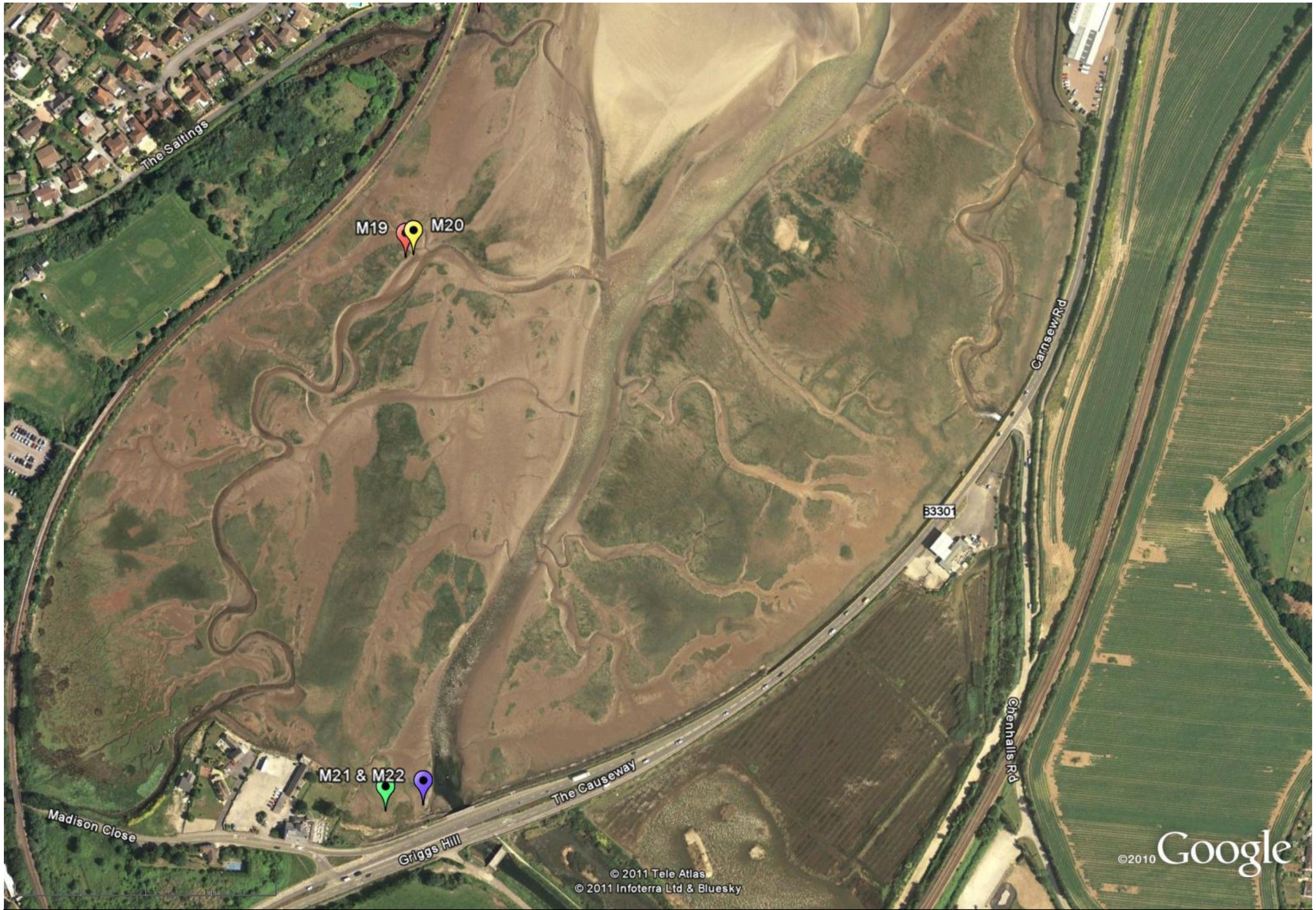


Figure 6.3 Location of sampling sites in Upper Lelant. Red = *Nereis*, White = *Arenicola*, Green = *Carcinus*, Yellow = *Corophium*, Pink = *Crangon*, Purple = *Littorina*

KEY FOR TABLES 6.2 – 6.7		
Site with highest value for that metal	Hayle probably high compared to other estuaries	Hayle very high compared to other estuaries

Table 6.2 Metals in Harbour Ragworm, *Nereis diversicolor*

Nereis diversicolor Harbour ragworm Metal (all as dry wt)	Units	M6 Copper-house upper	M9 Copper-house lower	M15 Carnsew	M16 Carnsew	M18 Lelant mid	M19 Lelant Mid to upper	Mean Hayle Aug 2010	Max Hayle Aug 2010	Range SW estuaries Bryan et al 1985	Max UK* (excl this study)	Location (excl this study)	Comments * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	Flag
Arsenic	mg/kg	190	116	45.2	43.5	55.8	114	94	190	8 - 84	199	Humber near smelter (Sahu & Jones, 1991)	84 mg/kg at Hayle November 1984, similar to mean in August 2010.	
Cadmium	mg/kg	0.18	0.239	0.084	0.075	0.149	0.149	0.146	0.239	0.14 - 5.0	10.0	Severn estuary (Havard, 1991)	0.47 mg/kg at Hayle November 1984, quite high compared to August 2010 results.	
Chromium	mg/kg	10.8	11.2	1.09	1.87	7.91	7.7	6.8	11.2	0.2 - 0.6	0.8	Pill Creek, Fal (Bryan & Gibbs, 1983)	<0.3 mg/kg at Hayle November 1984. Very high values for Hayle in August 2010 may be partly due to lack of depuration. Chromium source also possible.	
Copper	mg/kg	1270	356	414	378	456	1650	754	1650	19 - 1430	1430	Restronguet Creek (Bryan et al, 1985)	1210 mg/kg at Hayle November 1974. Maximum at Hayle exceeds Restronguet Creek maximum.	
Iron	mg/kg	8190	7900	1240	1320	8470	13100	6703	13100	349 - 734	735	Tresillian River, Fal (Bryan & Gibbs, 1983)	734 mg/kg at Hayle in November 1974. Very high values for Hayle in August 2010 may be partly due to lack of depuration. *Nereis* regulates iron content (Bryan et al, 1985).	

Table 6.2 Metals in Harbour Ragworm, *Nereis diversicolor* (cont).

***Nereis diversicolor* Harbour ragworm**	**Units**	**M6 Copper-house upper**	**M9 Copper-house lower**	**M15 Carnsew**	**M16 Carnsew**	**M18 Lelant mid**	**M19 Lelant Mid to upper**	**Mean Hayle Aug 2010**	**Max Hayle Aug 2010**	**Range SW estuaries Bryan et al 1985**	**Max UK* (excl this study)**	**Location (excl this study)**	**Comments** * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	**Flag**
Lead	mg/kg	25.2	25.1	3.82	4.41	17.8	33	18	33	2 - 685	685	Gannel (Bryan et al, 1985)	4.2 mg/kg at Hayle in November 2010. Most SW estuaries 2 - 7 mg/kg, therefore Hayle August 2010 results are high.	
Manganese	mg/kg	115	113	21.7	18.4	119	174	94	174	5.7 - 14.1	58	Orwell (Wright & Mason, 1999)	5.7 mg/kg at Hayle in Nov 1974. High values for Hayle in August 2010 may be partly due to lack of depuration. However, depuration results in artificially low values of Mn (Bryan & Hummerstone, 1973). *Nereis* regulates Mn (Bryan et al, 1985).	
Mercury	mg/kg	0.166	0.084	0.116	0.122	0.084	0.089	0.110	0.166	0.05 - 2.5	2.5	Severn at Sharpness (Bryan et al, 1985)	0.22 mg/kg at Hayle November 1984, similar to max in August 2010	
Nickel	mg/kg	6.97	7.45	2.49	3.21	7.33	6.82	5.71	7.45	2.3 - 13.3	60	Severn estuary (Havard, 1991)	9.1 mg/kg at Hayle November 1984, similar to maximum in August 2010	
Strontium	mg/kg	62.9	124	24.7	23.1	50	68.8	59	124	NA	NA	NA		
Zinc	mg/kg	243	245	119	110	167	245	188	245	163 - 466	~1000	Severn estuary (Havard, 1991)	260 mg/kg at Hayle November 1984, similar to maximum in August 2010. *Nereis* regulates zinc content (Bryan et al, 1985).	

Table 6.3 Metals in Lugworm (*Arenicola marina*)

Arenicola marina **Lugworm**		**M7 Copper-house lower**	**M11 Carnsew**	**M17 Lelant mid/lower**	**Mean Hayle Aug 2010**	**Maximum Hayle Aug 2010**	**Maximum UK* (excl present study)**	**Location of UK maximum (excl present study)**	**Comments** * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	**Flag**
Metal (all as dry weight)	**Units**									
Arsenic	mg/kg	277	213	137	209	277	122	Not stated - possibly not UK	Casado-Martinez et al, 2010	
Cadmium	mg/kg	0.525	0.294	0.414	0.411	0.525	32	Severn estuary (Packer et al, 1980)	Cadmium is not high in lugworm from Hayle.	
Chromium	mg/kg	7.07	9.75	6.33	7.72	9.75				
Copper	mg/kg	255	127	72.4	151	255	45	Dullas Bay, Anglesey (Packer et al, 1980)	125 mg/kg reported in Casado-Martinez et al (2010) but location not given. Copper is elevated in lugworm from Hayle.	
Iron	mg/kg	6100	9400	8010	7837	9400				
Lead	mg/kg	14.6	18.3	14.3	16	18.3	40	Severn estuary (Packer et al, 1980)	Lead is relatively high in lugworm from Hayle.	
Manganese	mg/kg	80.3	117	137	111	137	10	Severn estuary (Packer et al, 1980)	Manganese is elevated in lugworm from Hayle, but this may be due to lack of depuration.	
Mercury	mg/kg	0.105	0.041	0.017	0.054	0.105	1.63	Orwell (Wright & Mason, 1999)	Mercury is not particularly high in lugworm from Hayle.	
Nickel	mg/kg	8.56	5.73	5.50	6.60	8.56	101	Orwell (Wright & Mason, 1999)	Nickel is not particularly high in lugworm from Hayle.	
Strontium	mg/kg	715	398	867	660	867	NA			
Zinc	mg/kg	143	112	117	124	143	330	Severn estuary (Packer et al, 1980)	Zinc is moderately elevated in lugworm from Hayle.	

Table 6.4 Metals in *Corophium volutator*

Corophium volutator An amphipod crustacean		M8 Copperhouse lower	M20 Lelant mid/upper	Mean Hayle Aug 2010	Maximum Hayle Aug 2010	Maximum UK* (excl present study)	Location of UK maximum (excl present study)	Comments * = Maximum values in reports obtained by Aquatonics Ltd. Very little data for *Corophium volutator*.	Flag
Metal (all as dry weight)	**Units**								
Arsenic	mg/kg	27.4	18.5	23.0	27.4				
Cadmium	mg/kg	0.231	0.341	0.286	0.341			Approx 32 mg/kg was obtained for *Corophium* exposed in the laboratory to cadmium contaminated sediments for 10 days (Bat & Raffaeli, 1999)	
Chromium	mg/kg	1.14	0.73	0.94	1.14				
Copper	mg/kg	207	255	231	255	499	Restronguet Creek (Bryan & Gibbs, 1983)	Approx 225 mg/kg was obtained for *Corophium* exposed in the laboratory to copper contaminated sediments for 10 days (Bat & Raffaeli, 1999)	
Iron	mg/kg	845	581	713	845	732	Restronguet Creek (Bryan & Gibbs, 1983)		
Lead	mg/kg	4.85	2.93	3.89	4.85				
Manganese	mg/kg	28.1	17.3	22.7	28.1				
Mercury	mg/kg	0.039	0.078	0.059	0.078				
Nickel	mg/kg	<0.3	<0.3	<0.3	<0.3				
Strontium	mg/kg	932	1020	976	1020				
Zinc	mg/kg	93.3	92.1	92.7	93.3	254	Restronguet Creek (Bryan & Gibbs, 1983)	Approx 270 mg/kg was obtained for Corophium exposed in the laboratory to zinc contaminated sediments for 10 days (Bat & Raffaeli, 1999)	

Table 6.5 Metals in Brown Shrimp, *Crangon crangon*

Crangon crangon Brown shrimp Metal (all as dry weight)	Units	M4 Copperhouse upper	M13 Lelant mid	Mean Hayle Aug 2010	Max Hayle Aug 2010	Maximum UK* (excl present study)	Location of UK maximum (excl present study)	Comments * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	Flag
Arsenic	mg/kg	29.3	20.5	24.9	29.3				
Cadmium	mg/kg	0.507	0.48	0.494	0.507	15.4	Oldbury, Severn estuary (Culshaw et al, 2002)	Cadmium is accumulated by *Crangon crangon*. Cadmium and other metals are probably shed in large amounts when the shrimp moults.	
Chromium	mg/kg	0.37	0.36	0.365	0.37	1.0	Location not given (Mance & Yates, 1984)		
Copper	mg/kg	165	169	167	169	107	Barry Island, Bristol Channel (Culshaw et al, 2002)	57.3 max in Dutch coastal waters (Everaarts et al, 1990). *Crangon crangon* can regulate body concentrations of copper (Bryan and Gibbs, 1983).	
Iron	mg/kg	580	484	532	580				
Lead	mg/kg	3.65	2.36	3.01	3.65	1.30	Lower Medway estuary (Wharfe & Van den Broek, 1977)		
Manganese	mg/kg	18	9.82	14	18				
Mercury	mg/kg	0.055	0.058	0.057	0.058	0.26	Lower Medway estuary (Wharfe & Van den Broek, 1977)		
Nickel	mg/kg	<0.3	<0.3	<0.3	<0.3				
Strontium	mg/kg	605	801	703	801				
Zinc	mg/kg	66.6	71.3	69.0	71.3	136	Ilfracombe (Culshaw et al, 2002)	Max of 83.1 mg/kg reported from Dutch coastal waters. Max of 35.8 mg/kg from lower Medway estuary. *Crangon crangon* can regulate body concentrations of copper (Bryan and Gibbs, 1983).	

Table 6.6 Metals in Shore Crab (*Carcinus maenas*)

Carcinus maenas Shore crab		M5 Copperhouse	M12 Carnsew	M22 Lelant upper	Mean Hayle Aug 2010	Maximum Hayle Aug 2010	Maximum UK* (excl present study)	Location of UK maximum (excl present study)	Comments * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	Flag
Metal (all as dry weight)	**Units**									
Arsenic	mg/kg	70.3	19.3	24.7	38.1	70.3				
Cadmium	mg/kg	0.091	0.108	1.18	0.46	1.18	3.00	Lower Medway estuary (Wharfe & Van den Broek, 1977)		
Chromium	mg/kg	2.15	0.96	0.66	1.26	2.15				
Copper	mg/kg	264	138	221	208	264	527	Restronguet Creek (Bryan & Gibbs, 1983)		
Iron	mg/kg	1860	729	938	1176	1860				
Lead	mg/kg	11.3	3.56	4.03	6.3	11.3	4.13	Lower Medway estuary (Wharfe & Van den Broek, 1977)		
Manganese	mg/kg	203	37.9	363	201	363				
Mercury	mg/kg	0.036	0.037	0.048	0.040	0.048	0.44	Lower Medway estuary (Wharfe & Van den Broek, 1977)		
Nickel	mg/kg	<0.3	<0.3	<0.3	<0.3	<0.3				
Strontium	mg/kg	1670	1690	1600	1653	1690			Very few studies analyse strontium.	
Zinc	mg/kg	93.2	71.8	133	99.3	133	282	Restronguet Creek (Bryan & Gibbs, 1983)		

Table 6.7 Metals in Rough Periwinkle (*Littorina saxatilis*)

Littorina saxatilis Rough periwinkle	M3 Copperhouse upper	M10 Carnsew	M21 Lelant upper	Mean Hayle Aug 2010	Maximum Hayle Aug 2010	Comments Maximum* UK concentrations in closely related species, *Littorina littorea* * = maximum in papers and reports seen by Aquatonics Ltd, may not be comprehensive	Flag
Metal (all as mg/kg dry weight)							
Arsenic	145	52.3	61.2	86.2	145	70 mg/kg *in Littorina littorea* from Restronguet Creek (Bryan et al, 1985)	
Cadmium	2.16	1.57	4.21	2.65	4.21	210 mg/kg in *Littorina littorea* from Clevedon (Severn estuary) Bryan & Gibbs, 1983). 13.2 mg/kg in *L. littorea* from the Thames (Grays) (Bryan et al, 1985). 4.5 mg/kg in *L. littorea* from Restronguet Creek (Bryan et al, 1983).	
Chromium	5.98	2.69	2.51	3.73	5.98	1.6 mg/kg in *Littorina littorea* from Mersey estuary (Bryan et al, 1985)	
Copper	1380	233	494	702	1380	1375 mg/kg in *Littorina littorea* from Restronguet Creek (Bryan et al, 1983). 249 mg/kg *in L. littorea* at Penarth (Ireland & Wootton, 1977). 98.6 mg/kg in *L. littorea*, Orwell (Wright & Mason, 1999).	
Iron	5010	2310	2130	3150	5010	1285 mg/kg *Littorina littorea* from Restronguet Creek (Bryan et al, 1983).	
Lead	14.7	9.19	9.22	11.0	14.7	70 mg/kg in *Littorina littorea* from West Looe (Bryan & Gibbs, 1983). 27.0 mg/kg in *L. littorea* from Restronguet Creek (Bryan et al, 1983). 15.0 mg/kg in *L. littorea* at Penarth (Ireland & Wootton, 1977).	
Manganese	207	127	205	180	207	158 mg/kg in *Littorina littorea* from Restronguet Creek (Bryan et al, 1985). 94.6 mg/kg in *L. littorea*, Orwell (Wright & Mason, 1999). 59.8 mg/kg *in L. littorea* at Penarth (Ireland & Wootton, 1977).	
Mercury	0.182	0.121	0.072	0.125	0.182	1.48 mg/kg in *Littorina littorea* from Mersey estuary (Bryan et al, 1983). 0.99 mg/kg in *Littorina littorea*, Orwell (Wright & Mason, 1999).	
Nickel	6.94	5.66	5.69	6.10	6.94	19.1 mg/kg in *Littorina littorea*, Orwell (Wright & Mason, 1999). 15.3 mg in *L. littorea* from Restronguet Creek (Bryan et al, 1983).	
Strontium	119	65.9	220	135	220	Very few studies analyse strontium.	
Zinc	221	192	336	249.7	336	956 mg/kg in *Littorina littorea* from Restronguet Creek (Bryan et al, 1983). 274 mg/kg in *L. littorea*, Cardigan Bay, Wales (Ireland, 1973). 186 mg/kg in *L. littorea* at Penarth (Ireland & Wootton, 1977).	

Table 6.8 Summary of metals that are elevated in biota at Hayle.

Metal	*Nereis diversicolor* Harbour ragworm	*Arenicola marina* Lugworm	*Corophium volutator* Amphipod crustacean	*Crangon crangon* Brown shrimp	*Carcinus maenas* Shore crab	*Littorina saxatilis* Rough periwinkle
Arsenic	Yes	Yes	NA	NA	NA	Yes
Cadmium	No	No	NA	Probably	Probably	Probably
Chromium	Yes	NA	NA	Probably	NA	Yes
Copper	Yes	Yes	Yes	Yes	Probably	Yes
Iron	Yes	NA	Yes	NA	NA	Yes
Lead	Probably	Probably	NA	Yes	Yes	Probably
Manganese	Yes	Yes	NA	NA	NA	Yes
Mercury	No	No	NA	No	No	No
Nickel	Probably	No	NA	NA	No	No
Strontium	NA	NA	NA	NA	NA	NA
Zinc	Probably	Probably	Probably	Yes	Probably	Probably

Red highlight metals of greatest concern (As, Cu, Fe and Mn)
Orange highlight also of concern (Cr, Pb & Zn)

APPENDIX 7. FISH POPULATION SURVEY OF COPPERHOUSE POOL, HAYLE

1. SUMMARY

A fish survey was conducted by Aquatonics Ltd and APEM on 7 – 8 September 2010 to provide baseline data on fish utilisation of Copperhouse Pool.

The main survey of the low water pool in Copperhouse Pool on 8 September 2010 used the 'sandeel' seine net that had been used in the previous survey of Copperhouse Pool in 2001. This 45 m x 2.4 m net has 8 mm mesh in the centre, 16 mm inner wings and 36 mm mesh outer wings. Two sweeps were followed by a single sweep with a 25 m x 2.7 m deep, 3 mm mesh net. Additionally, on 7 September an upstream location in Copperhouse Pool was sampled close to high tide using a small seine net (10 m x 2.7 m).

All fish caught were identified and species recorded. Numbers in 0+ (< 5 cm), >0+ to 15 cm, 15 – 30 cm and > 30 cm size categories were recorded. Length measurements were taken for a sub-sample of 30 to 50 fish of each of the main species.

A total of eight species of fish represented by more than 4000 individuals were recorded. The species composition and age distribution of fish caught in the survey demonstrate that Copperhouse Pool is an important nursery area for several fish species.

The dominant age cohort for the catch was 0+ fish (2010 recruits). The very large numbers of the young of year (0+) Golden Grey Mullet, *Liza aurata* and Sand Smelt, *Atherina presbyter* are particularly noteworthy. Sea Bass and Flounder juveniles also make use of Copperhouse Pool.

In terms of biomass, Golden Grey Mullet was the dominant species. With such large numbers of juvenile Golden Grey Mullet in Copperhouse Pool it is possible that the Hayle Estuary Complex is one of the key nursery areas for this species in the South West.

Gobies (*Pomatoschistus* spp.) in the 0+ category occurred in large numbers, but field identifications are difficult. A small sub-sample identified 0+ age category fish as Common Goby and a few larger specimens (1+ age category) as Sand Goby, but small specimens counted in the field are likely to include both species.

The species mix was compared with results for the previous survey of fish in Copperhouse Pool (2001). In terms of biomass, Golden Grey Mullet was the dominant species in both surveys. Sand Smelt, the dominant species in terms of numbers in 2010, was also common in 2001. Less common species varied between surveys: Pilchard and Lesser Weever were not recorded in 2001; Gilthead Sea Bream was not recorded in 2010.

In view of the importance of Copperhouse Pool as a nursery area for Golden Grey Mullet, Sand Smelt and other species such as Sea Bass and Flounder it is important that the proposed new bridge is designed to ensure minimal changes to the flow regime into and out of Copperhouse Pool and through the low water pool.

2. BACKGROUND

Aquatonics Ltd were appointed by Parsons Brinckerhoff Ltd to manage and coordinate a survey to obtain baseline data on fish species utilising Copperhouse Pool, Hayle, in order to inform subsequent development at Hayle. The proposed development involves building a new bridge across the downstream end of Copperhouse Pool. The most recent survey of fish utilising Copperhouse Pool took place almost 10 years ago (1-2 October 2001) and was conducted by the Environment Agency and Aquatonics (then Aquatic Environmental Consultants), using a 'sandeel' seine net. After discussions with Simon Toms from the Environment Agency, we decided to replicate the previous survey as closely as possible to allow comparison of results.

APEM were appointed as sub-consultants to Parsons Brinckerhoff and provided two experienced fish taxonomists for the survey: Adrian Pinder and Stephen Smith, who worked with Anne Smith, Phil Smith, and Jasper Michie from Aquatonics Ltd.

3. METHODS

The main survey of fish of the low water pool at Copperhouse Pool (SW 5589 3772) was conducted on 8 September 2010, starting at approximately 12 noon. This was about 3 hours before the lowest level in the pool, which continues to drain for about 3 hours after the low water mark (11:58 BST at St Ives on 8 Sept 2010). This timing replicated the procedures that had been followed in 2001.

The previous day, on the afternoon of the 7 September, after site reconnaissance and planning had been completed, we examined the fish species at an upstream location on Copperhouse Pool, close to high tide, by taking three small (10 m x 2.7 m) seine samples.

For seine netting of the low water pool on 8 September, we used the 'sandeel' net that was used in the 2001 survey of fish in Copperhouse Pool, having obtained this on loan from the Environment Agency. This 45 m net has a graduated mesh size of 8 mm in the centre panel, increasing to 16 mm in the inner wings and 36 mm in the outer wings. The net had a stated depth of 2 metres but when stretched under its own weight the depth was measured as 2.4 metres. Prior to seining, stop nets with a 3 mm mesh were placed across the side channels, to prevent fish escaping into the channels (Photo 7.1). The seine net was then used to encircle fish prior to drawing them in towards the bank (Photo 7.2).

In practise, some fish (larger mullet in particular) escaped the net by jumping the float line. Also, the depth of the low water pool exceeded the net depth and more active fish could escape beneath the net. It is probable that the profile of the low water pool has changed since 2001. In view of the incomplete capture of fish in the pool in the first sweep, once recorded, these fish were returned to the canalised section of Copperhouse Pool (Photo 7.3) and a second sweep was conducted. Again, fish were returned to the nearby canalised section. Finally a single sweep was performed using a slightly deeper seine net (2.7 m deep x 25 m long) with a smaller mesh size (3 mm). Unfortunately, despite our best efforts to handle fish carefully and keep tanks aerated, we experienced some mortalities of 0+ Sand Smelt caught in the smaller mesh net.

To minimise stress and maximise survival after release of fish, catches were processed as rapidly as possible after landing. All fish landed were transferred to holding bins that were continuously aerated using a portable aeration system and power pack (Photo 7.4). The dissolved oxygen level in the water was recorded at intervals using a portable Hach LDO probe and meter to ensure there was sufficient oxygen availability.

All fish were identified and species recorded. To gain information on size/age categories, we recorded the numbers in each of the following age or size groupings: 0+; >0+ to 15 cm; 15 – 30 cm; > 30 cm. Length measurements were taken for a sub-sample of 30 to 50 fish of each main species, so as to minimise handling times.

Results for the three catches were combined to provide information on the species and size composition of fish in the low water pool.

Photo 7.1. Prior to seine netting two stop nets were placed across channels entering the low water pool.

Photo 7.2. Hauling in the first netting of fish in the low water pool of Copperhouse Pool.

Photo 7.3. Taken at 11.22, showing one of the exits from Copperhouse Pool and the canalised section.

Photo 7.4. Showing two of the aerated bins and recording of catch.

4. RESULTS

4.1 Community structure

A total of eight species of fish represented by 4,491 individuals were recorded (Figure 7.1, Photos 7.5 to 7.9). Sand Smelt, *Atherina presbyter* (Photo 7.5) and Golden Grey Mullet *Liza aurata* (Photo 7.6) dominated the community representing 57.9 % and 35.8 % of the catch respectively. Gobies (*Pomatoschistus* spp.) accounted for most of the remaining catch (5.7 %) and were mainly common gobies (*Pomatoschistus microps*). A small number of Sand Goby were also identified and a few Sea Bass (Photo 7.8), Pilchard, two Flounder (Photo 7.7) and a single Lesser Weever (Photo 7.9).

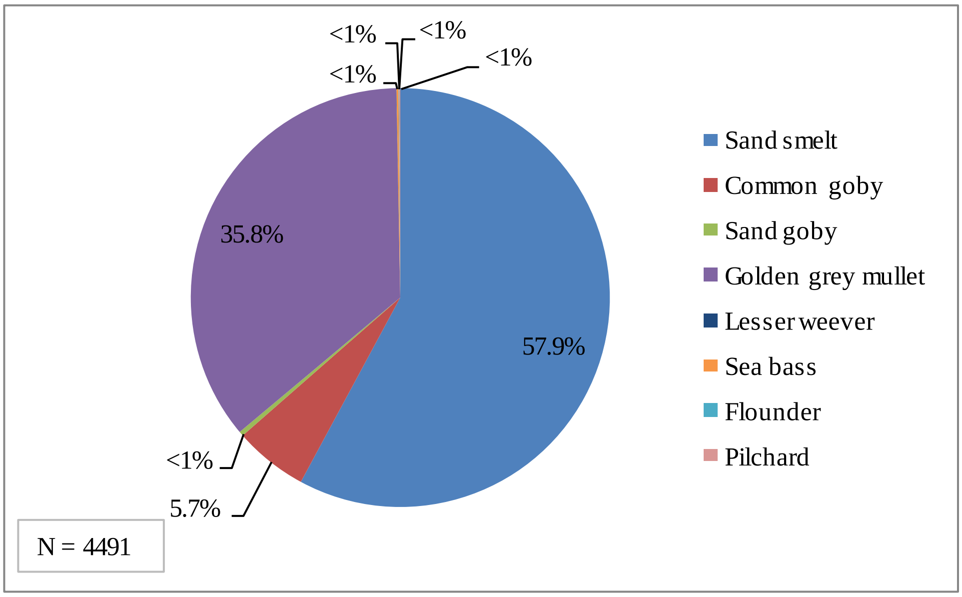


Figure 7.1 Relative species composition of fish caught in the low water pool at Copperhouse Pool, 8th Sept 2010.

4.2 Age cohorts and length frequency histograms

The dominant age cohort for the catch was 0+ fish (2010 recruits). Length frequency histograms for all species are shown in Figures 7.2 and 7.3.

All Sand Smelt and most of the Golden Grey Mullet caught in Copperhouse Pool were less than 5 cm and in the 0+ year group (Table 7.1, Figure 7.2), but 22% of Golden Grey Mullet were older, larger specimens. Length frequency histograms showed four age cohorts for Golden Grey Mullet caught in the survey (0+ to 3+), while Sand Smelt were exclusively from the 2010 year class.

Photo 7.5 Sand Smelt, *Atherina presbyter*, caught in Copperhouse Pool

Photo 7. 6 Golden Grey Mullet, *Liza aurata* caught in Copperhouse Pool

Photo 7.7 Flounder, *Platichthys flesus*, caught in Copperhouse Pool

Photo 7.8 Sea Bass, *Dicentrarchus labrax*, caught in Copperhouse Pool

Photo 7.9 - Lesser Weever, *Echiichthys vipera* caught in Copperhouse Pool

Gobies (*Pomatoschistus* spp.) were not identified to species level in the field. A small sub-sample of fish was examined in the laboratory. Of these, most were small specimens, in the 0+ category, and were identified as Common Goby. A few larger specimens, probably in the 1+ age class, were identified as Sand Goby (Figure 7.2). However, the total number of 0+ common gobies entered in Table 7.1 probably includes some 0+ sand gobies.

Table 7.1 Number of each species caught in seine nets grouped by length (08/09/2010)

Common name	Scientific name	Total numbers				Total
		0+	>0+ <15 cm	15-30 cm	>30 cm	
Sand smelt	*Atherina presbyter*	2,599	0	0	0	2,599
Common goby	*Pomatoschistus microps*	255	0	0	0	255
Sand goby	*Pomatoschistus minutus*	0	16	0	0	16
Golden grey mullet	*Liza aurata*	1,249	351	7	0	1,607
Lesser weever	*Echiichthys vipera*	0	1	0	0	1
Sea bass	*Dicentrarchus labrax*	2	0	5	0	7
Pilchard	*Sardina pilchardus*	0	4	0	0	4
Flounder	*Platichthys flesus*	0	2	0	0	2

4.3 Upper Copperhouse Pool seine netting

Table 7.2 shows the results for seine netting in upper Copperhouse Pool on 7 September 2010. Juvenile Golden Grey Mullet and Sand Smelt were common species in upper Copperhouse Pool.

Table 7.2 Number of species caught in seine nets grouped by length (07/09/2010)

Common name	Scientific name	Total numbers				Total
		0+	>0+ <15 cm	15-30 cm	>30 cm	
Sand Smelt	*Atherina presbyter*	41				41
Golden Grey Mullet	*Liza aurata*	34	49			83
Gobies	*Pomatoschistus* spp.	2				2

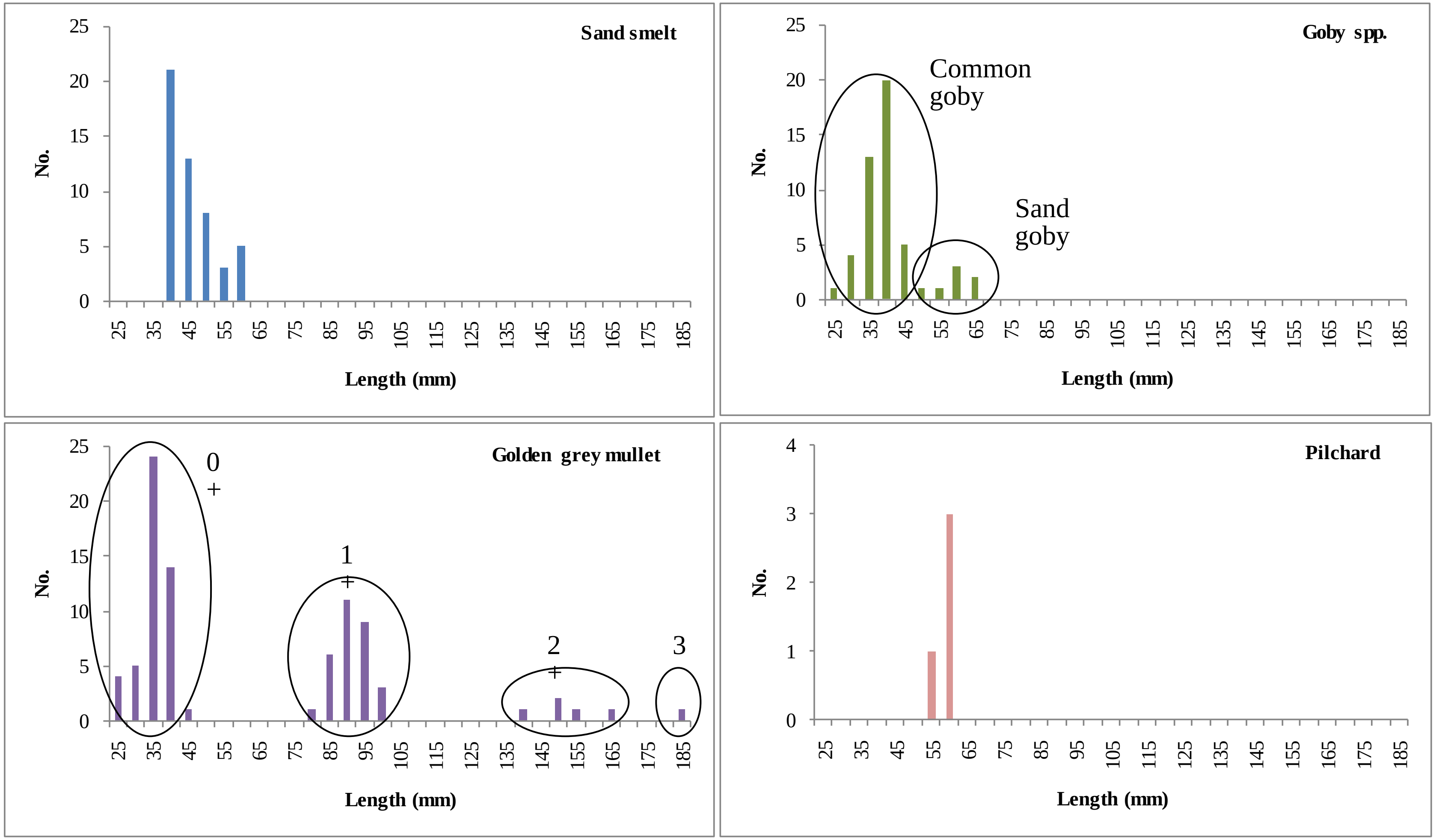


Figure 7.2 Length frequency histograms for Sand Smelt, Golden Grey Mullet, gobies (Common Goby and Sand Goby) and Pilchard caught in the low water pool of Copperhouse Pool on 8 September, 2010.

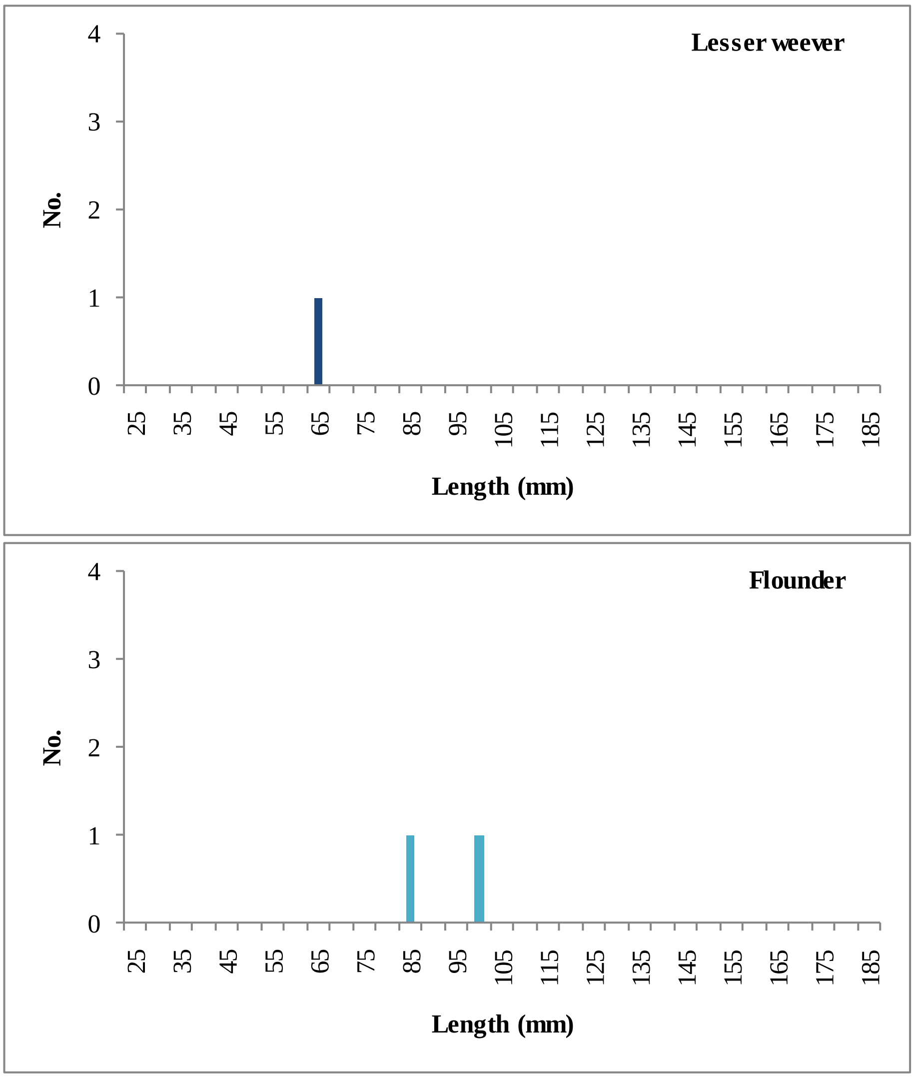


Figure 7.3 Length frequency histograms for Lesser Weever and Flounder in the low water pool of Copperhouse Pool, Hayle on 8 September, 2010.

5. DISCUSSION

The survey of the low water pool in Copperhouse Pool, and opportunistic seine netting on the northern bank of the upstream end of Copperhouse Pool, showed that it provides important intertidal feeding and refuge habitats for fish.

The species composition, age distribution and high numbers of some species caught in the survey demonstrate that Copperhouse Pool is an important nursery area for several fish species. The very large numbers of the young of year (0+) Golden Grey Mullet and Sand Smelt are particularly noteworthy. Gobies, Bass and Flounder juveniles also make use of Copperhouse Pool.

Our survey methods allow comparison of the results with those obtained in the 2001 survey of Copperhouse Pool conducted by the Environment Agency & Aquatonics (Aquatic Environmental Consultants). The results for both surveys are summarised in Table 7.3. No length measurements or information on age classes were collected in 2001 so it is not possible to compare the demographics of the fish caught in the two surveys. However, collection of this information in the 2010 survey will allow such comparisons in future surveys.

Table 7.3 Number of each species caught by seine netting in 2001 (1/2 Oct) and 2010 (8 Sept).

Common name	Scientific name	Number 2001	Number 2010
Sand Smelt	*Atherina presbyter*	20 to 30	2,599
Common Goby	*Pomatoschistus microps*	0	255
Sand Goby	*Pomatoschistus minutus*	>1000	16
Golden Grey Mullet	*Liza aurata*	>1000	1,607
Thick-Lipped Grey Mullet	*Chelon labrosus*	30 to 40	0
Lesser Sandeel	*Ammodytes tobianus*	Approx 300	0
Sea Bass	*Dicentrarchus labrax*	30 to 50	7
Gilthead Sea Bream	*Sparus auratus*	10	0
Pilchard	*Sardina pilchardus*	0	4
Lesser Weever	*Echiichthys vipera*	0	1
Flounder	*Platichthys flesus*	1 (or plaice)	2

The total number of fish caught in the 2 surveys is fairly similar given the approximations of numbers in the catch in 2001 and the probable escape of larger specimens in 2010. In each survey, 8 species were recorded although there were some differences between species present (Table 7.3). In particular, Gilthead Sea Bream and Sandeel were not recorded in the recent survey of Copperhouse Pool, but were identified in 2001, while Pilchard and Lesser Weever were not recorded in the previous survey of Copperhouse Pool.

5.1 Golden Grey Mullet

Golden Grey Mullet occur frequently around the South West and Welsh coasts in estuaries and shallow bays, where they are important in recreational fishing and are fished commercially, although the fishery is less commercially valuable than the Bass fishery.

Copperhouse Pool provide an ideal habitat for species of mullet which feed on mouthfuls of mud and seaweeds, which they filter out on their gills before swallowing the worms, crustaceans and seaweed. On the channel side of the low water pool, rocks and associated algae will also provide suitable food for mullet that scrape off algae and diatoms from rocks.

Our survey showed that Copperhouse Pool is an important nursery area for Golden Grey Mullet. Three different year classes were identified (see Figure 2) but most were the young of year (0+) and 1+ fish. Golden Grey Mullet was co-dominant in the fish community identified in the 2010 survey and similar numbers were found in the 2001 survey (Table 7.3). In terms of biomass Golden Grey Mullet was the dominant species. With such large numbers of Golden Grey Mullet in Copperhouse Pool it is possible that the Hayle Estuary Complex is one of the key nursery areas for this species in the South West.

In 2001, a small number of Thick-Lipped Mullet were also identified in Copperhouse Pool (Table 7.3) but the 2010 survey did not identify any Thick-Lipped Mullet in the catch. However, some mullet escaped over the float and probably further fish escaped beneath the lead line, so Thick-Lipped Mullet may have been present, but not recorded.

5.2 Sand Smelt

Sand Smelt are a common estuarine and inshore fish and young fish typically occur in dense schools.

In the recent survey (8 Sept 2010**),** juvenile Sand Smelt (0+ age group) were the dominant species (in numbers), and were also common in the upstream survey the previous day. In contrast, only small numbers were caught in the 2001 survey (Table 7.3). The Sand Smelt were mainly caught in the final sweep with the 3 mm micromesh seine. Although this sweep revealed the full importance of Copperhouse as a nursery area for Sand Smelt, there were some mortalities.

5.3 Gobies

Gobies were identified in reasonable numbers in both 2001 and 2010 surveys (Table 7.3) and can therefore be expected to occur on a regular basis in Copperhouse Pool.

The dominant species in 2010 was the Common Goby which has greater tolerance of low salinities whereas the 2001 survey recorded only Sand Goby. However, the two species are difficult to tell apart in field conditions, especially for 0+ which dominated the catch in 2010. Comparison of pooled numbers of gobies in 2001 and 2010 is probably more reliable than comparisons for individual species. The number of gobies caught in 2010 was less than in 2001 but this could reflect the fact that the net did not reach the seabed over the complete sweep. Gobies tend to sit on the sediment and those in the centre of the pool could easily have escaped the sweep.

5.4 Sea Bass

Sea bass are an important fish for anglers and commercial fishermen and a series of designated inshore nursery areas have been set up to allow the slow-growing bass to gain protection from fishing pressures while they are in their nursery area (Pickett et al., 1995). The Hayle Estuary is not currently a designated (protected) nursery area for Sea Bass. However, the results for the 2010 survey of Copperhouse Pool and for the earlier 2001 survey indicate that Copperhouse Pool has importance as part of the nursery area for Sea Bass in the Hayle Estuary.

A small number of juvenile Sea Bass (7 individual fish) were caught in the 2010 survey of Copperhouse Pool, while 20-30 juvenile bass were caught in the 2001 survey. The fork lengths of the Sea Bass caught in the 2010 survey, assessed against age-length relationships for Sea Bass, indicates that 5 of the fish were 2+ (body lengths 156 to 164 cm) and 2 were young of this year (6.1 and 6.6 cm). Such young Sea Bass will probably remain in

Copperhouse Pool or the wider Hayle Estuary Complex for several years. It is likely that larger Bass (3+ and possibly 4+ fish) were also present in Copperhouse Pool during our survey, but avoided capture. Bass are carnivorous fish and 2+ juveniles are likely to be feeding on the smaller juvenile fish, such as the 0+ Sand Smelt, Golden Grey Mullet and gobies identified in our survey, as well other species such as the shore crab, *Carcinus* (Kelley, 2002) that is readily available in the Hayle Estuary complex.

5.5 Gilthead Sea Bream

Juvenile Gilthead Sea Bream were caught in Copperhouse Pool in the 2001 survey (Table 7.3), but none were caught in the 2010 survey. Gilthead Sea Bream are uncommon in Northern waters but were first reported in Hayle in 1970, at East Quay (Fahy et al., 2005), where it was thought to be at the northern limit of its range. Their typical location includes lagoons, saline ponds and estuarine marshes of variable salinity, so Copperhouse Pool is a suitable habitat. Since 2001, numbers have generally increased in South West estuaries (e.g. Fal, Helford and Fowey) so despite their absence from the recent survey, it is probable that Gilthead Sea Bream will occur from time to time in the Hayle estuary and will enter Copperhouse Pool.

6. REFERENCES

Aquatic Environmental Consultants (2001). Fish Population Survey of Hayle Harbour, Copperhouse Pool and Lower Lelant Water, October 2001.

Fahy, E, Green, P & Quigley, DTG. (2005). Juvenile *Sparus auratus* L. on the south coast of Ireland. Journal of Fish Biology, Volume 66, 283-289.

Kelley, DF (2002). Abundance, growth and first winter survival of young bass in nurseries of south-west England. Journal of the Marine Biological Association UK, Volume 82, 307-319.

Pickett, GD, Eaton, DR, Cunningham, S, Dunn, MR, Potten, SD & Whitmarsh, D (1995). An appraisal of the UK bass fishery and its management. Laboratory Leaflet No 75. Ministry of Agriculture Fisheries and Food, Directorate of Fisheries Research.

Wheeler, A, Blacker, RW, Pirie, SF (1975). Rare and little-known fishes in British seas in 1970 and 1971. Journal of Fish Biology, Volume 7, 183-201.