Technical Annex 12I Aquatic Ecology of The Hayle Complex

AQUATIC ECOLOGY OF THE HAYLE COMPLEX

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1. INTRODUCTION

This report summarises the aquatic ecology of the Hayle estuary complex. The faunal groups considered are algae (seaweeds), macroinvertebrates (ie invertebrates visible to the naked eye) and fish.

The Hayle estuary complex (Lelant Water, Hayle Harbour, Penpol, Carnsew Pool and Copperhouse Pool) is the most south-westerly estuary in Britain. It is relatively shallow and sheltered. These five distinct areas together make up a varied mosaic of estuarine and marine habitats. St Ives Bay has also been considered in the Environmental Impact Assessment, but the only possible ecological impacts there are through alteration of nursery habitats for fish in the Hayle estuary complex. These are addressed in Chapter 12 of the Environmental Statement. Very recently the possibility of beach nourishment using clean dredged sands from parts of Hayle harbour have been raised. This would also have an impact on localised areas of St Ives Bay close to the beach nourishment works.

1.1 Historical Use and Sluicing Lagoons

The history of Hayle in relation to aquatic ecology is examined in a report prepared for the Nature Conservancy Council (Gill, 1989). A report by Sea Sediments (1983) provides background information on the historical sluicing regime. Information on the industrial history and archaeology of Hayle is contained in Section 10 of the Environmental Statement.

The Hayle estuary complex has several man-made features that influence its aquatic ecology. The most important of these features are the two sluicing pools (Copperhouse and Carnsew) which were built in the late 18th century (Copperhouse by the Cornish Copper Company, completed in 1788) and early 19th century (Carnsew by Harveys of Hayle in 1833) to keep the harbour area free of sediment (Vale, 1966; Sea Sediments, 1983). Other important man-made features are the harbour spit of Middle Weir (1819), the Copperhouse Canal (1769/87) and the large areas of vertical stone walls in the harbour, Penpol and elsewhere.

1.2 Metal Contamination

Another anthropogenic factor which influences aquatic ecology in the Hayle area is its industrial history, which peaked during the 18th and 19th centuries. Hayle was home to two of the three largest early 19th century mine engine foundries in the world (Harvey's 1779-1903 and Copperhouse 1820-1869). Harvey's helped produce the largest steam engines ever built (Cornwall Archaeological Unit, 2000).

There was metal mining in the watersheds, smelting of copper and iron in Hayle, iron foundries in Hayle and import of large quantities of coal (Vale, 1966). Copper smelting produced large amounts of slag which was cast into blocks known as "scoria" which were offered free to workers (www.cornish-mining.org.uk/sites/cpprhs.htm). These scoria blocks can be seen in many buildings in Hayle (especially around Copperhouse Pool) and other in other structures such as Black Bridge. The legacy of this industrial history is still apparent in the high concentrations of metals in sediments, especially Copperhouse Pool (Smith, 1988) and the large amounts of metal-rich slag from copper smelting and Harvey's foundry on the shore in many areas.

The impact of contaminants on the ecology of the Hayle estuary complex is considered in detail in section 7.

1.3 Salinities

Salinity measurements have not been made on a systematic basis in the Hayle complex. It is likely that many areas (e.g. Carnsew Pool, most of Copperhouse Pool and most of the harbour) only experience salinities that are close to full strength seawater (approximately 34 psu) due to the low volume of freshwater in relation to the volume of seawater present. Areas with reduced salinity occur near to freshwater inputs:

- upper part of Penpol
- along the channel cut by Mill Leat in Copperhouse Pool,
- in Copperhouse Canal (Angarrack stream)
- upper reaches of Lelant Water and along the channels cut by the River Hayle and minor tributaries though Lelant Water.

1.4 Sediments

Sediments in the Hayle complex are very varied, ranging from fine silts in parts of Copperhouse Pool, Carnsew Pool and Penpol, though muddy sands and muddy gravels to clean sands in the harbour area. This variety of sediment types and variations in salinities would normally be expected to result in a high overall diversity, but contamination (especially by metals such as arsenic, copper and zinc) prevents colonization by many invertebrates.

1.5 Factors Affecting Distribution of Estuarine and Marine Species

The main factors that affect the distribution of estuarine and marine invertebrates and algae are:

- Salinity
- Sediment or substratum type (particle size and organic content)
- Turbidity or amount of suspended solids
- Currents
- Exposure to waves
- Height on the shore or depth in relation to light penetration
- Temperature, especially extremes

- Pollution by metals, tributyl tin, organic enrichment, hydrocarbons etc
- Introduction of alien species via shipping (eg in ballast water)
- Disturbance due to human activities, e.g bait-digging, dredging and fishing

The interactions of these factors produce a huge variety of estuarine and marine biotopes, which grade into each other. Although marine ecologists can describe the distributions of biotopes in relation to the factors listed above it is much more difficult to make accurate predictions about the biotopes that will occur under a new scenario. For example the change from a unconsolidated sandy sediment to one with a small amount of mud present results in a large increase in diversity and biomass, but it may be difficult for physical and numerical models of sediments to show a subtle change.

2. DESCRIPTION OF THE MAJOR SUB-UNITS

2.1 Lelant Water

Lelant Water is the most natural of the sub-units, and comprises intertidal mudflats and sandflats and a small amount of subtidal habitat (the low water channel of the Hayle River and minor tributaries). Prior to 1828 Lelant Water was much larger than it is today and would have included larger areas of upper mudflats and saltmarsh (Sea Sediments, 1983). It has been suggested that there was little accumulation of sediment in Lelant Water in the period from 1848 to 1983 (Sea Sediments, 1983). The main habitats are:

- Saltmarsh, especially near Lelant Saltings
- A fringe of boulders and cobbles around some of the periphery, eg next to Carnsew
- Intertidal mudflats
- Intertidal sandflats
- Subtidal sediments, mainly clean sands

Salinities may be quite low in the upper reaches during periods of neap tides and high freshwater flows.

2.2 Hayle Harbour

Hayle Harbour supports the following habitats:

- Vertical harbour and quay walls (collapsed in places)
- Steep cobbles and boulders on parts of the upper shore
- Intertidal sands, including Cockle Bank
- Subtidal sediments, mainly clean sands, but also tidal rapids over rocks near Carnsew Pool

Clean sands in the outer harbour area were examined by the Oil Pollution Research Unit (Gill, 1989). They found a very sparse fauna, dominated by the spionid polychaete worm

Pygospio elegans. There were also a few oligochaete worms and the isopod crustacean *Eurydice pulchra*.

A recent survey of clean sands in the outer harbour has revealed a more diverse fauna, possibly due to the larger number of sampling sites (Aquatonics Ltd, 2007b). Species present included sand-eels (*Ammodytes tobianus*), catworm (*Nephtys cirrosa*), *Pygospio elegans*, and toothed Pirimela crab (*Pirimela denticulata*).

2.3 Penpol

Penpol was originally a sandy creek where the Penpol River (Mellanear Stream) discharged into the estuary (Sea Sediments, 1983). The present shape of Penpol was formed when South Quay was built in 1819 and East Quay shortly afterwards. Bed levels in Penpol in a survey in 1983 were similar to those in 1848 (Sea Sediments, 1983).

Penpol is a linear, man-made estuarine habitat, with quay walls on the western side and intertidal muds and gravelly muds on the east bank. The freshwater input if from the Mellanear Stream, which drains a relatively small catchment. Although metal contamination from this stream has not been assessed it is likely to be lower than from the Angarrack, Mill Leat or Hayle River.

The main habitats in Penpol are:

- Vertical quay walls (on the western side)
- Cobbles and boulders (upper shore on the eastern side)
- Intertidal muds and gravelly muds (upper to lower shore on the estern side)
- Subtidal sediments in the low water channel

2.4 Carnsew Pool

Carnsew Pool was constructed by Harveys of Hayle in 1833 as a sluicing pool to keep the harbour free of sediment. Water currently enters and leaves Carnsew Pool through tunnels, and there is a cill on the Carnsew side of the tunnels. There is currently no ability to sluice from Carnsew Pool. Salinities are virtually fully marine as there are no freshwater inputs. The main habitats are:

- Permanent subtidal area in the NE part, towards the cill. This includes areas with water depths of -4.0m ODN, compared to a retained tidal level of + 0.2 m ODN. Near the cill there are tidal rapids.
- Intertidal mudflats, especially in the NW part of Carnsew Pool
- Intertidal sand, occurs in patches near the cill and tunnels and as a larger area on the north bank, close to high water.
- A small area of sedimentary saltmarsh (*Salicornia* spp and *Suaeda maritima*) on the upper shore at the NW corner.
- Intertidal cobbles and boulders, forming a continuous band around Carnsew Pool

Due to the throttling effect of the tunnels the high water levels in Carnsew never reach those in the unconfined harbour. On a high water spring (HWS) tide levels are approximately 600 mm lower in Carnsew Pool than in the harbour or Lelant Water. The throttling effect of the tunnels delays the time of high water in Carnsew, by approximately 77 minutes on a HWS tide. Low water levels in Carnsew Pool are never as low as those found in the harbour, due to the cill, which is at approximately 0.2 m ODN.

Carnsew Pool contains the deepest area of permanent water in the Hayle complex and this combined with the high salinity and sheltered conditions makes it an excellent nursery area for many species of marine fish.

The survey by OPRU (Gill 1989) found that the most diverse communities were close to the Carnsew cill (referred to as a weir in their report). The OPRU report includes the following description of the cill area, which is included in detail as it is probably the most diverse area for invertebrates and algae:

"Within the Hayle estuary, algal species that were unique to the scoured weir lip at Carnsew Pool were *Laminaria digitata*, *Cladostephus spongiosus*, and Rhodophycota such as *Palmaria palmata*, *Chondrus crispus*, *Lomentaria clavellosa*, *Plumaria elegans*, *Hypoglossum hypoglossoides* and Corallinaceae indet. Lower shores supported *Balanus crenatus*, large specimens of *Mytilus edulis*, and *Anomia* spp. beneath stones. The algae provided cover for animals such as amphipods, littorinids and *Carcinus maenas*. Lobes of the bryozoans *Alcyonidium gelatinosum* were evident on all lower shores, with *Umbonula littoralis*, *Bowerbankia imbricata*, *Cryptosula pallasiana* and the hydroid *Obelia geniculata* only occurring at the Mid-Channel Pier. Other species that were unique to the weir lip of Carnsew Pool were *Balanus perforatus*; *Spirorbis spirorbis and S. inornatus*; the bryozoans *Alcyonidium hirsutum*, and *Electra pilosa*; the hydroid *Aglaophenia pluma* and the sponges *Hymeniacidon perleve* and *Leucosolenia botryoides*."

2.5 Copperhouse Pool

Copperhouse Pool was constructed by the Cornish Copper Company as a sluicing reservoir to keep the harbour free of sand. The basin, canal and sluice gates at Ventonleague were constructed prior to 1758 (Sea Sediments, 1983). Construction of the sluice at the entrance to Copperhouse Pool was completed in 1788. Copperhouse Pool sediments are highly contaminated with metals such as arsenic, copper and zinc. The two freshwater inputs (Angarrack Stream and Mill Leat) are still contaminated by metals such as arsenic. Considerable sedimentation has occurred in Copperhouse Pool, so that the higher parts are only covered on spring tides. The timing of the main period of sedimentation is disputed, many people think it is relatively recent but it has also been argued that it was probably prior to 1834 (Sea Sediments, 1983).

The main habitats in Copperhouse Pool are:

- Vertical walls on the upper shore
- Saltmarsh
- Boulders and cobbles fringing the perimeter and along the Angarrack Canal
- Mudflats
- Raised areas of intertidal with a very sparse invertebrate fauna (mainly enchytraeid worms) and large quantities of green filamentous algae (including *Enteromorpha* spp).
- Angarrack Canal subtidal habitat
- Mill Leat subtidal habitat, including an almost permanent pool near the sluice gate

3. BIOTOPES PRESENT

3.1 Biotope Classification

Biotopes are habitats and their associated biological communities. Each JNCC biotope code is a combination of substrate type and characterising species. In the Hayle estuary the substrate types are:

LR	Littoral Rock (i.e. intertidal rock)
IR	Infralittoral Rock (i.e. shallow subtidal rock)
LS	Littoral Sediments (i.e. intertidal sediments)
SS	Sublittoral Sediments (i.e. subtidal sediments)
X	Mixed Substrata

Other abbreviations used in relevant JNCC biotope codes include:

Asc	*Ascophyllum nodosum* (knotted wrack)
B	Barnacles
Bar	Barren
Cer	*Cerastoderma edule* (cockle)
Cir	Cirratulids (a group of sedentary polychaete worms)
Cvol	*Corophium volutator* (an amphipod crustacean)
Ent	*Enteromorpha* spp. (a green alga)
Eph	Ephemeral
FS	Full salinity
Fserr	*Fucus serratus* (serrated wrack)
Fspi	*Fucus spiralis* (spiral wrack)
Fves	*Fucus vesiculosus* (bladder wrack)
Hed	*Hediste diversicolor* (ragworm, also known as *Nereis diversicolor*)
Mac	*Macoma balthica* (Baltic tellin, a bivalve)
Mo	Mobile
Mu	Mud
Mus	Mussels
Ol	Oligochaete worms
Pel	*Pelvetia canaliculata* (a fucoid seaweed)

Sa	Sand
Scr	*Scrobicularia plana* (peppery furrow shell)
Sem	*Semibalanus balanoides* (a barnacle)
St	Strandline
Str	*Streblospio shrubsolii* (a sedentary polychaete worm)
T	Tideswept
Tal	Talitrids (sand-hoppers)
UEst	Upper estuarine

3.2 Biotopes Recorded in Intertidal and Inshore Regions of St Ives Bay

Intertidal biotopes on the beach at Hayle have been assessed as part of the Environmental Impact Assessment of the proposed Wave Hub (Emu Ltd, 2005). Subtidal biotopes in St Ives Bay have been assessed in a report by Halcrows (2006) as part of the Wave Hub EIA. The main intertidal and shallow subtidal biotopes in St Ives Bay are described below.

3.2.1 Shallow Subtidal Biotopes in St Ives Bay

Shallow subtidal biotopes on the most inshore part of the cable route were:

SS.SSA.IFiSa.IMoSa Infralittoral mobile clean sand with sparse fauna. Moderately well-sorted medium sand at a depth of about 5m, very exposed to waves. This biotope was found at the most inshore site on the cable route. It was characterised by a low diversity faunal community comprising the polychaetes *Nephtys cirrosa*, *Paraonis fulgens* and *Magelona filiformis,* the amphipod *Urothoe brevicornis* and the bivalve *Angulus tenuis.*

SS.SSA.IFiSaNCirBat *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand. Moderately well to well sorted fine sand, often formed into waves or ripples, at a depth of 14-20m and exposed or very exposed to waves. This biotope was characterised by sparse infaunal communities dominated by the amphipods *Urothoe poseidonis* and *Bathyporeia* spp. and polychaetes of the genus *Magelona*. The epifauna community associated with the biotope was dominated by sand gobies and sole. This biotope occurred on the proposed cable route, immediately offshore from SS.SSA.IFiSa.IMoSa (see above).

The Halcrow report (2006) also describes a biotope complex (SS.SMX.CMx - circalittoral mixed sediment) in some shallow (22 to 28m) parts of the nearshore cable route. This complex comprised SS.SMX.OMx Offshore circalittoral mixed sediment overlain by SS.SCS.CCS.PomB *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles. The substrate was pebbles, often with considerable amounts of shell. This biotope was characterised by very high densities of the porcelain ‘crab’ *Pisidia longicornis* and of epilithic tube-building polychaetes of the family serpulidae (mainly *Pomatoceros triqueter*). Other taxa found in abundance included the polychaetes *Typosyllis* spp., *Harmothoe* spp., *Polydora caeca* and the amphipods *Corophium sextonae* and *Leptocheirus tricristatus*. The epifauna recorded from the trawl samples was dominated by *P.*

longicornis and the brittle star *Ophiothrix fragilis*, although the sea urchin *Psammechinus miliaris*, queen scallop *Aequipecten opercularis* and spider crab *Inachus phalangium* were also regularly recorded.

3.2.2 Intertidal Biotopes on Hayle Beach

The survey by Emu Ltd (2005) showed that the intertidal area to the east of the mouth of the Hayle estuary was an extensive sandy beach with no evident boundaries between upper, mid and lower shore. No obvious biota were present (e.g. burrows, casts) and on site digging revealed no anoxic layer, nor change in sediment type below the surface. The biotope was most similar to LS.LSa.MoSa barren or amphipod dominated mobile sand shores. The sands contained little very fine sand and no mud. The sands were not cohesive with little water retention (Emu Ltd, 2005).

The upper-shore was characterised by dry compact sand delimited by sand dunes or bedrock. Scattered stranded seaweeds were present on the upper-shore at the time of the survey but were not considered to constitute a real strandline. No marine infauna were recorded from the upper-shore cores; only a surface dwelling collembolan was found.

On the mid shore, the sand became more wet and rippled. Most of the invertebrates in the core samples were polychaete worms. The lower shore was characterised by very wet sand and deep ripples. The bivalve mollusc *Spisula solida* was recorded in situ on the eastern edge of the estuary, and analysis of the core samples revealed a macro-fauna comprising mainly crustaceans (*Pontocrates arenarius* and *Eurydice pulchra*). Copepods and polychaetes (*Nephtys cirrosa*) were also recorded but in low number (Emu Ltd, 2005).

A fucoid community was recorded on the eastern edge of the estuary at the western boundary of the survey area. The substrate was patches of pebbles, cobbles and boulders overlying sand. The biotope LR.LLR.F.FvesFS was recorded on boulders and cobbles which supported dense population of *Fucus vesiculosus* and *F. vesiculosus* var. *linearis*. The green alga *Enteromorpha* sp. was also recorded in low abundances and scattered plants of *F. serratus* and *Chondrus crispus* occurred at the edge of the estuary. Under-storey fauna included limpets (*Patella vulgata*), barnacles (*Balanus crenatus, Elminius modestus*), flat periwinkles (*Littorina obtusata*) and shore crabs (*Carcinus maenas*). The whole area appeared as a raised platform at the mouth of the estuary, therefore fairly current swept. As a consequence, the surrounding sand appeared dimpled with dimples inter-connected via small channels with permanent tidal flow. Seaweeds recorded in these channels included red (*Polysiphonia denudata, Ceramium rubrum, C. shuttleworthianum, Gelidium pusillum*) and brown (*Hincksia granulosa, Scytosiphon lomentaria, Laminaria saccharina*). Visible fauna on the sandy sediment included serpulid tubeworms (*Pomatoceros* sp.) and sandmason worms (*Lanice conchilega*). Due to the limited extent of the channels, they were not considered to constitute a separate biotope in the study (Emu, 2005).

3.3 Biotopes Recorded in Surveys in the Hayle Complex

In the most recent surveys at Hayle (Smith, 2000 and Aquatonics Ltd, 2007a and 2007b) biotopes were assessed using the biotope classifications produced by the Joint Nature Conservation Committee (JNCC). The latest version of the JNCC biotope classifications is available on the internet (Connor et al, 2004).

The January 1989 survey (Smith, 1989a) pre-dated the biotope definitions. Biotope matching for the results from this survey is approximate as the survey concentrated on invertebrates; algae were not recorded in detail.

The following biotopes have been recorded during the surveys for the proposed harbour development:

Strandline, Mixed Substrates and Hard Substrates

LS.LSa.St.Tal	Talitrids on the upper shore and strandline.
LR.LLR.F.Pel	*Pelvetia canaliculata* on sheltered littoral fringe rock
LR.MLR.BF.PelB	*Pelvetia canaliculata* and barnacles on moderately exposed littoral fringe rock
LR.FLR.Eph.Ent	*Enteromorpha* spp. on freshwater-influenced and/or unstable upper eulittoral rock
LR.LLR.F.Fspi.X	*Fucus spiralis* on full salinity upper eulittoral mixed substrata
LR.LLR.F.Fves	*Fucus vesiculosus* on moderately exposed to sheltered mid eulittoral rock
LR.LLR.F.Fves.X	*Fucus vesiculosus* on mid eulittoral mixed substrata
LR.HLR.MusB.Cht.Cht	*Chthamalus montagui* and *Chthamalus stellatus* on exposed upper eulittoral rock
LR.HLR.MusB.Sem.Sem	*Semibalanus balanoides*, *Patella vulgata* and *Littorina* spp. on exposed to moderately exposed or vertical sheltered eulittoral rock
LR.LLR.F.Asc.X	*Ascophyllum nodosum* on full salinity mid eulittoral mixed substrata
LR.LLR.F.Asc	*Ascophyllum nodosum* on very sheltered mid eulittoral rock
LR.LLR.F.Fserr	*Fucus serratus* on sheltered lower eulittoral rock
IR.MIR.KT.LdigT	*Laminaria digitata*, ascidians and bryozoans on tide-swept sublittoral fringe rock
IR Unmatched	Tidally scoured bedrock in harbour below Carnsew Weir

Soft Sediments Sampled with Corer

LS.LSa.MoSa.BarSa	Barren littoral coarse sand
LS.LSa.MoSa.Ol.FS	Oligochaetes in full salinity littoral mobile sand
LS.LSa.MoSa	Barren or amphipod dominated mobile sand shores
LS.LSa.MoSa.AmSco.Eur	*Eurydice pulchra* in littoral mobile sand

LS.LSa.FiSa.Po.Ncir	*Nephtys cirrosa* dominated littoral fine sand
LS.LMu.UEst.Hed.Ol	*Hediste diversicolor* and oligochaetes in littoral mud
LS.LMu.UEst.Hed.Str	*Hediste diversicolor* and *Streblospio shrubsolii* in littoral sandy mud
LS.LMu.UEst.Hed.Cvol	*Hediste diversicolor* and *Corophium volutator* in littoral mud
LS.LSa.MuSa.BatCare	*Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand
LS.LMx.Mx.CirCer	Cirratulids and *Cerastoderma edule* in littoral mixed sediment
LS.LSa Unmatched	Full salinity mobile sand dominated by *Pygospio elegans*
LS.LSa Unmatched	Full salinity mobile sands with *Capitella capitata* and oligochaetes
SS.SMu Unmatched	Full salinity sheltered sublittoral mud with *Arenicola marina*
SS.SMuMx Unmatched	Mixed subtidal sediments in Carnsew Pool
SS.SSA.IFiSa.IMoSa	Infralittoral mobile clean sand with sparse fauna

Each of these is considered below. Comments on how common the biotope is in the UK are from our interpretation of the distribution map for each biotope on the JNCC web site.

3.3.1 Strandline, Mixed Substrates and Hard Substrates

LS.LSa.St.Tal Talitrids on the upper shore and strandline

Strandlines in the Hayle complex occur on sheltered sloping shores in areas such as Lelant Water, Carnsew Pool and Copperhouse Pool. These strandlines support a relatively low diversity of species, including two species of sand-hopper (*Orchestia mediterranea* and *O. gammarellus*) and the sea-slater *Ligia oceanica* (Smith, 1989; Smith, 2000; Aquatonics Ltd, 2007a). Other taxa recorded in the standlines include staphylinid beetle larvae and enchytraeid oligochaetes. On upper shore clean sands near the entrance to the harbour we recorded the talitrid *Talorchestia deshayesii* (Aquatonics Ltd, 2007b)

The JNCC strandline biotope was also the best match for the area of eroding fill that forms a a small cliff along parts of Carnsew Pool (Aquatonics Ltd, 2007a)

In parts of Carnsew Pool where the upper shore is very consolidated fill material the best match with JNCC biotopes was also LS.LSa.St.Tal (Talitrids on the upper shore and strandline) (Aquatonics Ltd, 2007a).

This strandline biotope is very common and is likely to be present in all UK estuaries.

LR.LLR.F.Pel *Pelvetia canaliculata* **on sheltered littoral fringe rock**

Noted in harbour at outlet from Carnsew Pool and in Carnsew Pool in the 2000 survey (Smith 2000) and from a small area in Carnsew in December 2006 (Aquatonics Ltd, 2007a). Likely to occur on parts of the upper shore in Lelant Water. This is a very common biotope and is present in many UK estuaries.

LR.MLR.BF.PelB *Pelvetia canaliculata* **and barnacles on moderately exposed littoral fringe rock**

The only example of this biotope was not a close match, as the substrate was a wooden electricity pole on the shore at Carnsew Pool (Aquatonics Ltd, 2007a). This is a very common estuarine and marine biotope in the UK.

LR.FLR.Eph.Ent *Enteromorpha* **spp. on freshwater-influenced and/or unstable upper eulittoral rock**

This biotope was recorded in the upper reaches of Penpol in the December 2006 survey (Aquatonics Ltd, 2007a). It is a very common estuarine biotope and is relatively species-poor.

LR.LLR.F.Fspi.X *Fucus spiralis* **on full salinity upper eulittoral mixed substrata**

This biotope was recorded at a mid shore site on mixed substrate in Carnsew Pool during the December 2006 survey (Aquatonics Ltd, 2007a). This is a common marine biotope in the UK.

LR.LLR.F.Fves *Fucus vesiculosus* **on moderately exposed to sheltered mid eulittoral rock**

This biotope is widespread in Carnsew Pool and Penpol (Aquatonics Ltd, 2007a) and in Copperhouse Pool (Smith, 2000). This is a common biotope and occurs in most estuaries in the UK.

LR.LLR.F.Fves.X *Fucus vesiculosus* **on mid eulittoral mixed substrata**

This biotope occurs in Carnsew Pool, Penpol and small parts of the harbour (Aquatonics Ltd, 2007a and b). It is likely to occur in parts of Lelant Water that have not been surveyed. This is a common biotope in UK estuaries.

LR.HLR.MusB.Cht.Cht ***Chthamalus montagui*** **and** ***Chthamalus stellatus*** **on exposed upper eulittoral rock**

This biotope was recorded on hard substrates on the Triangular Spit and the harbour wall close to the area proposed for the sand-trap (Aquatonics Ltd, 2007b).

LR.HLR.MusB.Sem.Sem ***Semibalanus balanoides*****,** ***Patella vulgata*** **and** ***Littorina*** **spp. on exposed to moderately exposed or vertical sheltered eulittoral rock**

This biotope was recorded on the lowest part of the harbour wall at the entrance to Penpol in the December 20906 survey (Aquatonics Ltd, 2007a). It is a common estuarine and marine biotope in the UK.

LR.LLR.F.Asc.X ***Ascophyllum nodosum*** **on full salinity mid eulittoral mixed substrata**

This biotope occurs near the outlet of Carnsew Pool into the harbour (Smith, 2000), in Carnsew Pool (Smith, 2000; Aquatonics Ltd, 2007a) and on parts of Triangular Spit (Aquatonics Ltd, 2007b). This biotope is moderately common in the UK, especially in SW England and the west coasts of Scotland.

LR.LLR.F.Asc ***Ascophyllum nodosum*** **on very sheltered mid eulittoral rock**

The survey in February 2000 showed this biotope is widespread in the Hayle complex (Smith, 2000). It was recorded on Cockle Bank, North Quay and Lelant Water near Carnsew Pool. In December 2006 it was also recorded in Penpol (Aquatonics Ltd, 2007a). This is a commonly recorded biotope in the UK where rock or seawalls occur in sheltered parts of the estuary.

LR.LLR.F.Fserr ***Fucus serratus*** **on sheltered lower eulittoral rock**

In the 2000 survey this biotope was recorded in the harbour near the outlet from Carnsew Pool and in Carnsew Pool close to the weir (Smith, 2000). This biotope was also recorded on the extreme lower shore in Carnsew Pool, close to the weir in the December 2006 (Aquatonics Ltd, 2007a). The December 2006 survey showed that this biotope in Carnsew Pool supported a wide range of invertebrates such as bryozoans and amphipod crustaceans. This biotope is moderately common in the UK, provided that there is sufficient shelter from waves.

IR.MIR.KT.LdigT ***Laminaria digitata*****, ascidians and bryozoans on tide-swept sublittoral fringe rock**

This biotope was recorded in Carnsew Pool, adjacent to the weir (Smith, 2000). The substrate was mixed sediment with large boulders and a stone sill. This site experiences full salinity and high currents speeds. The rocks were covered in dense algae, primarily *Laminaria digitata* and *Sargassum muticum*, with red algae, *Ulva lactuca* and *Enteromorpha* spp. Purse sponges (*Grantia compressa*), cushion sponges (primarily *Esperiopsis fucorum*) large mussels (*Mytilus edulis*) and large shore crabs (*Carcinus maenas*) were common in crevices.

The match with the JNCC biotope IR.MIR.KT.LdigT isn't very good due to the absence of ascidians and bryozoans. However, the bryozoans in this biotope encrust the large seaweeds and would probably have been recorded from this site if seaweeds had been brought back for microscopic examination.

The JNCC distribution maps shows that this biotope is unusual in the UK, with most examples being from western Scotland. The example in Carnsew Pool is not as species-rich as expected and is therefore not likely to be considered a good example.

IR Unmatched **Tidally scoured bedrock in harbour below Carnsew Weir**

In the 2000 dive survey the area immediately downstream from Carnsew Weir was examined. The substrate was subtidal bedrock, which was scoured by high tidal currents. It was characterised by a low algal turf with mussels and sponges (*Hymeniacidon perleve* and *Esperiopsis fucorum*), with occasional *Laminaria* sporelings close to the sluice. This biotope did not closely match any of the JNCC biotopes.

3.3.2 Soft Sediments Sampled with Corer

LS.LSa.MoSa.Ol.FS **Oligochaetes in full salinity littoral mobile sand**

In our surveys this biotope has only been recorded in Carnsew, at an upper intertidal site with coarse sand and gravel overlying cobbles (Aquatonics Ltd, 2007a). The diversity of this biotope is low, in the example from Carnsew the only taxa recorded were enchytraeid oligochaete worms, a halacarid mite and several flatworms (possibly *Uteriporus vulgaris*). This biotope is very rarely recorded in southern England or Wales and most records come from NE England and Scotland.

LS.LSa.MoSa **Barren or amphipod dominated mobile sand shores**

A core sample from Carnsew Pool (near the weir) in December 2006 had some similarities to this biotope, though the match was not very good (Aquatonics Ltd, 2007a). The sediment was well-sorted medium sand and densities of the various nemertean, polychaete and oligochaete worms were low. There were no amphipods present.

A core sample from the sand-trap survey (Aquatonics Ltd, 2007b) was also matched to this biotope. This biotope is relatively common in the UK.

LS.LSa.MoSa.AmSco.Eur ***Eurydice pulchra* in littoral mobile sand**

This biotope was only recorded at a single core site in the May 2007 survey of the proposed sand-trap area, but the match wasn't very good. *Eurydice pulchra* is an isopod crustacean that is adapted to living in mobile sands. This biotope is largely restricted to open coasts with mobile sands and in these areas is not uncommon in the UK.

LS.LSa.FiSa.Po.Ncir ***Nephtys cirrosa* dominated littoral fine sand**

This biotope was recorded from one core at the proposed sand-trap location, but the match wasn't complete as the sediment was medium to coarse sand (Aquatonics Ltd, 2007b).

LS.LSa Unmatched **Full salinity mobile sands with *Capitella capitata* and oligochaetes**

Two core samples from sands in the harbour had high densities of the polychaete *Capitella capitata*, an indicator of contaminated or physically disturbed sediments (Smith, 2000). The sand mason worm (*Lanice conchilega*) was also present and moderate densities of oligochaete worms were recorded in one of the samples. It is likely that if metal concentrations were lower other species such as catworm (*Nephtys cirrosa*) and burrowing amphipods would also have been present. Due to the lack of characterizing species it is not possible to match these samples with any JNCC biotopes.

LS.LSa.MoSa.BarSa **Barren littoral coarse sand**

This biotope was recorded from two cores in the proposed sand-trap area (Aquatonics Ltd, 2007b) and in the 2000 survey in Lelant Water near the low water channel (Smith, 2000). The same biotope probably occurs over large areas of Lelant Water towards the mouth of the estuary, and probably mobile sands in the lower reaches of the harbour. In the UK this biotope is recorded from the middle and upper shore of free-draining sandy beaches. The lack of invertebrates means that it is not viewed as being of high conservation interest.

LS.LSa Unmatched **Full salinity clean sand dominated by *Pygospio elegans***

This biotope has been recorded at four sites near North Quay in 1989 (Smith, 1989a) and at sites in Lelant Water in 1989 and 2000 (Smith 1989a; Smith, 2000). Most samples were clean sands, one from Lelant water was muddy sand. Characteristic features were high densities of the spionid *Pygospio elegans* and few other species apart from *Capitella capitata* and enchytraeid oligochaetes. There was no close match with any of the JNCC biotopes.

LS.LSa.MuSa.BatCare ***Bathyporeia pilosa*** **and** ***Corophium arenarium*** **in littoral muddy sand**

This biotope was recorded at a lower shore intertidal site in Lelant Water where the sediment was muddy sand (Smith, 1989a), but the species of *Corophium* was *C. volutator* rather than *C. arenarium.* The latter prefers sandy sediments. This biotope is not very common in the UK. Most examples are from the Severn estuary, west Wales and the NW coast of England.

LS.LMu.UEst.Hed.Ol ***Hediste diversicolor*** **and oligochaetes in littoral mud**

This biotope was recorded in 1989 at single sites in Copperhouse Pool, Carnsew Pool and Lelant Water (Smith, 1989a). In 2000 it was recorded in muddy sediments in Copperhouse Pool (Smith, 2000). In December 2006 it was recorded in suitable muddy sediments in Penpol (Aquatonics Ltd, 2007a). This biotope occurs in the upper muddy reaches of many estuaries in England and Wales.

LS.LMu.UEst.Hed.Str sandy ***Hediste diversicolor*** **and** ***Streblospio shrubsolii*** **in littoral mud**

In the 1989 survey this biotope was recorded at one site in Copperhouse Pool (Smith, 1989a) In 2000 this biotope was recorded in muddy intertidal sediments in Carnsew Pool (Smith, 2000) and in 2006 at one site in Penpol (Aquatonics Ltd, 2007a). This biotope is common in muddy estuaries in England and Wales.

LS.LMu.UEst.Hed.Cvol ***Hediste diversicolor*** **and** ***Corophium volutator*** **in littoral mud**

This biotope is the most common sediment biotope in Copperhouse Pool and was also recorded occasionally in Lelant Water (Smith, 1989a). This biotope is of special importance for wading birds, as the two main species are important prey for wading birds. This is a relatively common biotope in the upper reaches of muddy estuaries in the UK.

LS.LMx.Mx.CirCer **Cirratulids and** ***Cerastoderma edule*** **in littoral mixed sediment**

This biotope has only been recorded in Penpol, in the December 2006 survey (Aquatonics Ltd, 2007a). The core sample was from gravelly mud in the mid to upper reaches of Penpol, on the lower part of the intertidal. The most numerous invertebrates were an undescribed species of cirratulid polychaete worm usually referred to as *Tharyx* sp. A. This species is common in estuaries in southern England and south Wales. There were occasional lugworm (*Arenicola marina*) casts nearby. The core sample included one large cockle (*Cerastoderma edule*). This is an unusual biotope in the UK and most records come from SW Wales and the south coast of England.

SS.SSA.IFiSa.IMoSa **Infralittoral mobile clean sand with sparse fauna**

This biotope was recorded in the low water channel in the proposed sand-trap area (Aquatonics Ltd, 2007b). It is probably also present along the low water channel in Lelant Water.

SS.SMu Unmatched **Full salinity sheltered sublittoral mud with *Arenicola marina***

Dive surveys of Carnsew Pool in 2000 obtained cores from subtidal sediments. Two of the four subtidal sites in Carnsew were from a soft mud plain with numerous lugworm (*Arenicola marina*) casts, occasional shore crabs (*Carcinus maenas*) and snakelocks anemones (*Anemonia viridis*) attached to small stones. The infauna was of low diversity and was dominated by *Tharyx* sp. A and *Capitella capitata* (Smith, 2000).

SS.SMuMx Unmatched **Mixed subtidal sediments in Carnsew Pool**

The deeper area of Carnsew Pool was surveyed in the 2000 survey by divers. A core sample was also obtained (Smith, 2000). The substrate was cobbles, boulders, pebbles and *Mytilus* shells on silty sand. This site supported the most diverse epifauna of the five subtidal sites visited in the 2000 survey. Boulders were covered in a red algal turf, with encrusting and cushion sponges and large numbers of snakelocks anemones (*Anemonia viridis*). The non-native seaweed *Sargassum muticum* was common on large boulders. Carpet anemones (*Cereus pedunculatus*) were common, and *Sagartiogeton undatus* anemones were occasional, within the sediment. Shore crabs (*Carcinus maenas*) and velvet swimming crabs (*Necora puber*) were common. Several large edible crab carapaces were seen, but no live specimens. *Eulalia viridis* worms were common on the sediment. The sediments contained a wide range of infaunal species (including several unusual species), and were the most diverse of the 13 sites surveyed. There was no good match with any of the JNCC Biotopes.

4. CONSERVATION INTEREST

4.1 Definitions

Definitions of International, National, Regional and Local conservation importance are given in Davidson *et al* (1991) and are included below:

“Qualifiers used to express perceived conservation importance:

International

Communities which are outstandingly good examples of their type in the north-east Atlantic. Communities recorded at only a few locations in the north-east Atlantic. Species which are recorded at only a few locations in the north-east Atlantic. Species recorded in higher abundance in the area under consideration than anywhere else in the north-east Atlantic or where the area is one of only a very few locations where large quantities are recorded.

National

Communities which are outstandingly good examples of their type in Britain. Communities recorded in only a very few similar physiographic situations in Britain. Both of these definitions refer to communities which are or are likely to be widely occurring in other similar physiographic situations in the north-east Atlantic. Species which are recorded at only a few locations in Britain but are more widespread in other parts of the north-east Atlantic. Species recorded in higher abundance at locations under consideration than in any others elsewhere in Britain or where the site is one of only a very few locations where large quantities are recorded in Britain.

Regional

Communities which are present in similar physiographic situations elsewhere in Britain but which are outstandingly good examples of their type in the location under consideration or are as good examples as similar communities present elsewhere in Britain. Communities recorded at only a few locations in the same biogeographic region. Species which are unrecorded or recorded at only a few locations in similar physiographic situations in Britain but which are widespread in other similar sites in other parts of Britain. Species recorded in higher abundance in the area under consideration than in any other part of Britain or where the site is one of only a very few locations where large quantities are recorded in Britain.

Local

Communities which are widespread throughout Britain with as good or better examples at several other locations. The selection of only species which are of higher than local importance precludes the use of this category in the species lists.”

4.2 Assessment of Conservation Importance

Different experts may have various views on the conservation importance of marine benthic habitats in the vicinity of Hayle. Our suggestions take into account the various criteria used by the JNCC for assessing marine sites:

- Naturalness
- Representativeness
- Rarity
- Diversity
- Fragility
- Size
- Situation
- Recorded history
- Research and education potential
- Restoration potential
- Intrinsic appeal
- Vulnerability
- Urgency
- Feasibility

4.3 Seaweeds and Invertebrates

The survey by Gill (1989) did not find any sites within the Hayle complex that were of Regional or National conservation interest, though the report noted that the communities near Carnsew Weir were diverse. Other detailed ecological surveys of invertebrates and seaweeds carried out as part of the EIAs of various proposed developments of the Hayle harbour area have also failed to find sites of high conservation interest, but two (Smith, 2000; Aquatonics Ltd, 2007a) have noted that the areas just upstream and downstream of Carnsew Weir are probably intermediate between Local and Regional conservation importance. These areas experience high current speeds and have relatively coarse sediments (and therefore low concentrations of contaminants). They support a relatively diverse range of seaweeds and invertebrates such as sponges and tunicates. The deep water region of Carnsew Pool is also relatively diverse for invertebrates and included several unusual species of polychaete worm in the sediments (Smith, 2000).

The following classifications for invertebrates and algae are proposed by Aquatonics Ltd:

- Harbour — Local (approaching Regional at outlet from Carnsew)
- Cockle Bank — Local
- Penpol — Local
- Carnsew Subtidal — Local (approaching Regional near weir)

- Carnsew Intertidal — Local
- Copperhouse Pool — Local
- Lelant Water — Intertidal Pools and Rocks – Local
Sandflats - Local

Classifications for Copperhouse Pool, Carnsew and Lelant Water would be upgraded when bird usage is also considered.

4.4 Fish

The most important area for fish in the Hayle complex is Carnsew Pool, which is considered to be of Regional conservation interest. Carnsew Pool supports gilthead bream (*Sparus aurata* and golden-grey mullet (*Liza aurata*) (Foster & Smith, 2001a). Lower Lelant Water, the harbour area and the seaward part of Copperhouse Pool also support a range of estuarine and marine fish (Foster & Smith, 2001b). Upper Lelant Water, Penpol and the middle and upper parts of Copperhouse Pool have not been surveyed for fish.

5. UNUSUAL RECORDS

5.1 Intertidal Invertebrates

No Nationally Rare or Scarce marine invertebrates (Sanderson, 1996) have been recorded in intertidal surveys carried out on behalf of Natural England or its predecessors (Gill, 1989) or during surveys to assess the aquatic invertebrates and algae as part of the EIA of the Hayle harbour development (Smith, 1989a; Smith, 2000; Aquatonics Ltd 2007a).

In the December 2006 survey the only unusual invertebrate recorded was a sabellid polychaete worm called *Amphiglena mediterranea*. This was found on the extreme lower shore at Carnsew, among seaweed. Aquatonics Ltd has not previously recorded this species in any surveys. It was also a new record for Dr Peter Garwood, the polychaete specialist who provides our QA. *Amphiglena mediterranea* has a south-western distribution in the UK, suggesting that it requires relatively mild conditions.

5.2 Intertidal Seaweeds

No Rare or Scarce intertidal seaweeds have been recorded in the Hayle complex, but there are occasional interesting records, such as the green seaweed *Codium tomentosum* at a site in Carnsew Pool (Aquatonics Ltd, 2007a). Additional surveys, particularly of areas immediately upstream and downstream of Carnsew Weir, would probably produce a longer list of seaweeds, some of which could be unusual.

5.3 Subtidal Invertebrates

Subtidal cores from Site 13 in Carnsew Pool in 2000 contained five polychaete worms that have a restricted distribution in the UK, but because of their small size and difficulties with identification they have probably been overlooked in most estuarine and marine surveys (Smith, 2000). The polychaetes were:

Microspio mecznikowianus
Ctenodrilus serratus
The cirratulid *Aphelochaeta* sp. (brooding its young inside a piece of sandstone)
A possibly undescribed species of cirratulid (*Caulleriella* sp.)
Polydora socialis

The JNCC does not usually define these difficult taxonomic groups as Rare or Scare, even if they meet the criteria for records, as they are likely to be under-recorded.

5.4 Subtidal Seaweeds

No Rare or Scarce subtidal seaweeds have been recorded in the Hayle complex, but additional survey work in Carnsew Pool would probably produce a longer list of species, some of which may be unusual.

5.5 Fish

The most unusual fish that occur in the Hayle complex are gilthead bream (*Sparus aurata* and golden-grey mullet (*Liza aurata*). Gilthead bream have been recorded in Carnsew Pool, in the harbour area immediately downstream from Carnsew Pool and in the lower part of Copperhouse Pool (Foster & Smith, 2001a, 2001b). Golden-grey mullet have been recorded in Carnsew Pool, a tidal pool in Lelant Water and in very high numbers in the lower part of Copperhouse Pool (Foster & Smith, 2001a, 2001b).

6. BIODIVERSITY ACTION PLANS

The UK Biodiversity Action Plan (UK Biodiversity Group, 1999) identifies broad habitat types (eg inshore subtidal sediment) and within each broad habitat there are priority habitats (eg saline lagoons, seagrass beds and maerl beds). Each priority habitat has a Habitat Action Plan with the following information:

- Current status
- Factors affecting the habitat
- Current action
- Action plan objectives and proposed targets
- Proposed action with lead Agencies

Within the Hayle estuary complex the following priority habitats are present:

- Coastal sand dunes (outside the scope of this section)
- Coastal saltmarsh
- Mudflats
- Sheltered muddy gravels

- Saline lagoons (considered present by Cornwall County Council, but not by Natural England)
- Tidal rapids

6.1 Coastal saltmarsh

The overall objective is of the Action Plan is to maintain the existing area of saltmarsh and maintain the quality in terms of community and species diversity. The only possible impacts on saltmarsh habitat within the Hayle estuary complex are in the upper reaches of Copperhouse Pool (mainly above Black Bridge) and a small area of Carnsew Pool (Aquatonics Ltd, 2007b). The extent of the impacts depends on the sluicing regime. Potential impacts are discussed in the Environmental Statement.

6.2 Mudflats

The objective of the Action Plan is to maintain at least the present extent and regional distribution of the UK's mudflats. This target will require compensating predicted losses to development by the restoration of mudflats. Whilst this may not be possible in the same location, it should be within the same littoral sediment cell.

The main area of mudflats that will be lost due to the development is in Penpol, where the half-tide gate will result in the lower parts of the mudflats becoming subtidal. The implications of this are considered in the Environmental Statement.

6.3 Sheltered muddy gravels

There are no extensive areas of this priority habitat in the Hayle estuary complex, but some small subtidal areas may be present in Carnsew Pool (Smith, 2000). In addition there are sheltered muddy gravels in Penpol (Aquatonics Ltd, 2007a).

The overall objective of the Action Plan is to maintain the extent, distribution and quality of sheltered muddy gravel bed habitats.

6.4 Sublittoral sands and gravels

It is perhaps surprising that there is a Habitat Action Plan for sublittoral sands and gravels, as the term encompasses a variety of different habitats and at least 17 biotopes in the UK.

There are no areas of sublittoral gravels in the Hayle estuary complex. Sublittoral sands are restricted to the low water channels in the harbour and Lelant Water.

The Action Plan objective is to protect the extent quality of a representative range of sublittoral sand and gravel habitats and communities (UK Biodiversity Group, 1999). We are not aware of any proposals that any of the representative examples should be in the Hayle estuary or St Ives Bay.

6.5 Saline lagoons

We have considered whether Carnsew Pool falls within the definition of a saline lagoon:

“bodies, natural or artificial, of saline water partially separated from the adjacent sea. They retain a proportion of their sea water at low tide and may develop as brackish, full saline or hyper-saline water bodies.”

Lagoons usually include specialist species that are adapted to the unusual conditions found in lagoons.

The overall objective of the Action Plan for saline lagoons is to maintain and enhance the current number, area and distribution of coastal lagoons in the UK. Where feasible any loss of lagoon habitat should be compensated by creating new habitat as near to the original site as possible (UK Biodiversity Group, 1999).

Although Carnsew Pool may be considered to be a saline lagoon, a study commissioned by RSPB, Cornwall County Council and English Nature (now Natural England) concluded that it is an estuarine sandy pool rather than a saline lagoon (Bamber and Evans, 2000). We agree with this view, for the following reasons:

- Lack of specialist lagoon species
- Most of the content of Carnsew is discharged at low water
- Metal pollution restricts the species that can colonise Carnsew Pool.

However, the fish fauna of Carnsew Pool is considered to be an important feature.

The Scoping Opinion prepared by Cornwall County Council Natural Environment Service states that both Carnsew and Copperhouse Pool are saline lagoons. We have rechecked with Natural England and they consider neither to be saline lagoons, (email from Roger Covey, Natural England, 10 July 2007).

Impacts on Carnsew Pool due to the development are considered in the Environmental Statement.

6.6 Tidal rapids

Tidal rapids occur where there is a restriction (usually a natural feature) in a tidal area that is sufficient to significantly increase current speeds during parts of the tidal cycle. In the Hayle estuary complex there are tidal rapids on either side of the tunnels at Carnsew Pool. Previous surveys have shown that these areas are the most diverse for invertebrates and algae. These areas will be the most vulnerable to reduced velocities, or increased sedimentation, as they support species that require clean, well-oxygenated water.

The overall objective of the Action Plan for tidal rapids is to “maintain the extent, variety and quality of marine communities in tidal rapids based on best available information” (UK Biodiversity Group, 1999).

6.7 Biodiversity Action Plans for Estuarine/Marine Invertebrates and Algae

In addition to Action Plans for priority habitats there are also Action Plans for species or groups of species (UK Biodiversity Group, 1999). The only species recorded in the Hayle complex which has a BAP is the native oyster (*Ostrea edulis*). A single specimen was recorded from Carnsew Pool in December 2006. The BAP objective for native oysters is to "Maintain and, where possible, expand the existing geographical distribution and abundance of the native oyster within UK inshore waters." (UK Biodiversity Group, 1999). It would be possible to encourage oysters in Carnsew Pool by aquaculture, but any introduced stock may be genetically different and it would therefore require detailed discussions with Natural England and Defra.

The Biodiversity Action Plans for Cornwall include a reference to a single live specimen of a bivalve known as the fan shall (*Atrina fragilis*) found on the north coast of Cornwall, near Hayle, with many more records from south Cornwall and the Scillies (Cornwall Wildlife Trust, 2004). This species is one of the largest bivalves in European waters, reaching a length of 30-48 cm (UK Biodiversity Group, 1999) and is protected under Schedule 5 of the Wildlife and Countryside Act 1981. The BAP objective for fan shells is to "Maintain and, if possible, enhance the distribution and status of *A. fragilis* within the UK" (UK Biodiversity Group, 1999).

7. WADER PREY

The variety of wader prey in the Hayle estuary complex is restricted by metal contamination. Despite this, the area supports a variety of wading birds and as far as we are aware none of the densities of wading birds are lower than expected. This is probably due to the fact that where sediments are suitable the Hayle estuary, Carnsew and Copperhouse Pool support relatively high densities of important wader prey such as ragworm (*Nereis diversicolor*) and the amphipod crustacean *Corophium volutator* (Gill, 1989; Smith, 1989a; Smith, 2000; Aquatonics, 2007a). The densities of peppery furrow shell (*Scrobicularia plana*) recorded at Hayle are low compared to other UK estuaries. This may affect the carrying capacity

As expected, the maximum densities of *Nereis diversicolor* and *Corophium volutator* occur in the muddy sediments found in the upper reaches of Lelant Water, the intertidal mudflats in Carnsew Pool and the upper reaches of Carnsew Pool. Recorded densities of these two major prey species in various locations are summarized in Table 1.

TABLE 1. ESTIMATED DENSITIES OF WADER PREY

Nereis diversicolor	**Location**	**Density (per square metre)**	**Study**
	Carnsew Pool	1830	Gill, 1989
	Carnsew Pool	0 – 600 Mean 170	Smith, 1989a
	Carnsew Pool (intertidal only)	0 – 2400 Mean 1100	Smith, 2000
	Carnsew Pool (sandy sediments only)	0	Aquatonics Ltd, 2007a
	Copperhouse Pool	500 – 1750	Gill, 1989
	Copperhouse Pool	0 – 3300 Mean 640	Smith, 1989a
	Copperhouse Pool (lower only)	0 – 900 Mean 450	Smith, 2000
	Penpol	0 – 4248 Mean 1450	Aquatonics Ltd, 2007a
	Cockle Bank	0	Smith, 2000
	North Quay	0 – 150 Mean 30	Smith, 1989a
	North Quay	0	Smith, 2000
	Harbour mouth	0	Gill, 1989
	Upper Lelant Water	1500	Gill, 1989
	Upper Lelant Water (did not include Lelant Saltings)	0 – 450 Mean 86	Smith, 1989a
	Middle Lelant Water	750	Gill, 1989
	Middle Lelant Water	0 – 2100 Mean 550	Smith, 1989a
	Lower Lelant Water	0	Smith, 2000
Corophium volutator	**Location**	**Density (per square metre)**	**Study**
	Carnsew Pool	0	Gill, 1989
	Carnsew Pool	0	Smith, 1989a
	Carnsew Pool (intertidal only)	0	Smith, 2000
	Carnsew Pool (sandy sediments only)	0	Aquatonics Ltd, 2007a
	Copperhouse Pool	3880 - 9780	Gill, 1989
	Copperhouse Pool	0 – 8550 Mean 1380	Smith, 1989a
	Copperhouse Pool (lower only)	0	Smith, 2000
	Penpol	0-336 Mean 59	Aquatonics Ltd, 2007a
	North Quay	0	Smith, 1989a

	North Quay	0	Smith, 2000
	Cockle Bank	0	Smith, 2000
	Harbour mouth	0	Gill, 1989
	Upper Lelant Water	4980	Gill, 1989
	Upper Lelant Water (did not include Lelant Saltings)	0 – 6150 Mean 1240	Smith, 1989a
	Middle Lelant Water	0	Gill, 1989
	Middle Lelant Water	0 – 7050 Mean 1350	Smith, 1989a
	Lower Lelant Water	0	Smith, 2000
Scrobicularia plana	**Location**	**Density (per square metre)**	**Study**
	Carnsew Pool	100	Gill, 1989
	Carnsew Pool	0	Smith, 1989a
	Carnsew Pool (intertidal only)	0	Smith, 2000
	Carnsew Pool (sandy sediments only)	0	Aquatonics Ltd, 2007a
	Copperhouse Pool	0	Gill, 1989
	Copperhouse Pool	0	Smith, 1989a
	Copperhouse Pool (lower only)	0	Smith, 2000
	Penpol	0	Aquatonics Ltd, 2007a
	North Quay	0	Smith, 1989a
	North Quay	0	Smith, 2000
	Cockle Bank	0	Smith, 2000
	Harbour mouth	0	Gill, 1989
	Upper Lelant Water	180	Gill, 1989
	Upper Lelant Water (did not include Lelant Saltings)	0	Smith, 1989a
	Middle Lelant Water	0	Gill, 1989
	Middle Lelant Water	0	Smith, 1989a
	Lower Lelant Water	0	Smith, 2000
Cerastoderma edule	**Location**	**Density (per square metre)**	**Study**
	Carnsew Pool	0	Gill, 1989
	Carnsew Pool	0	Smith, 1989a
	Carnsew Pool (intertidal only)	0	Smith, 2000
	Carnsew Pool (sandy sediments only)	0	Aquatonics Ltd, 2007a
	Copperhouse Pool	0	Gill, 1989
	Copperhouse Pool	0	Smith, 1989a
	Copperhouse Pool (lower only)	0	Smith, 2000
	Penpol	Occasional	Gill, 1989

	Penpol	0 – 118 Mean 30	Aquatonics Ltd, 2007a
	Cockle Bank	0	Smith, 2000
	North Quay	0 – 150 Mean 60	Smith, 1989a
	North Quay	0	Smith, 2000
	Harbour mouth	0	Gill, 1989
	Upper Lelant Water	0	Gill, 1989
	Upper Lelant Water (did not include Lelant Saltings)	0	Smith, 1989a
	Middle Lelant Water	0	Gill, 1989
	Middle Lelant Water	0 - 150 Mean 25	Smith, 1989a
	Lower Lelant Water	0	Smith, 2000
Hydrobia ulvae	**Location**	**Density (per square metre)**	**Study**
	Carnsew Pool	0	Gill, 1989
	Carnsew Pool	0	Smith, 1989a
	Carnsew Pool (intertidal only)	300 Mean 300	Smith, 2000
	Carnsew Pool (sandy sediments only)	0	Aquatonics Ltd, 2007a
	Copperhouse Pool	0	Gill, 1989
	Copperhouse Pool	0	Smith, 1989a
	Copperhouse Pool (lower only)	0	Smith, 2000
	Penpol	0	Gill, 1989
	Penpol	0	Aquatonics Ltd, 2007a
	North Quay	0	Smith, 1989a
	North Quay	0	Smith, 2000
	Harbour mouth	0	Gill, 1989
	Cockle Bank	0	Smith, 2000
	Upper Lelant Water	0	Gill, 1989
	Upper Lelant Water (did not include Lelant Saltings)	0	Smith, 1989a
	Middle Lelant Water	0	Gill, 1989
	Middle Lelant Water	0	Smith, 1989a
	Lower Lelant Water	0	Smith, 2000

7. CONTAMINANTS IN SEDIMENTS AND BIOTA

The historical contamination of sediments in the Hayle region is an important factor that structures estuarine and marine benthic communities. As far as we are aware no studies have shown impacts of metals on fish or birds in the Hayle area. The distribution of seaweeds in the Hayle area has not been studied in relation to metal content of sediments, but it seems likely that parts of the Hayle complex (eg Copperhouse Pool) have a restricted seaweed flora due to metals such as copper.

Evidence for the importance of metal and other pollution on invertebrates comes from three main sources:

1. Comparison of the Hayle fauna with other similar estuaries that are uncontaminated shows that the Hayle is unusually species-poor. The species that do occur are very similar to those found in Restronguet Creek (Bryan and Gibbs, 1983). Restronguet Creek is regarded as the most metal-contaminated estuarine area in the UK.

2. The concentrations of metals such as arsenic and copper in those invertebrates that have been studied are high in Hayle compared with other sites in the UK.

3. Concentrations of metals such as arsenic, copper and zinc in Hayle sediments are higher than sediment guidelines values that show the concentrations at which ecological effects would be expected. The standards that are most widely used were developed in Canada (Canadian Council of Ministers for the Environment, 1999) and are referred to here as Canadian Sediment Quality Standards.

The Environment Agency and Natural England have adopted Canadian Sediment Quality Standards to assess contamination levels (Environment Agency, 2005). The Canadian Sediment Quality Standards provide Interim Sediment Quality Guidelines (ISQG) and Probable Effects Levels (PEL). The ISQG is the concentration at which ecotoxicological effects may first occur.

From comparison of the species present in Hayle estuary complex with other cleaner estuaries in the UK it seems very likely that metal pollution has a severe impact on the invertebrate communities. The diversity of invertebrates in Hayle is especially low considering the mosaic of estuarine and marine habitats present. Some common estuarine species such as the mudsnail (*Hydrobia ulvae*), peppery furrow shell (*Scrobicularia plana*) and catworms (*Nephtys* sp.) have not been recorded in surveys at Copperhouse Pool and their absence is most likely due to high concentrations of metals such as copper. These species are important prey items for some wading birds and fish and their absence is therefore of significance further up the food chain. Other prey for waders and fish are present, in particular ragworm (*Nereis diversicolor*), small amphipods (mainly *Corophium volutator*) and oligochaete worms.

The metals of particular concern in the Hayle complex are copper, zinc and arsenic. (Smith, 1988), but other metals such as lead can also occur at very high concentrations. Concentrations of these metals in sediments in various parts of the Hayle complex have been compared with the Canadian sediment quality guidelines (Table 2). Many locations in the Hayle area have mean sediment concentrations that are 2-10 times the PEL for each of these metals separately. It is therefore not surprising to find that the invertebrate fauna is very restricted.

In general, the highest concentrations of metals occur in areas that are close to freshwater discharges that contain high concentrations of metals. The principal sources of metals in modern times are:

- The Hayle River
- The Angarrack River which is canalised in Copperhouse Canal through most of its passage through Copperhouse Pool
- Mill Leat, which runs under Black Bridge and then through Copperhouse Pool

7.1 Metals in Sediments

Sediments that contain a high proportion of clays and silts (mud) will generally contain higher concentrations of contaminants than nearby sandy sediments. The areas with the highest concentrations of contaminants are therefore muddy sediments in the upper reaches of Lelant Water and in Copperhouse Pool (Table 2). These areas have mean concentrations of metals which are many times the PEL:

Arsenic	Copperhouse Pool	Mean As concentration 10-20 x PEL
	Lelant Water (upper)	Mean As concentration 13-15 x PEL
Copper	Copperhouse Pool	Mean Cu concentration 8-10 x PEL
	Lelant Water (upper)	Mean Cu concentration 11 x PEL
Zinc	Copperhouse Pool	Mean Zn concentration about 4 x PEL
	Lelant Water (upper)	Mean Zn concentration about 3 x PEL

From the above analysis it would appear that of the three metals it is probably arsenic and copper that are of greatest concern, but the zinc concentrations by themselves would be sufficient to cause reductions in biodiversity.

There are several areas where construction works will directly disturb sediment (eg lower Copperhouse Pool close to the proposed road bridge, Penpol, Cockle Bank, harbour and harbour mouth). Of the various construction works proposed, the foundations for the road bridge at Copperhouse Pool will disturb the most contaminated sediments. We have calculated the mean concentrations of arsenic, copper and zinc in the upper 50 cm of sediment on the

TABLE 2. METALS IN SEDIMENTS		Min	Mean	Max	PEL	Mean/PEL	Max/PEL
Arsenic							
Upstream of Black Bridge	1976	240	1551	4080	41.6	37.3	98.1
Copperhouse Pool	1979		950		41.6	22.8	NA
Copperhouse Pool (0-10 cm deep)	1988a	48	755	3830	41.6	18.1	92.1
Copperhouse Pool (50 - 150 cm deep)	1988a	10	555	3400	41.6	13.3	81.7
Copperhouse Canal	1988b	172	458	780	41.6	11.0	18.8
Copperhouse Stream (Mill Leat)	1988b	338	657	1030	41.6	15.8	24.8
North Quay	1998	34	71	89	41.6	1.7	2.1
South Quay	1998	12	40	94	41.6	1.0	2.3
Cockle Bank	1998	10	89	276	41.6	2.1	6.6
Cockle Bank	2004	1.6	123	645	41.6	3.0	15.5
Lelant Water (upper)	1976	12	607	1920	41.6	14.6	46.2
Lelant Water (upper)	1979		550		41.6	13.2	NA
Lelant Water (lower)	1988b	108	126	144	41.6	3.0	3.5
Lelant Water (lower)	1998		88		41.6	2.1	NA
Penpol Dock	1988b		93		41.6	2.2	NA
Carnsew Pool	1988b	56	98	140	41.6	2.4	3.4
Mouth of the Hayle estuary	1988b		42		41.6	1.0	NA
Copper							
Upstream of Black Bridge	1976	270	1038	2600	108	9.6	24.1
Copperhouse Pool (0-10 cm deep)	1988a	100	1083	9315	108	10.0	86.3
Copperhouse Pool (50 - 150 cm deep)	1988a	30	861	4090	108	8.0	37.9
North Quay	1998	62	350	739	108	3.2	6.8
South Quay	1998	13	225	526	108	2.1	4.9
Cockle Bank	1998	41	175	339	108	1.6	3.1
Cockle Bank	2004	1	255	1476	108	2.4	13.7
River Hayle (freshwater)	1977	100	1500	4900	108	13.9	45.4
Lelant Water (upper)	1976	68	1187	2760	108	11.0	25.6
Lelant Water (lower)	1998		106		108	1.0	NA
Zinc							
Upstream of Black Bridge	1976	560	1223	2290	271	4.5	8.5
Copperhouse Pool (0-10 cm deep)	1988a	64	1059	2880	271	3.9	10.6
Copperhouse Pool (50-150 cm deep)	1988a	150	1223	15347	271	4.5	56.6
North Quay	1998	304	356	416	271	1.3	1.5
South Quay	1998	47	178	338	271	0.7	1.2
Cockle Bank	1998	47	162	280	271	0.6	1.0
Cockle Bank	2004	16	287	1762	271	1.1	6.5
River Hayle (freshwater)	1977	100	700	1600	271	2.6	5.9
Lelant Water (upper)	1976	80	858	3450	271	3.2	12.7
Lelant Water (lower)	1998		151		271	0.6	NA
Notes							
1976 = Yim, 1976							
1979 = Pap paper 293 Langstone, 1980							
1988a = second report by Berridges							
1988b = Southampton University Report							
1998 = WSP report							
Mean > 10 x PEL							
Max > 20 x PEL							

lowest transect sampled at Copperhouse in surveys by Aquatic Environmental Consultants in 1988. The mean concentrations were:

- Arsenic 8.5 x PEL
- Copper 9.8 x PEL
- Zinc 3.6 x PEL

Although Cockle Bank has much lower concentrations of metals, the removal of this structure has the capability to put contaminated sediment into suspension. It would be of particular concern if large quantities of contaminated suspended sediments were transported into areas that are relatively uncontaminated, such as Carnsew Pool and Lower Lelant Water.

At Cockle Bank the ratios of mean concentration to PEL were:

- Arsenic 2.1 – 3.0 x PEL
- Copper 1.6 – 2.4 x PEL
- Zinc 0.6 – 1.1 x PEL

As a general principle, areas of clean sand such as the harbour mouth and lower Lelant Water usually have mean metal concentrations of <1 x PEL (Table 2), whereas areas of mixed sediment (eg Cockle Bank) have mean concentrations that are 1 - 3 x PEL.

Harbour mouth (close to proposed sand trap)

- Arsenic 1 x PEL
- Copper no data
- Zinc no data

North Quay

- Arsenic 1.7 x PEL
- Copper 3.2 x PEL
- Zinc 1.3 x PEL

South Quay

- Arsenic 1.0 x PEL
- Copper 2.1 x PEL
- Zinc 0.7 x PEL

A study on the impacts of copper on nematodes in the Hayle estuary, Restronguet Creek and Percuil River found that impacts occurred at sediment copper concentrations above approximately 200 µg/g (Millward and Grant, 2000). This is lower than the mean values for most of the Hayle complex apart from lower Lelant Water (see Table 2).

7.2 Metals in Biota

Arsenic concentrations in the invertebrates *Nereis diversicolor* (ragworm) *Scrobicularia plana* (peppery furrow shell) and the seaweed *Fucus vesiculosus* (bladderwrack) were analysed from a large number of UK sites, including Hayle, by Langstone (1980). In all three species the specimens from Hayle had maximum concentrations that were only exceeded by those from Restronguet Creek in the Fal estuary. Restronguet Creek is known to be the most metal contaminated estuary in the UK, due to the mine drainage it receives from the Wheal Jane mine. The exact location of the specimens from Hayle is unknown, but *Scrobicularia plana* has not been recorded in ecological surveys of Copperhouse Pool so the most likely locations are upper Lelant Water or perhaps Carnsew Pool. Table 3 summarises the data from Langstone (1980) for the Hayle estuary, Restronguet Creek and 21 locations in the Severn estuary and Bristol Channel.

TABLE 3. CONCENTRATIONS OF ARSENIC IN BIOTA FROM HAYLE (data from Langstone, 1980).

Location	Date	Sediment (µg/g dry weight)	*Fucus vesiculosus* (µg/g dry wt)	*Nereis diversicolor* (µg/g dry wt)	*Scrobicularia plana* (µg/g dry wt)
Severn & Bristol Channel	November 1978	7-12	13-28	5.9-16	13-26
Hayle	September 1979	550-950	138	73-83	97-106
Restronguet Creek, Fal	April 1978 – April 1979	120-2500	63-160	58-87	160-190

Of the metals analysed in ragworm (*Nereis diversicolor*) from the upper Hayle estuary, those that were elevated compared to other UK sites were arsenic and copper (Bryan et al, 1985). Arsenic concentrations were almost four times higher than in ragworms from Restronguet Creek. Copper concentrations were 0.85 times as high as those in ragworm from Restronguet Creek. Silver was also elevated compared to clean sites, but was similar to concentrations in ragworm from Restronguet Creek. Zinc was only slightly elevated in ragworm from Hayle, probably due to the ability of this species to regulate concentrations of zinc in its body. Metals that appear to be of no concern in ragworm from Hayle are cadmium, chromium, nickel, lead and tin (Bryan et al, 1985). Plots of metal concentrations in the bivalve *Scrobicularia plana* (peppery furrow shell) confirm that the metals that are elevated in the Hayle estuary are arsenic and copper (Bryan et al, 1980).

A study of the possible adverse impacts of contaminated prey on wading birds of the Severn estuary has been undertaken (Smith et al, 2006), but no similar analysis has been carried out for the Hayle estuary. Such a study is outside the scope of the EIA for the proposed development at Hayle, especially as the most contaminated sediments (upper reaches of Copperhouse pool and upper Lelant Water) will not be disturbed by construction. However, for arsenic and copper we have done some preliminary calculations of intakes by bar-tailed godwit, assuming that they only eat ragworm (*Nereis diversicolor*). We have used the following assumptions:

- Typical mass of bar-tailed godwit =321 g (data from Goss-Custard et al, 2006)
- Typical intake of prey per day by bar-tailed godwit = 200 g wet weight (pers. Comm. Nick Cutts, IECS)
- Conversion factor for wet weight to dry weight of *Nereis diversicolor* = 0.17 (Vedel and Riisgard, 1993)
- No Observable Adverse Effects Levels (NOAELs) from US Environmental Protection Agency reviews of avian toxicity (US Environmental Protection Agency 2005 & 2007) are reliable.

7.2.1 Arsenic

Ragworm from the Hayle estuary have a mean arsenic concentration of 78µg/g (data from Langstone, 1980). This value is slightly lower than the concentration of 84µg/g given by Bryan et al (1985) for ragworm from the Hayle estuary. The avian NOAEL for arsenic is 2.24 mg As/kg body weight/day (US Environmental Protection Agency, 2005).

The calculated daily intake of arsenic by bar-tailed godwit on the Hayle estuary is 2.65 mg/day, equivalent to 8.26 mg/kg body weight/day. This is 3.7 times the avian NOAEL.

This intake of arsenic may be sufficient to affect behaviour and growth, but may not affect survival (US Environmental Protection Agency, 2005). The speciation of the arsenic in the ragworm will also affect its toxicity. The naturally occurring organometallic form arsenobetaine (commonly found in marine organisms) has a very low toxicity (Koch et al, 2007).

7.2.2 Copper

Ragworm from the Hayle estuary have a copper concentration of 1210µg/g (data from Bryan et al, 1985). The avian NOAEL for copper is 18.5 mg Cu/kg body weight/day (US Environmental Protection Agency, 2007).

The calculated daily intake of copper by bar-tailed godwit on the Hayle estuary is 41.14 mg/d, equivalent to 128 mg/kg body weight/day. This is 6.9 times the avian NOAEL. This intake of copper is expected to cause toxicological effects, including reduced growth, reproductive effects (reduced sperm viability, reduced number of eggs per nest, lower egg weight) and possibly an increased mortality (US Environmental Protection Agency, 2007).

8. ALGAL BLOOMS

Algal blooms are a natural feature of freshwaters, estuaries and marine waters. However, it is possible for human activities to influence the location, timing, severity and species present within the bloom. Many marine algal blooms do not produce toxins that are toxic to marine life, and for these species the main concern is that the collapse of the bloom (ie when the algae die) removes large amounts of oxygen from the water, resulting in low concentrations of dissolved oxygen that are toxic to some marine species. This type of impact is widely recorded, and can affect invertebrates and fish. Examples include lugworm mortalities in the eastern Irish Sea (Helm et al, 1974) and fish mortalities on the SW coast of Norway (Tangen, 1977) due to blooms of *Gyrodinium aureolum*. More locally there have been suggestions that a large scale summer kill of dog whelks (*Nucella lapillus*) in Bude Bay in 1995 may have been due to a toxic algal bloom (Gibbs et al, 1999).

Algal blooms occur when the conditions are suitable for a particular species. The most important factors are:

- Stability of the water column, with low mixing (ie calm weather)
- Water temperature above a minimum (depending on the species)
- Suitable concentrations of nutrients
- Suitable concentrations of trace elements (eg iron, see Wells et al, 1991)
- pH may be important in estuaries, as it will determine the speciation and availability of essential and toxic trace metals
- Light levels suitable, ie turbidity below a threshold required by that species.

Some phytoplankton are highly mobile and in daytime are able to swim into surface waters where light levels are optimal. In shallow waters the night-time accumulation of some species (eg *Gyrodinium aureolum*) is probably sufficient to significantly reduce oxygen concentrations, with resultant mortalities of marine life (Tangen, 1977).

In some freshwater incidents algal blooms have been treated with copper sulphate to kill them and many algae are very sensitive to copper in the water. For the Hayle complex the relatively high concentrations of copper in the water and sediments may help reduce the incidence of algal blooms, but the genus *Alexandrium* which is associated with Paralytic Shellfish Poisoning (PSP) occurs regularly in samples from the equally contaminated Fal estuary from early May to late September (ICES, 2006).

Toxic algal blooms have the capacity to affect all marine life, and people that consume seafood. The presence of viviers in Hayle Harbour makes it even more important to ensure that the proposed development does not increase the possibility of algal blooms, either toxic species or non-toxic species.

Although it is often assumed that long periods of stable water conditions are required for algal blooms to form this is not always the case. For example, algal blooms are known to be associated with neap tide conditions, even in relatively open waters such as South San Francisco Bay (Cloern, 1991) and Southampton Water.

An additional issue is the likelihood that any algal bloom will include species that are toxic to shellfish, fish, birds or mammals. This could have a significant adverse impact on the ecology and fisheries of the Hayle harbour area.

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