REPORT ON CONDITIONS DURING NORMAL TIDAL CYCLE IN COPPERHOUSE POOL AND RECOMMENDATIONS REGARDING TRIAL TIDAL EXCLUSION

DR PHIL SMITH AND PROF ANNE SMITH, AQUATONICS LTD

28 JULY 2011

DISCLAIMER

This report offers our scientific opinion on the likely impacts of a trial tidal exclusion. It was produced to meet a very short deadline and therefore we have not had time to include all supporting evidence. Additional information, for example on methods used during the study and references, can be provided to consultees upon request.

We cannot be held liable for any unpredicted impacts of a trial exclusion.

1. EXECUTIVE SUMMARY

1.1 Recommendation

Our recommendation is that a single high tide exclusion could be done without any likely damage to aquatic species in Copperhouse Pool, provided that the following mitigation measures are carried out:

1. The trial should be postponed if the predicted air temperature for Hayle is above 20°C (forecast taken no later than 36 hours before the gate being closed). The previous suggested maximum was 25°C for air temperature and 24°C for water temperature. REASON: The reduction in maximum permitted air temperature is required due to the fact that on 21 July 2011 maximum water temperature in the low water pool exceeded maximum air temperature by up to 4°C.
2. The trial should be postponed if heavy rain occurs during the 24 hour period before the trial, or if heavy rain is forecast during the day of the trial exclusion.
   REASON 1: The salinity in the low water channel in the upper part of Copperhouse Pool fell to 3.9 psu during the 21 July study. This is just over 10% of seawater (34-35 psu). Salinity in the low water channel will probably fall even lower during a trial exclusion. Toxicity tests on brown shrimp (a common species in the low water channel) show that it can tolerate 2 psu salinity, but not 1 psu. We think salinities may approach 2 psu during normal weather, but could fall to 1 psu or below after or during heavy rain.
   REASON 2: Fish in the low water pool experienced salinities down to 7.2 psu during the normal tidal cycle on 21 July 2011. These will fall further, perhaps down to 4 -5

psu during a trial exclusion during dry weather or drizzle, due to the increased influence of freshwater inputs over an additional 12 hours. Heavy rain before or during the trial would further lower salinities to perhaps 3 psu, which could cause fish mortalities.

3. Sandbags at the main low water exit from the low water pool.
   REASON: Placement of sandbags at the main exit channel from the pool and along the edge between here and the edge of the causeway should raise the volume of the low water pool significantly and reduce the rate of dilution. The effect of the sandbags on metal concentrations is more complex, as some metals (eg arsenic) declined when seawater entered on the flood tide, but other metals (eg copper) rose with the flood tide. Overall we recommend that the use of sandbags (provided they are filled with inert material) will be beneficial.

   The bags must be removed before the next incoming tide, so as to avoid impeding tidal inflow.

The only other mitigation measures we can suggest are probably not practical, e.g.

- Adding salt to the low water pool and low water channel to increase salinity. We estimate that 3-4 tonnes of salt would need to be added to the low water pool. A more precise figure would require an accurate volume for the low water pool.
- Fine seawater spray over areas of seaweeds to keep them hydrated.
- Horticultural fleece over seaweeds to retain moisture.
- Pump water from the harbour into the low water pool.

1.2 Weather Conditions for the Trial Exclusion

The best conditions would be cool (maximum daytime <18° C), cloudy with a gentle breeze or no wind. There should have been little rain prior to the exclusion, but light drizzle on the day would help keep seaweeds hydrated.

The worst conditions would be either hot, dry and windy (which would cause seaweeds to become unusually dehydrated and unacceptably high water temperatures) or high freshwater flows due to rainfall prior to the study or moderate to heavy rain on the day of the exclusion.

1.3 Assessment of Individual Species

The following species are very unlikely to be affected by a single tidal exclusion, even in the absence of mitigation:

- Cord grass (*Spartina anglica*)
- Glasswort (*Salicornia* spp.)
- Rough periwinkle (*Littorina saxatilis*)

- Shore crab (*Carcinus maenas*)
- *Corophium volutator* (an amphipod crustacean)
- Sea slater (*Ligia oceanic*)
- Lugworm (*Arenicola marina*)
- Ragworm (*Nereis diversicolor*)
- Enchytraeid oligochaete worms
- Saltmarsh invertebrates such as *Cillenus lateralis*
- Marine bristle tail (*Petrobius maritimus*)

The list of species most unlikely to be affected by a trial tidal exclusion includes nearly all the most important wader prey found in Copperhouse Pool. This suggests that overwintering and migrant birds will not experience any reduction in prey densities.

Moderately sensitive groups that could be affected by a single tidal exclusion (without mitigation) are:

- Fish in the low water pool
- Gobies in the low water channel

The most sensitive species may show some minor sublethal effects due to a trial tidal exclusion (even with the proposed mitigation), but we do not predict any significant mortalities:

- Brown shrimp (*Crangon crangon*) in the low water channel. Additional salinity measurements and checking for dead or dying brown shrimp now proposed.
- Bladder wrack (*Fucus vesiculosus*). Detailed monitoring included.
- Spiral wrack (*Fucus spiralis*). Monitoring now proposed.
- Knotted wrack (*Ascophylum nodosum*). Monitoring now proposed.
- Filamentous green algae (e.g. *Ulva* spp – which was previously in *Enteromorpha* & *Rhizoclonium riparium*). Detailed monitoring proposed for filamentous green algae.

1.4 Monitoring Programme

The information obtained during this initial study of baseline conditions has influenced our proposed monitoring programme. We have added some new items but also removed others or reduced their frequency. Table 1 provides a summary.

Nearly all the revised monitoring can be carried out on the lower third of Copperhouse Pool. The only exception is occasional visits to the upper part of the low water channel to assess salinity and brown shrimp. The revised scheme means that all three field staff will be working closely together, which should aid recording and provide additional H&S benefits.

Table 1. Summary of Monitoring

	Previous proposal	Revised proposal
Meteorological data		
Air temperature, humidity, wind speed, cloud cover	Yes	Yes
Water quality in low water pool		
DO, pH, NH_3, salinity & temperature	Yes	Yes
Dissolved metals	Yes	Yes*
Total metals	Yes	Yes*
Fish behaviour in low water pool		
Visual observations	Yes	Yes
Video recording	Yes	Yes
Still photography as required	Yes	Yes
Low Water Channel		
Salinity & temp in low water channel	No	Yes
Invertebrates		
Crangon crangon toxicity tests	Yes	No
Crangon crangon checks for mortality in LW channel	No	Yes
Corophium volutator behaviour	Yes	Yes**
Nereis diversicolor behaviour	Yes	Yes***
Arenicola marina cast counts	Yes	Yes**
Littorina saxatilis activity / behaviour	Yes	No
Seaweeds & higher plants		
Pocket PEA – *Fucus vesiculosus*	Yes	Yes
Pocket PEA – *Fucus spiralis*	No	Yes
Pocket PEA – *Ascophylum nodosum*	No	Yes
Pocket PEA – *Salicornia*	Yes	No
Pocket PEA – filamentous green algae	Yes	Yes
Visual observations all species	Yes	Yes
Water content of *Fucus vesiculosus* by oven drying	Yes	Yes

* Reduced list of metals required now we have baseline data. For total metals we only need zinc.

** At reduced frequency

*** Only if we observe unusual behaviour, with large numbers on the surface

2. OVERVIEW OF METHODS

All sampling sites were marked with numbered canes. A handheld GPS was used to obtain the NGR of each cane. The location of sampling sites near the lower water pool are shown in Figure 15. Sampling sites in the upper part of Copperhouse Pool are shown in Figure 16.

2.1 Fish

Surveys of Copperhouse Pool (October 2001 and September 2010) have shown that it is an important nursery area for fish. When Copperhouse Pool empties, a large low water pool (approximately 25 m radius) is retained near Copperhouse Bridge and many young fish remain in this pool. In the 2010 survey of the low water pool, a partial catch of fish in the pool caught more than 4000 fish, with juvenile Golden Grey Mullet, mostly 0+ or 1+ fish, representing the dominant biomass. Thick-lipped Grey Mullet were also identified in the 2001 survey at Copperhouse. Surveys have also shown that Copperhouse Pool is a nursery area for Sand Smelt and Sea Bass, and juvenile Gilthead Seabream and Sandeel occur in the pool from time to time.

To assess the possible impacts of the proposed tidal exclusion on young fish in Copperhouse Pool we monitored fish behaviour and changes in water quality during a normal tidal cycle.

We used a combination of visual survey and video recording from a fixed location to assess fish activity. The video imagery was assessed for any signs of surface activity due to fish. Numbers of fish active at the surface over a one minute period were calculated from the video. The results were assessed in relation to water quality parameters and other factors.

2.2 Water Quality

Meters were used to obtain the following data in the field:

- Salinity - recorded in practical salinity units (psu); values are equivalent to parts per thousand (ppt)
- Water temperature (°C)
- pH
- Ammonia (total, mg/l)
- Dissolved oxygen (mg/l and % saturation)

Unionised ammonia is the toxic form of ammonia and the proportion of unionised ammonia in a sample varies with temperature and pH. A spreadsheet developed by Aquatonics Ltd was used to calculate unionised ammonia from total ammonia, pH & temperature.

Water samples for metal analysis were obtained from 4 locations in and around the low water pool using a sample bottle on a telescopic pole. This prevented disturbance of the fish or the sediments. Each sample was placed in 250 ml plastic bottles and stored in a cool box with ice packs during the day. In total 26 samples were sent in a cool box with ice packs by courier to the laboratory (Chemtest). A further sample from the low water channel was also sent to Chemtest, but not in a cool box. The Chemtest Laboratory analysed the following metals for total and dissolved fractions:

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

2.3 Meteorological Conditions

All the meteorological observations were made at Site 11, towards the upper end of Copperhouse Pool (see Figure 16 for location).

A handheld met station (WindMate 300) was used to monitor the following parameters at approximately hourly intervals:

- Temperature (°C)
- Humidity (%)
- Mean wind speed (m/s) over approximately 1 minute
- Maximum wind speed (m/s) over approximately 1 minute

We also noted whether it was sunny and estimated the percentage cloud cover. During the study, the cloud cover directly overhead was generally low but there was cloud visible in a circle around Hayle.

2.4 Seaweeds and Higher Plants – Pocket PEA

A Pocket PEA fluorimeter (Hansatech Instruments) was used to assess the response of seaweed and *Spartina* photosynthetic systems to normal drying conditions. The Pocket PEA chlorophyll fluorimeter uses focussed, high intensity light from red LEDs to induce a fast chlorophyll fluorescence response from a dark adapted sample. The Pocket PEA method requires the use of a special leafclip system. This is a multi-purpose tool which provides dark adaptation for the sample (required for the measurement of maximum photochemical efficiency), defines the measurement area on the sample and prevents ambient light leakage into the highly sensitive photodiode used by the instrument for chlorophyll fluorescence detection.

For the three species we assessed (*Rhizoclonium riparium*, *Fucus vesiculosus* and *Spartina*) we obtained 4 replicate measurements per species at approximately 1 hour intervals throughout the day. The Pocket PEA produces data on several parameters, the most important of these is Fv/Fm, the proportion of variable fluorescence (Fv) to maximum fluorescence (Fm). The Fv/Fm ratio is widely used by plant physiologists as a sensitive measure of plant photosynthetic performance. Maximum values for Fv/Fm for unstressed plants are usually in the range 0.8 to 0.85, and this value falls as the plant's photosynthetic ability declines due to any form of stress, for example desiccation. The highest Fv/Fm values we obtained were for *Spartina*, which reached Fv/Fm values of up to 0.81.

We have also included some data for the Performance Index (PI) parameter calculated by the Portable PEA. The PI values can be viewed as an overall measure of the ability to withstand stress, so high PI values are good. The PI values obtained in the field were quite variable, but showed variations throughout the day which were probably due to desiccation stress.

We also tried to use the Pocket PEA method on *Salicornia*, but got error messages which prevented its use. The error messages may have been due to the morphology of *Salicornia*, which does not have flat leaves. We had modified the dark adaptation clip (as recommended by the manufacturer) but could still not get readings from the fluorimeter. For this reason we have dropped *Salicornia* from future monitoring using the Pocket PEA.

For the brown seaweed *Fucus vesiculosus* the study was continued the following day by bringing a rock back to the laboratory in an air-tight container. We were able to extend the drying period and simulate the effects of rainfall followed by re-immersion in seawater. This gave valuable data on the likely impacts of a tidal exclusion and the effects of rainfall.

2.5 Water Content of *Fucus vesiculosus*

The water content of *Fucus vesiculosus* during the normal drying cycle was assessed by taking 4 replicate samples from the uppermost parts of the plants (the lowest parts in contact with the sediment remained damp throughout the day). These were placed in weighed glass vials which were sealed with plastic lids to prevent loss of moisture. The vials were re-weighed with the *Fucus* sample then dried to constant weight at 80C. The water present in each sample was then calculated on an Excel spreadsheet.

2.6 Visual observations of seaweeds and higher plants

At approximately hourly intervals we visually assessed the condition of the main plant species in the upper part of Copperhouse Pool. We used close focus binoculars on nearby plants and these gave a clearer view of condition for species such as *Salicornia*, *Rhizoclonium riparium* and *Fucus vesiculosus*. Swards of *Spartina* were examined using normal binoculars and individual plants nearby were also assessed. The visual observations produced some ancillary information on condition which was useful (for example we noted that *Fucus vesiculosus plants* were rehydrating before they were covered by the tide), but it was not as sensitive as the water content and the Pocket PEA techniques.

2.7 Activity of rough periwinkles, *Littorina saxatilis*

At approximately hourly intervals, rough periwinkles were collected from a site on the upper intertidal (where they were exposed to air) and placed in water at 24 psu. The time taken for 50% of individuals out of 20 per container to start to move was recorded. The test was run twice (consecutively) under standardised conditions. Water temperature was measured during the study. Water temperature during the tests ranged from 18 – 24.5°C.

2.8.1 Quadrat Counts of Invertebrates

Lugworm (*Arenicola marina*)

Counts of lugworm casts were made in 2 locations, one where there were high densities of casts near to the low water pool (Site 5) and one further upstream between the two raised areas covered with filamentous green algae (Site 4). In each case counts were made over an area of 1 m^2, by recording in 4 x 0.5 m^2 quadrats. The locations were marked with a central cane and 4 corner canes to ensure repeatability of site location. Counts were always made from the same starting square and in the same order for the 4 sub-areas, so that we could compare the 4 counts as well as the total count for each location over the natural tidal cycle. Counts of lugworm casts were made at approximately 2 hourly intervals.

***Corophium volutator* (an amphipod crustacean)**

We located areas with high densities of the amphipod crustacean *Corophium volutator* (Sites 16 and 17 on Figure 16). Counts were made of *Corophium volutator* on the surface at two 0.5 metre square quadrats at approximately hourly intervals. Within the quadrat we selected five 10 cm x 10 cm squares for detailed observation and counting. This smaller area was chosen due to the large number of *Corophium* holes present. We also examined the entire 0.5 square metre quadrat, in case the smaller 10 x 10 cm squares were unrepresentative.

Ragworm (*Nereis diversicolor*)

We failed to find any locations where ragworm (*Nereis diversicolor*) were on the surface and could be counted, but we did examine large areas to determine that the normal surface density is zero during low water (only a single specimen was observed in many tens of square metres that were checked). This will be a sufficient baseline if the trial exclusion results in increased ragworm activity on the surface.

2.9 Toxicity tests on brown shrimp, *Crangon crangon*

We were concerned that brown shrimp in the low water channel may be at the limits of their tolerance of salinity and metals, and that the exclusion of a high tide may result in mortalities. We collected brown shrimp (43 specimens, all juveniles) from the low water channel at the upper end of Copperhouse Pool at 16:30. These specimens were placed in clean seawater (made up from aquarium salts) with a salinity of 24 psu. All specimens were kept in 24 psu water until the start of the toxicity experiments the next day. There were no mortalities of the brown shrimp in this period.

We also collected a large sample of water from the low water channel for toxicity tests. The salinity of this sample was measured in the laboratory. A sample of harbour water was also collected for the toxicity tests.

In the laboratory the brown shrimps were initially tested in duplicate in two regimes:

- Low water channel water at 3.9 psu
- Harbour water at 34 psu

There were some mortalities in the low water channel toxicity test, but we could not tell whether this was due to the salinity or metal content. We therefore devised additional tests to examine the likely cause of mortality. The salinity of the 3.9 psu low water channel water was raised to 32 psu by the addition of aquarium salts. Brown shrimp from the previous 34 psu test were then exposed to this water to assess mortality (none occurred). We then used successive dilutions of this water to examine the effects of reduced salinity. The brown shrimps were taken slowly through a salinity gradient (32, 16, 8 4, 2 and 1 psu) and mortalities were noted. The only mortalities occurred in 1 psu and the LT50 (lethal time for 50% of individuals) was obtained by frequent assessment of mortalities at this salinity. A 24 hour test was also carried out on surviving brown shrimp at 1 psu.

3. RESULTS

3.1 Tidal Conditions During the Study

The times and heights of high water and low water at St Ives on 21 July 2011 are shown in Table 2.

Table 2. Tidal conditions on 21 July 2011

Tidal state (St Ives) 21 July 2011	Height (m)	Time (BST)
Low water	1.7	03:46
High water	5.8	09:36
Low water	1.9	15:56
High water	5.8	21:57

Tides on 21 July were midway between a spring tide (range 1.1 - 6.6 m on Sunday 17 July) and a neap tide (range 2.7 – 4.9 m on Monday 25 July). The highest parts of the intertidal in Copperhouse Pool (e.g. the sediments immediately below the seawall) were not covered by the high tides on 21 July.

We were on site from 09:00 to 21:40 so were able to assess a full tidal cycle.

Due to the cill at the entrance to Copperhouse Pool, there is a lag between the low water time in the harbour and in Copperhouse Pool. For example, it was noted that the minimum water level in the low water pool was at 19:27, when water started to flood back in. In the upper reaches of Copperhouse Pool the ebb tide in the low water channel continued until about 20:20; 4 hours 20 minutes after predicted low water.

3.2 Meteorological Conditions During the Study

The forecast for 21 July 2011 (Camborne) was moderately high pressure, sunny intervals and a maximum temperature of 16°C. Conditions were sunnier and warmer than predicted, with a maximum air temperature of 20°C and sunshine throughout most of the day. This was good for the study as it enabled us to examine desiccation effects on seaweeds and gave us a better insight into the relationship between air temperature and water temperature in the low water pool.

Figure 10 shows the air temperature and humidity during the study. Table 3 below summarises the meteorological data.

Table 3. Summary of Meteorological Conditions on 21 July 2011

	Minimum	Maximum
Pressure (mb)	1017	1019
Air temperature (°C) (alcohol thermometer in shade)	14	20
Humidity (%)	41	78
Cloud cover (%) note: lower values directly overhead	15	60
Mean wind speed (m/s)	0.1	1.0
Maximum wind speed (m/s)	0.3	1.4

The humidity data were very useful for interpreting the results from the Pocket PEA meter. Shading was also an important factor for the seaweeds later in the day and the time when each species became shaded by the seawall or trees along King George V Memorial Walk was noted.

3.3 Fish

3.3.1 Fish behaviour in the low water pool during a normal tidal cycle

Visual observations of fish behaviour in the low water pool and the channels nearby, between 10:00 and 21:00 on 21 July are summarised in Table 1. At the beginning of the observation period, at 10:00, harbour water was still entering the low water pool. Observations were continued throughout the ebb tide and until the next flood tide topped the sill at the entrance to the low water pool. Video recording allowed counts of the number of surface breaks to be monitored and these results are shown in Figure 1.

Increased numbers of herring gulls swooping close to the surface of the pool was evident at about noon, when the water level in the pool was low and fish had accumulated in the low water pool, but no capture of fish was observed. Cormorants (or possibly shags) gathered at the exit channel from the pool during the period 11-12; they remained on the raised intertidal stretch between the canal and the low water pool and were not seen to be catching any fish.

Between 12 noon and 14:30 there was a rapid increase in mullet activity resulting in surface breaking visible on the video records. We have noted this increased activity (and shoaling) during previous visits to Copperhouse and during the fish survey in September 2010, so in advance of our systematic observations on the 21 July, we had anticipated that the number of surface breaks would continue to increase throughout the ebb tide. This did not occur.

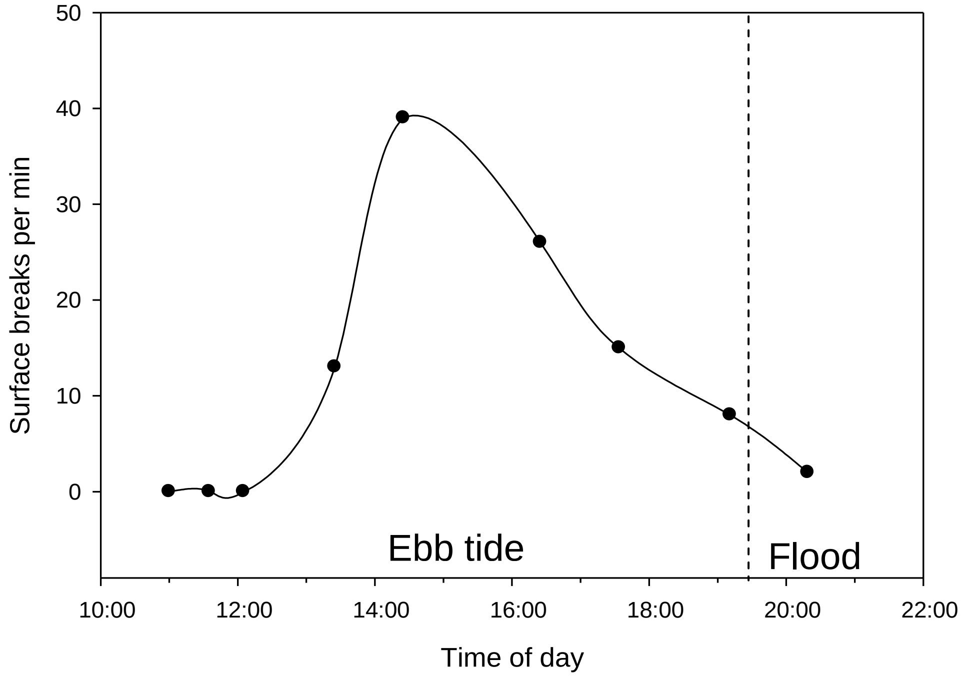
After 14:30, the number of surface breaks diminished, as shown in Figure 1, and this suggests that there is less swimming around when the fish settle down. By 19:11 only 8 breaks per min were recorded.

Table 4. Fish behaviour between 10:00 and 21:00 on 21 July 2011

Time	Tidal state	Visual observations from intertidal or car park
10:00-10:10	Inflow to low water pool, but approaching highest level	• 0+ fish mullet in shallow water close to intertidal - small shoals <10
11:00-11:10	Outflow from low water pool commenced	• Increased presence of juvenile fish. • Shoal (<10) 1+ mullet in margins of low water pool. • Several shoals of 0+ mullet, 10-20 fish per shoal in margins of pool.
11:35-11:45	Copperhouse Pool visibly empting at channel	• Increasing density of small shoals of juvenile mullet in shallow water
12:05-12:10	Ebb	• No signs of surface activity by fish in low water pool. • 0+ fish in shallow inflow channel • Increased gull activity over pool but no catches recorded in video records
13:25-13:43	Ebb	• Some signs of surface activity of mullet. • Some surface breaking. • Shoals of 0+ mullet in shallow inflow channel
14:25-14:30	Ebb	• Large amount of surface breaking by fish (mainly mullet) in deep section of pool. • Fish in shallow inflow channel.
15:25-15:35	Ebb	• Many fish surfacing in deep areas of pool. • Fish surfacing towards edge of intertidal (near site 8) – video record
16:22-16:30	Ebb	• Many mullet breaking the surface, but less than seen in 2010 • Lower density of 1+ and 2+ mullet in pool than in 2010 at this time • Lot of activity in shallows – too many surface breaks to count
17:30-17:40	Ebb slowing	• Little surface activity; plenty of 0+ and 1+ in shallows
19:05-19:15	Extreme low water level in pool	• Very still – little activity & reduced surface breaking.
20:15-20:20	Flood tide moving via channel into the low water pool	• Some jumping of large fish, probably 2+ mullet - possibly mullet from the canal entering the pool on the flood tide. • Many 0+, 1+ mullet seen moving upstream in the water channels, on the flood tide.

The video recording also captured images of fish jumping out of the water and showed a similar pattern of increased activity initially, but then settling down well before the arrival of the next flood tide, despite the high density of fish present. Video records before 14:00 did not show any fish jumps, but at 14:25 and 16:25, 3 jumps per min were recorded; this was reduced to 1 per min at 17:34; no jumps were captured on video at 19:11 or 20:19.

Figure 1 Number of surface breaks by fish in low water pool - 21 July 2011



3.3.2 Water quality and effects on fish in the low water pool

Water quality (salinity, dissolved oxygen, pH and ammonia, and metal concentrations) were monitored from 4 locations, which were marked with canes. National Grid References (NGRs) of the marker canes are given in Table 5 (below). Figure 15 shows the locations of these sites.

Salinity

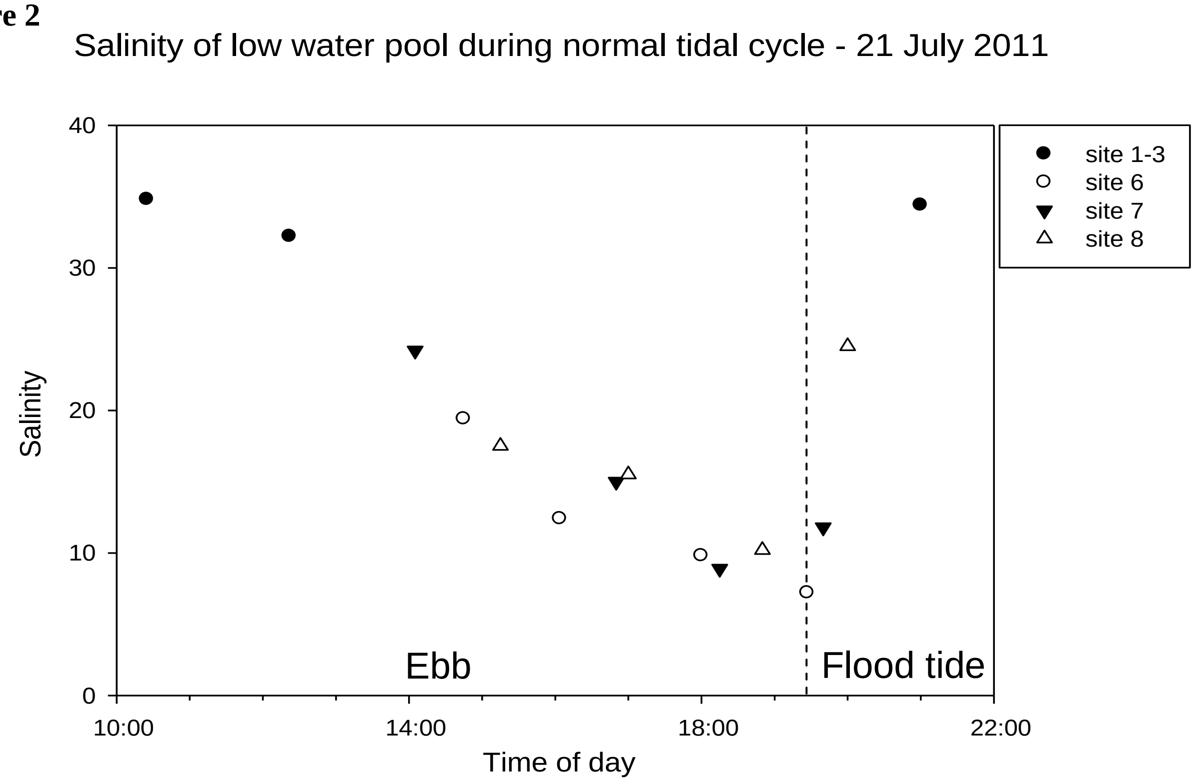
Figure 2 shows the salinities recorded within the low water pool in Copperhouse Pool between 10:25 and 21:00 on 21st July.

The salinity data show an important influence of freshwater inflow into the low water pool that must be considered in relation to the proposed tidal exclusion. At high tide, the salinity is equivalent to harbour water, at 34-35 psu. During the ebb tide, salinity of the low water pool decreases because of the continued passage of freshwater along channels that enter the low water pool. On 21st July, the salinity decreased to 10 psu or less at the 4 localities that

Table 5. NGRs and descriptions of water quality monitoring sites

Site	NGR	Site description
1-3	1 SW 55847 37745 2 SW 55853 37721 3 SW 55859 37736	Close to low water pool on side running parallel to King George V Memorial Walk. Sites 1-3 ran from the upper intertidal towards the channel that enters the northern side of the pool
6	SW 55871 37705	In deep section of pool on southern side, just beyond point where main freshwater input enters the pool
7	SW 55877 37711	On lobe of pool towards area of *Arenicola* on the intertidal mudflat on north-east side of pool
8	SW 55842 37721	On King George V Memorial Walk side of the low water pool, further towards causeway than sites 1-3

Figure 2



were monitored. Adjacent to the main freshwater input (Site 6) salinity reached 7.2. Salinity at this site declined slightly faster than at Sites 7 or 8 which were further from the freshwater influx (see Figure 15), but overall the data suggest that there is fairly rapid mixing within the pool. Even Site 8 on the King George V Memorial Walk side of the low water pool, reached a salinity of ~10 during the ebb tide (see Figure 1).

As a consequence of freshwater inflow into the low water pool, during the proposed tidal exclusion, salinity will inevitably reach lower levels. A value of 3.9 psu was recorded in the low water channel at the upper end of Copperhouse Pool and the low water pool could decrease to this level or below if there was no mitigation. Salinity tolerances of the species of fish in the low water pool are therefore important. The circumstances of the tidal exclusion will be highly unnatural as the fish will not be able to move to an area with higher salinity. Fortunately, the main species found in the pool have good tolerance of low salinities.

Mullet are the prime species and have been recorded in low salinity habitats. It is therefore considered unlikely that a single day of lower salinity resulting from tidal exclusion will be a significant problem for mullet in Copperhouse Pool.

Flounder have been recorded in Copperhouse Pool surveys. It is a euryhaline species (i.e. able to tolerate a wide range of salinities) that moves up and down estuaries and that can readily acclimate to different salinities, including freshwater. It therefore seems very unlikely that the predicted low salinity, for a single day, will be a problem for flounder.

Sea bass occur in Copperhouse Pool in small numbers. In our 2010 fish survey of the low water pool at Copperhouse, we caught seven 2+ Sea Bass fish in the pool, while in a previous survey in 2001, 20—30 juvenile Sea Bass were caught in the pool. Juvenile Sea Bass have been suggested to have a good ability to cope with low salinities and will be exposed to a period of low salinity on each tide in Copperhouse Pool. However, the 2+ fish Sea Bass, sandsmelt and sand eel could be close to the limits of their salinity tolerance during the natural tidal cycle. We have therefore recommended mitigation measures to limit a further decline in salinity.

Temperature

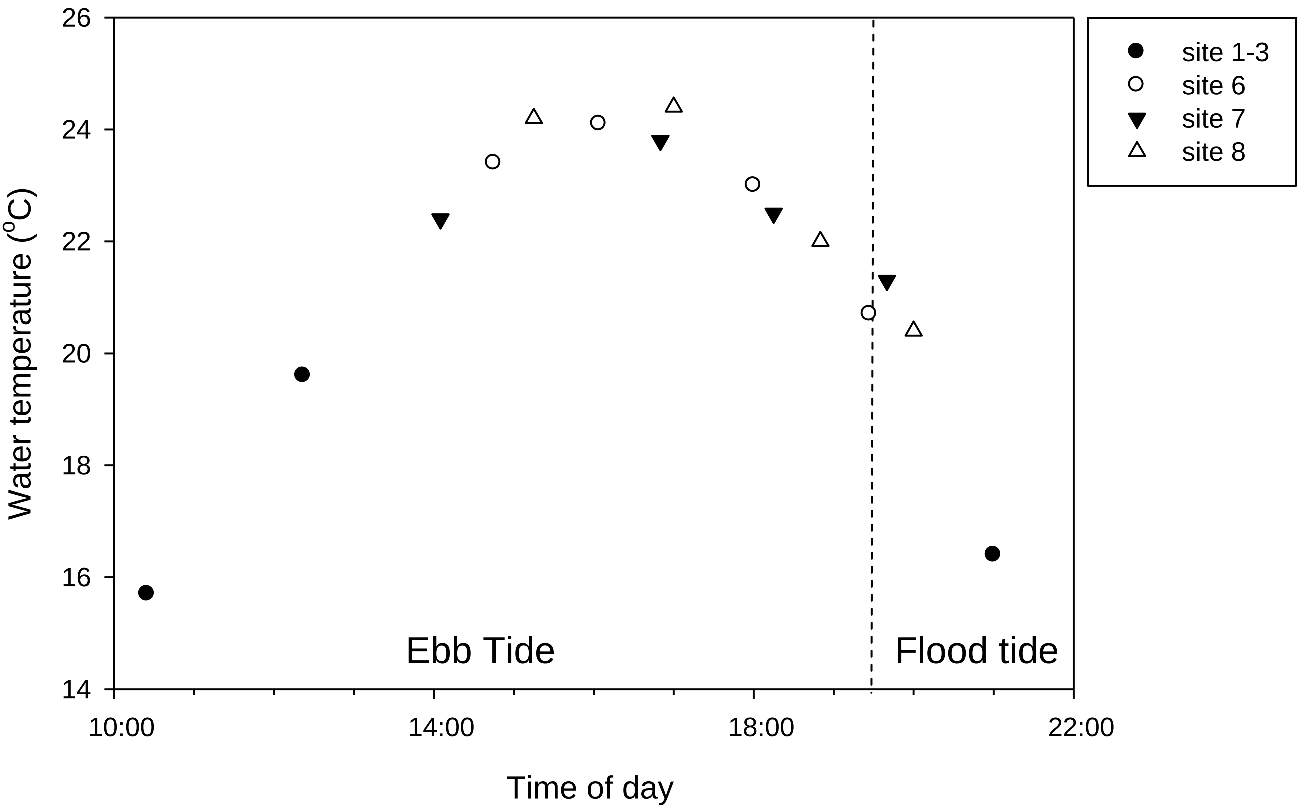
The 21 July was a clear sunny day with a peak air temperature of approximately 20 °C from 11:00 to 15:00. Air temperature declined from about 15:00 onwards and was 14 °C by 21:00. Water temperature (Figure 3) shows the combined influence of fluctuations in air temperature, the warming of a decreasing volume of water in the low water pool, thermal inertia of the water body, input of warmed freshwater during the low tide, and later in the day, the entry of cooler harbour water on the flood tide.

Water temperature was below air temperature from 10:00 to approximately 13:00. Thereafter, water temperature exceeded air temperature by several degrees and reached a peak of 24.4 ^{o}C at 17:00 whereas air temperature was 18.5 ^{o}C at 17:10. The entry of water from the harbour at 19:20 resulted in a rapid decline in water temperature.

Mullet and sea bass prefer warm waters; optimal temperatures are reported as 22-25 ^{o}C and 22 ^{o}C respectively, so under the normal tidal conditions experienced on 21 July the temperature conditions were ideal for these species. However, the proposed tidal exclusion will remove the temperature lowering effect of an influx of Harbour water and result in a longer period at higher temperatures that will increase the oxygen consumption of fish in the pool.

Figure 3

Water temperature during tidal cycle in low water pool - 21 July 2011



We therefore propose that exclusion should not take place if the predicted air temperature will exceed 20 °C since water temperatures above 25 °C would be likely to cause distress to some fish (such as gobies and sandsmelt).

It should be noted that there is always the possibility that actual air temperatures will be higher than predicted temperatures. For example, on the day of the survey, predicted air temperature was 16 °C and actual air temperature was 20 °C.

Dissolved Oxygen (DO)

Dissolved oxygen concentrations in the low water pool will be influenced by:

- Daily fluctuations in water temperature (oxygen solubility in water is reduced by an increase in temperature)
- Algal photosynthesis, in the margins of the pool when the intertidal is covered with water
- Biological Oxygen Demand (BOD) due to organic matter and nutrient content which determine oxygen use by bacteria in microbial degradation processes.
- Fish biomass and their oxygen consumption which increases with body temperature that closely follows water temperature (about 2-3 fold increase in oxygen requirement for a 10 ^{o}C rise in water temperature)

Dissolved oxygen records for the low water pool on 21st July are shown in Figure 4.

At present, the total biomass of fish in Copperhouse Pool appears to be significantly less than last year at this time. Although the fish population and species matrix could not be assessed from the surface observations, it appears that older mullet (2+ or older) are reduced in numbers and may have been temporarily displaced by disturbance. This could coincidentally be beneficial for the large numbers of younger cohorts that are still evident. In the event of a tidal exclusion we therefore predict that oxygen consumption by fish will be far less than we had anticipated based on previous assessments of fish populations in the pool.

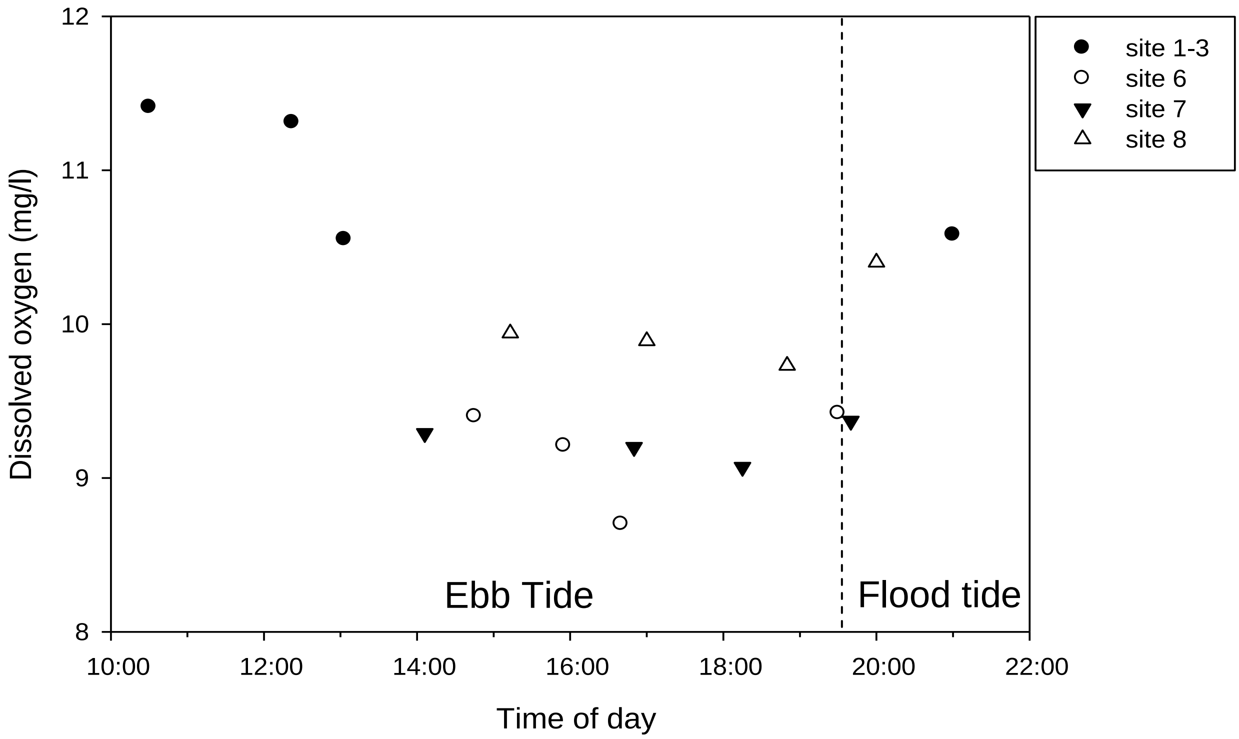
In a normal tidal cycle, on 21st July, all values for DO exceeded 100% saturation (range: 102 to 125.6 % saturation). Sites 1-3, in the marginal fucoid zone and the shallow water channel that feeds into the low water pool, were monitored early in the day and had the highest % saturation with oxygen (116 to 125.6 %). Deeper sites, (6, 7 & 8) above muddy sediments and would not have the benefits of nearby algal photosynthesis, and these sites showed lower % saturation with oxygen, although again DO always exceeded 100% (102 to 117.5 %). Good conditions for fish were maintained throughout the day, with lower fluctuations at a site over time than for changes in salinity or temperature. For example, at Site 7, DO between 14:00 and 10:00 was maintained between 103 and 107 % saturation.

For fish in the low water pool, what matters is the oxygen tension in the water or the concentration of dissolved oxygen (mg/l). Figure 4 shows that the changes in dissolved oxygen concentrations at each monitored site throughout the day.

Dissolved oxygen concentrations were not surprisingly highest in the shallow water margins (Sites 1-3) where DO of 10.6 and 11.4 mg/l were recorded. In these locations, atmospheric uptake of oxygen could have a significant influence on DO, which will be further elevated by algal photosynthesis. Young fish (0+ and 1+ cohort) were observed to make frequent good use of these habitats, and move back and forth in the shallow water (see Table 1). These locations might not exist during the proposed tidal exclusion if water levels are allowed to fall as in the current tidal cycle The recommendation to use of sandbags at the exit from the low water pool could maintain marginal habitats with higher DO for a longer period of time.

Figure 4

Dissolved oxygen in low water pool during normal tidal cycle - 21 July 2011



At Sites 6, 7 and 8 during the ebb tide, DO varied between 8.7 mg/l and 10.40 mg/l at high tide levels or on the flood tide When water temperature peaked (16:40 at site 6; see Figure 3), dissolved oxygen reached the lowest levels recorded that day (8.7 mg/l)

The tidal exclusion would hold fish in the confines of the low water pool for a longer period and therefore dissolved oxygen would continue to decline, reaching perhaps to 7 mg/l. We do not anticipate that a DO of 7 mg/l would be problematic for mullet, the main fish species in the pool. Mullet do not require high oxygen concentrations and may live in lagoons with oxygen concentrations of <3 mg/l.

pH

Before this survey we had envisaged that a high density of fish in the pool may potentially reduce water pH, but Table 2 shows that water pH was fairly stable throughout the tidal cycle, only varying between 8.2 and 8.5. This is probably due to a high buffering capacity of the water coupled with the somewhat lower biomass of fish in the low water pool than anticipated so that their release of carbon dioxide into the water did not acidify the water. With tidal exclusion for a day we do not anticipate that water pH would be significantly affected. Therefore the impact of pH on ammonia ionisation will not be relevant.

Table 6. pH, total ammonia and unionised ammonia in the low water pool throughout the day (21 July, 2011)

Time	Site	pH	Total Ammonia (mg/l) Measured	Unionised Ammonia (mg/l) Calculated
10:37	1	8.3	0.09	0.0052
12:22	2	8.2	NA	NA
13:03	3	8.3	0.02	0.0017
14:10	7	8.3	NA	NA
14:35	7	8.3	0.05	0.0043
14:45	6	8.3	0.08	0.0069
15:15	8	8.4	NA	NA
16:40	6	8.4	< detection limit	< detection limit
16:50	7	8.3	< detection limit	< detection limit
17:00	8	8.4	< detection limit	< detection limit
18:00	6	8.4	0.09	0.0099
18:15	7	8.5	0.02	0.0026
18:55	8	8.4	0.07	0.0072
19:30	6	8.4	0.07	0.0063
19:40	7	8.4	0.11	0.0108
20:00	8	8.3	0.06	0.0045
21:00	1	8.2	< detection limit	< detection limit

Ammonia

Fish excrete up to 90% of their nitrogenous waste as ammonia which is normally diluted by the water and therefore non-toxic, but a high density of fish in the low water pool could cause an increase towards toxic levels. Ammonia toxicity increases with higher temperatures, salinity and pH, mainly due to the increased proportion of unionised ammonia, (NH_3), which is 300-400 times more toxic than the ionized form (NH_4^+). From our measurements we have calculated the proportion of unionised ammonia.

Comparison of the lethal threshold concentrations for unionised ammonia for the fish species that have been recorded in the Copperhouse Pool with the highest concentrations recorded during our survey on the 21 July, gives an idea of the likelihood of problems due to ammonia accumulation. The highest concentration of unionised ammonia that we recorded was 0.011 mg/l (Table 2), but this only occurred on one occasion and it was after the return of harbour water into Copperhouse Pool, at 19:40. The next highest value of 0.63 mg/l also occurred after the start of tidal inflow to the pool. Such circumstances would not apply during tidal exclusion. This high value may have resulted from sediment disturbances, which were otherwise avoided during our sampling.

During the ebb tide, unionized ammonia concentrations varied from below detection (recorded as zero by the meter) to 0.0072 mg/l. Therefore the highest value during the ebb tide was less than 100-fold below the threshold concentration for mortalities of juvenile Sea Bass and less than 300-fold below the threshold concentration for mortalities of juvenile Gilthead Seabream (Lemarié et al., 1996; Wajsbrot et al., 1991).

There was a noticeable decrease in ammonia concentration during the ebb tide, reaching non-detectable levels (< 0.002 mg/l) which suggests that there is rapid and effective ammonia degradation in the pool. On this basis, we would not expect to see any damage to fish in the low water pool resulting from ammonia exposure during a tidal exclusion.

Metals (total & dissolved)

Table 7 shows the Environmental Quality Standards (EQS) for metals in estuarine waters. Generally it is the dissolved metals that are directly toxic to fish and the EQSs are usually stated as dissolved concentrations. However, for zinc the EQS is stated as the total (annual average). For water samples collected on 21 July, both total and dissolved metal concentrations were measured.

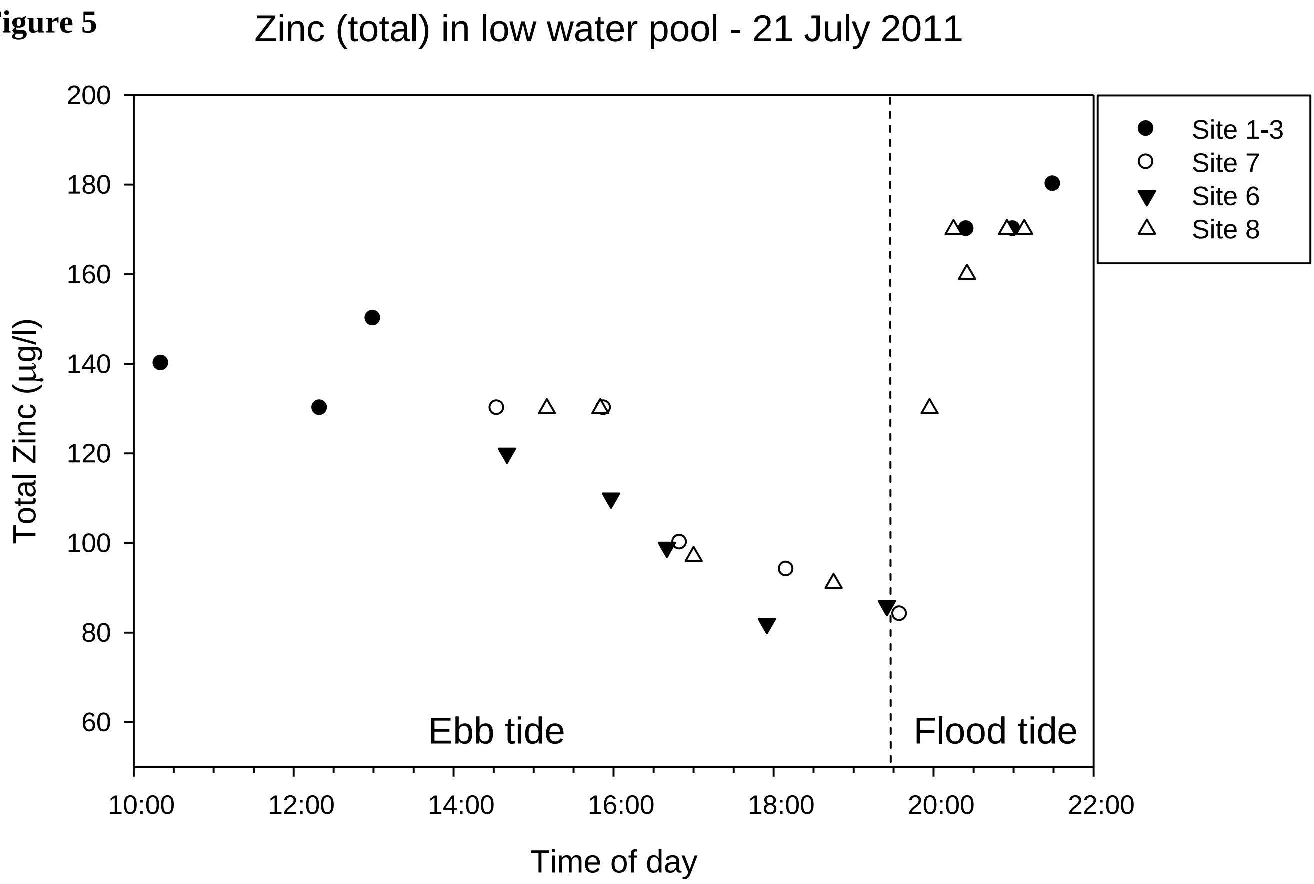
The analysis of water samples collected from the low water pool showed the dynamic changes in metal concentrations in a normal tidal cycle within the low water pool and the impacts of tidal influx of harbour water on the flood tide and freshwater on the ebb tide.

For mercury, lead and nickel there are no particular issues regarding exceedance of the EQS and these are not considered further.

Zinc

Zinc concentrations are high in Hayle Harbour (Table 3). On the incoming tide, the total zinc concentrations in the low water pool exceeded the EQS for total zinc by up to 4.5 fold. During the ebb tide the concentration of zinc decreased in the low water pool (Figure 5). This is probably due to attachment of zinc to the sediments in the pool, which we were careful to avoid disturbing by using a sampling pole. During the ebb tide, zinc concentrations decreased to just over 2-fold the EQS for total zinc in coastal and estuarine waters. This means that during the proposed tidal exclusion the zinc concentration in the pool will probably fall further and may get close to the EQS for total zinc.

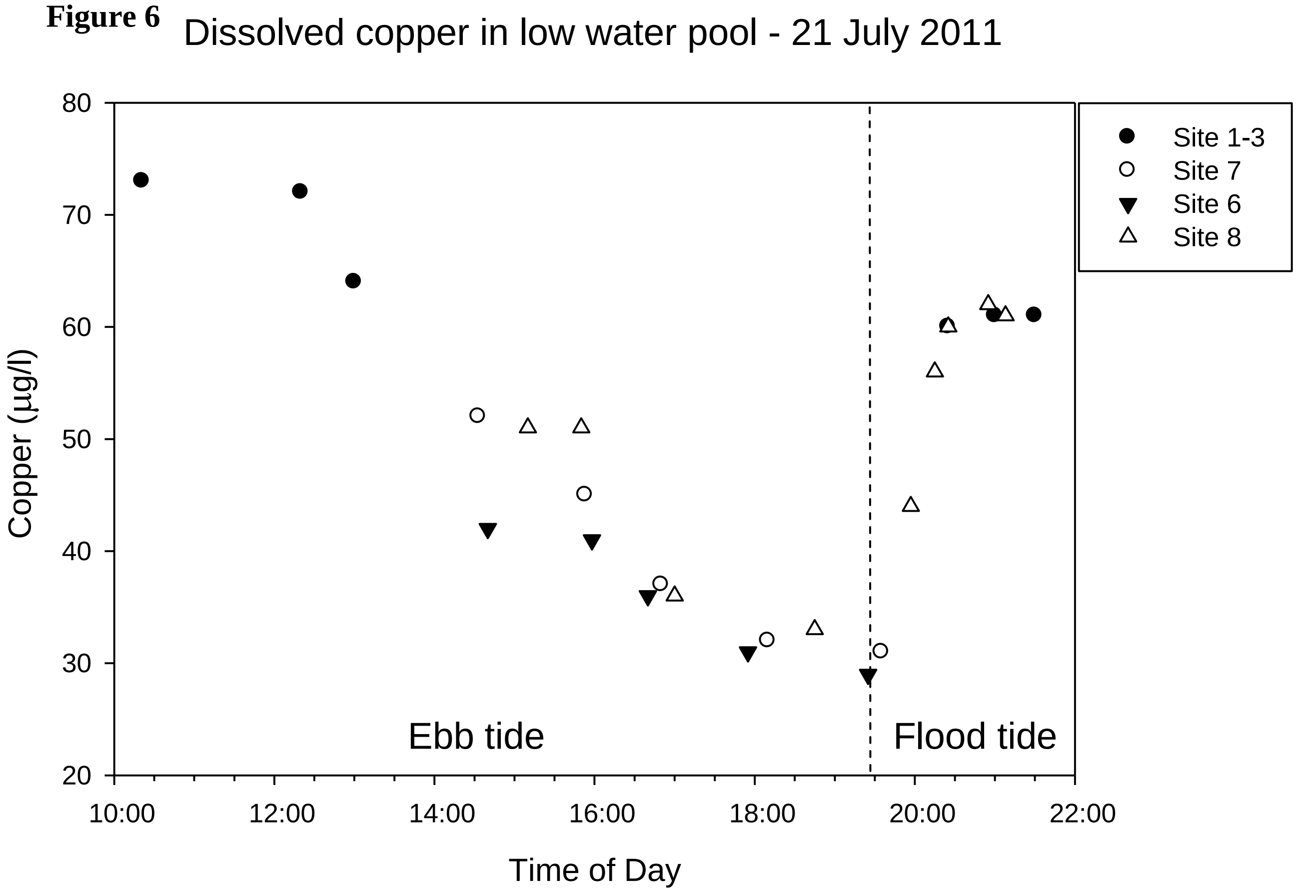
Figure 5



Copper

Copper concentrations were high in Hayle Harbour (Table 3) and the flood tide brought in high concentrations to Copperhouse Pool. On 21 July, the highest concentrations were seen at the beginning of the day, when the low water pool water exceeded the EQS for dissolved copper by 14.6 fold. During the ebb tide, the concentration of copper decreased in the low water pool (Figure 6), probably due to attachment to sedimentary material in the pool (as for zinc). During the ebb tide, dissolved copper concentrations decreased to 5.8-fold EQS. Although the rate of decrease in dissolved copper was decreasing towards the end of the ebb tide, we can expect that the water quality in the pool will improve further during the proposed tidal exclusion. The improvement in water quality will be helped by the inflow of freshwater containing lower concentrations of copper (dissolved copper in low water channel water was 3.6 x EQS).

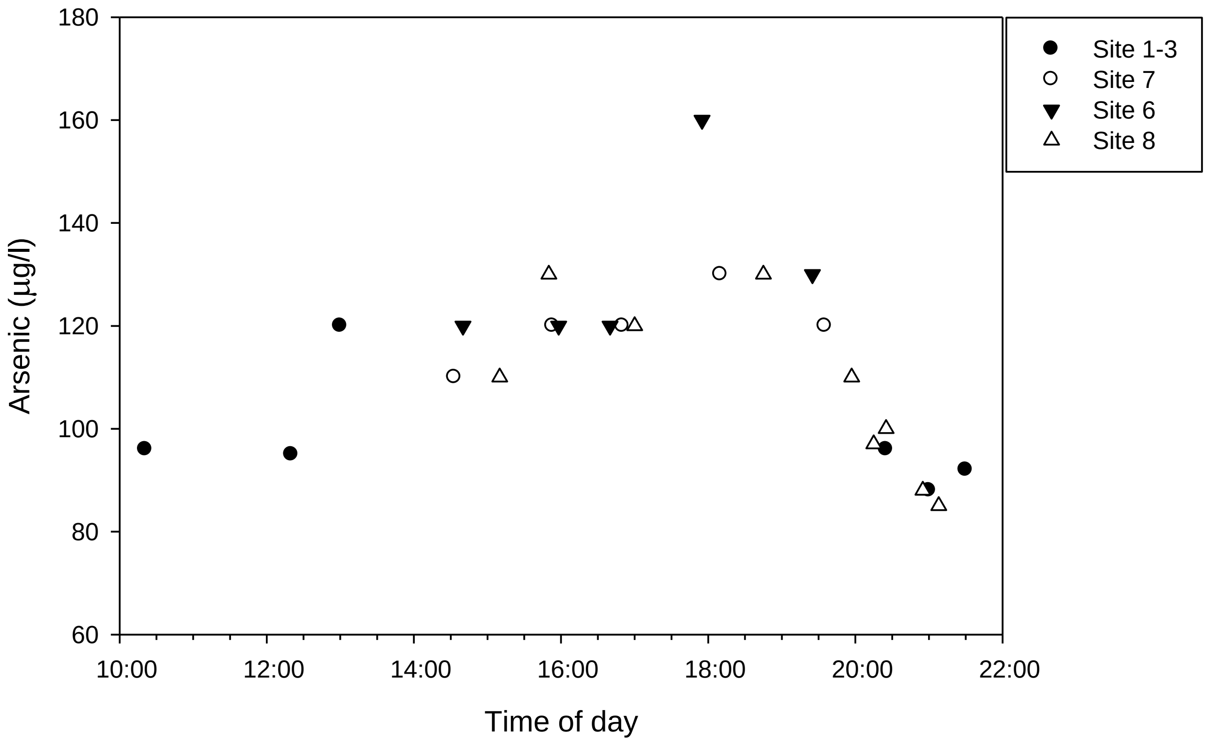
Figure 6



Arsenic

Arsenic concentrations were high in both the harbour and low water channel, exceeding the EQS by 2.8 and 4.4 fold respectively. During the ebb tide, there was a slight increase in the concentration of arsenic in the low water pool, which stabilised at about 130 µg/l, (Figure 7) perhaps reflecting the slightly higher concentrations in freshwater input. Concentrations of arsenic decreased rapidly with the next flood tide. In the proposed tidal exclusion, it is likely that arsenic concentrations will stabilise at slightly higher concentrations, perhaps around 160 µg/l, but this is unlikely to have any impact on the fish and invertebrates in the pool that have adapted to live in an environment with high concentrations of arsenic.

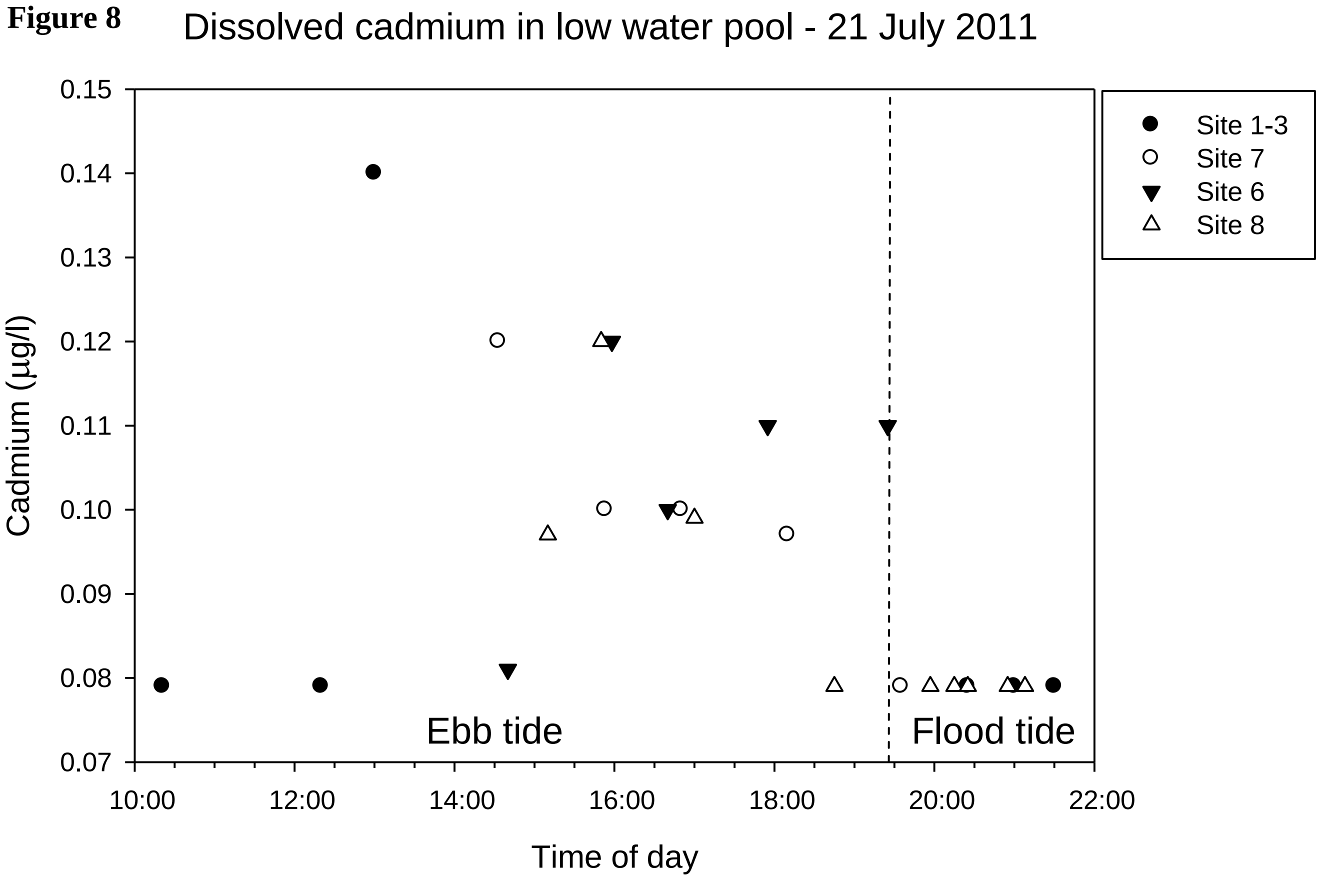
Figure 7 Dissolved arsenic in low water pool - 21 July 2011



Cadmium

Cadmium concentrations in the low water pool increased during the ebb tide but did not reach concentrations that exceeded the EQS for cadmium in coastal and estuarine water (Table 3). In harbour water, cadmium was below detection limits (<0.08 µg/l) so each tidal cycle reduces the cadmium concentration in the low water pool, which can be seen in Figure 8. Cadmium in the low water channel exceeded the highest concentration in the low water pool, so freshwater inflow could raise concentrations during the proposed tidal exclusion. However, binding to sediments could mean that there is at most a small increase in cadmium concentration. It is very unlikely that the EQS will be exceeded; in a normal tidal cycle the maximum concentration of cadmium in water from a channel entering the low water pool was 0.03 of the EQS.

Figure 8



Chromium

The results showed high concentrations of dissolved chromium in Hayle Harbour, which increased the concentration of dissolved chromium in the low water pool on each tidal cycle. The peak dissolved chromium concentration, at the start of our study was 16-fold the EQS for coastal and estuarine waters. However, the chromium EQS was set to protect organisms that are more sensitive than fish, so it is higher than necessary to protect fish.

Chromium concentrations decreased during the ebb tide (Figure 9) reaching 3.5-fold of the EQS. Chromium concentration in the low water channel was almost half of the lowest concentration recorded in the low water pool. Therefore both binding to sediments and dilution by cleaner freshwater input should reduce the concentration of chromium in the low water pool during the proposed tidal exclusion.

Figure 9 Dissolved chromium in low water pool - 21 July 2011

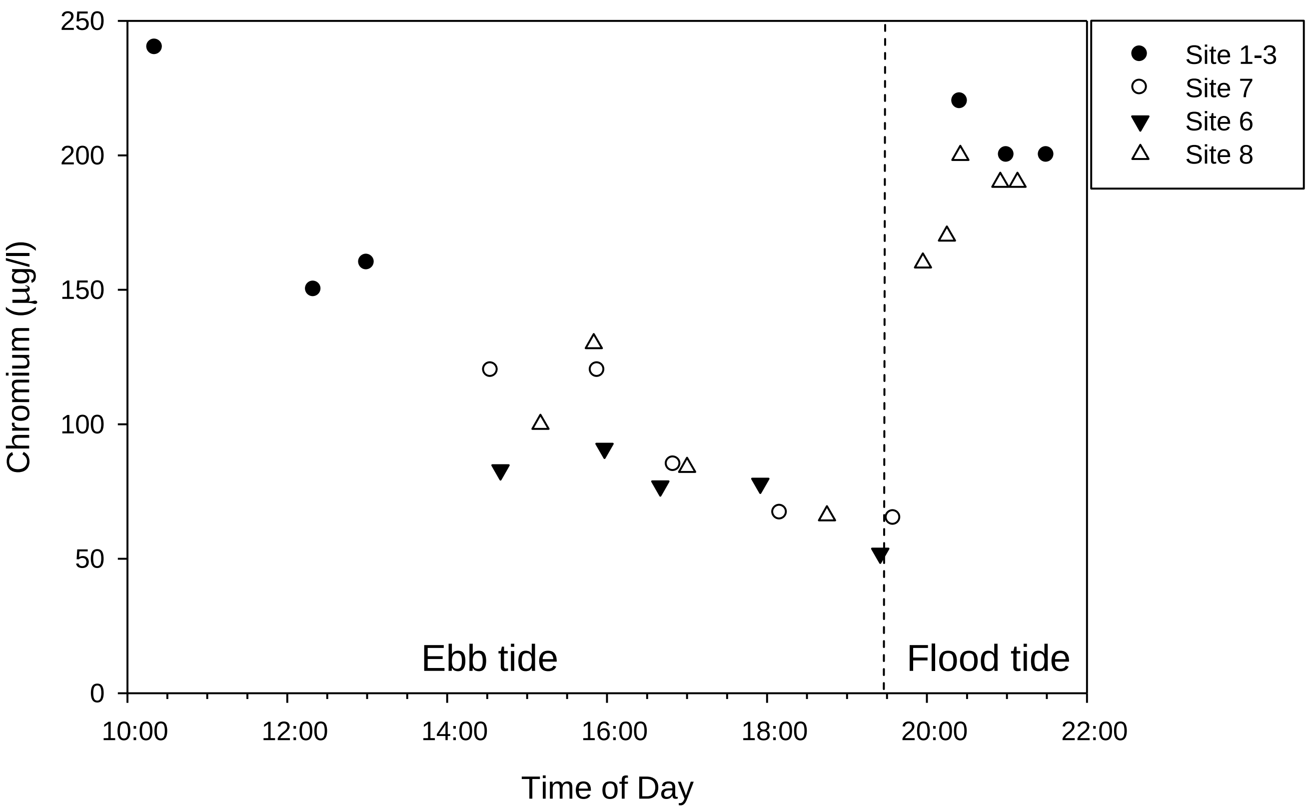


Table 7. Environmental Quality Standards (EQS) for dissolved metals (or total for zinc) in coastal and estuarine waters compared to the maximum values recorded in samples collected at Hayle on 21 July (LW Pool = low water pool).
EQS values are for annual average; NA = non-applicable.

Metal	**EQS Dissolved Metal µg/l**	**EQS Total Metal µg/l**	**Low water pool** Maximum Dissolved Metal conc. (time) µg/l	**Low water pool** Maximum Total Metal conc. (time) µg/l	**Harbour** Dissolved metal; total for zinc µg/l	**Low water channel** Dissolved metal; total for zinc µg/l	**Low water pool Ratio of Max conc : EQS** dissolved metal; total for zinc	**Harbour Ratio of Max conc: EQS** Dissolved metal; total for zinc
Arsenic	25	NA	160 (17:55)	160	70	110	6.4	2.8
Cadmium	5	NA	0.14 (13:00)	0.14	<0.08	0.16	<1.0	<1.0
Chromium	15	NA	240 (10:21)	270	210	28	16.0	14.0
Copper	5	NA	73 (10:21)	110	69	18	14.6	13.8
Lead	25	NA	<1.0	4.3 (10:20)	6.4	1.5	<1.0	<1.0
Mercury	0.5	NA	0.7 (20:25)	<0.50	0.54	<0.5	<1.0	<1.0
Nickel	30	NA	15 (20:25)	21 (20:25)	18	7.8	<1.0	<1.0
Zinc	NA	40	120 (20:25)	180 (21:30)	120	96	4.5	3.0

3.4 Seaweeds and Higher Plants

3.4.1 Bladder wrack, *Fucus vesiculosus*

Mean Fv/Fm and PI values for bladder wrack are shown in Figure 10. Water content of bladder wrack, air temperature and humidity are also shown. The study site (Site 15) is shown in Figure 16.

The results confirm our initial concerns that some intertidal algae are at their physiological limits during hot, sunny and/or windy weather. Water content of bladder wrack fell from 64% at the start of the study to 16% at 18:00. It then steadily increased to 36% immediately prior to being covered by the incoming tide and increased further to 48% when it had been covered by seawater for a few minutes. The increase in water content during the latter part of the low water period indicates that bladder wrack can partially rehydrate from atmospheric moisture.

During a trial tidal exclusion that the water content would probably fall below 16% during hot and/or breezy conditions, especially if humidity was low. For this reason we have put in extra safeguards regarding acceptable weather conditions during the tidal exclusion.

Note that Fv/Fm and PI values fell close to zero at 16:00, but then slowly recovered. It is likely that the recovery was due to increased humidity, as the rate of drying of the plants slowed down after 16:00 and by 18:00 the water content started to increase. The four *Fucus* plants we monitored were in shade from about 19:00 and this coincided with a short-term decrease in Fv/Fm and PI values. The bladder wrack plants we were studying were covered by the flood tide at about 21:10, about 15 minutes later than the lowest limit of bladder wracks near the study site.

A sample of bladder wrack plants attached to a rock were placed in an air tight container before they were inundated. The following day this sample was exposed to the air and readings of Fv/Fm and PI were obtained. The specimens were then sprayed with freshwater to simulate rainfall and were later inundated with seawater to assess recovery. The results are shown in Figure 11. The results show that light rainfall (ours was equivalent to two short rainfall events of 0.75 mm each, over a period of just under an hour) would be beneficial to bladder wrack plants, especially the Fv/Fm ratio. Re-immersion in seawater resulted in rapid a further increase in Fv/Fm values, to values similar to those of *Fucus vesiculosus* that had just been uncovered by the tide at the start of the study. The plants were left in seawater overnight (a longer period than would occur naturally, but does occur during occasional weekend events at Hayle) and the final Fv/Fm reading of 0.645 is the highest in the series. The PI data are more complex to interpret.

Figure 10. Response of *Fucus vesiculosus* to a normal tidal cycle.
Mean Fv/Fm & PI values plotted on right axis; other parameters on left axis.

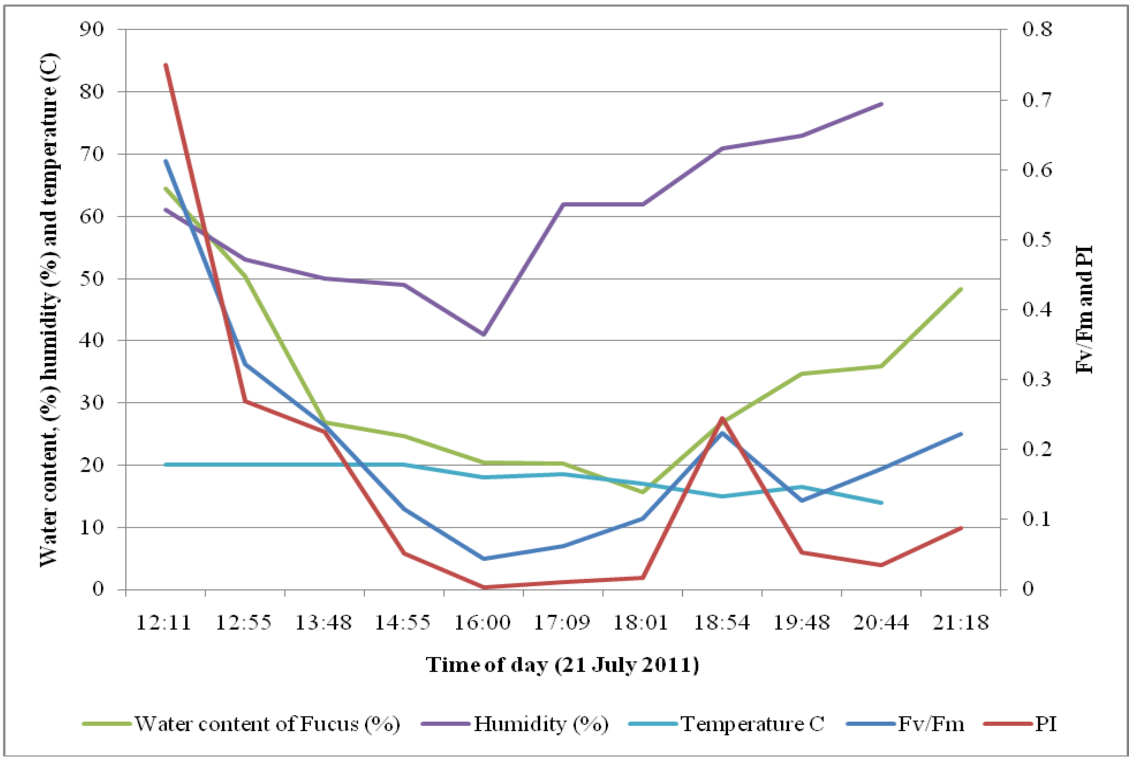
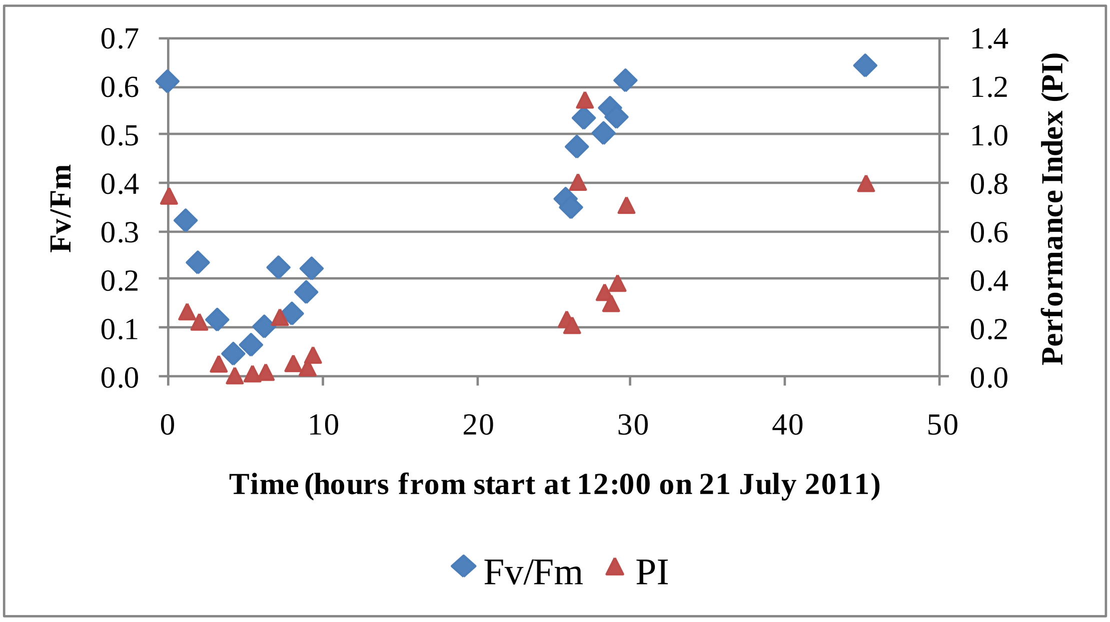


Figure 11. Extended study of *Fucus vesiculosus* response to desiccation, rainfall and re-immersion in seawater. First part of graph shows data for first day, and is the same data as in Figure 10 (above). Middle part of the graph is the second day, when the Fucus plants were initially in air, then wetted with freshwater, followed by immersion in seawater at 28.7 hours after start. The final data point is at 45.25 hours after start (09:16 on the third day) when the *Fucus* had been in seawater continuously for 15.55 hours. The final data point is expected to be similar to the highest Fv/Fm values that *Fucus vesiculosus* plants in Copperhouse Pool may reach.

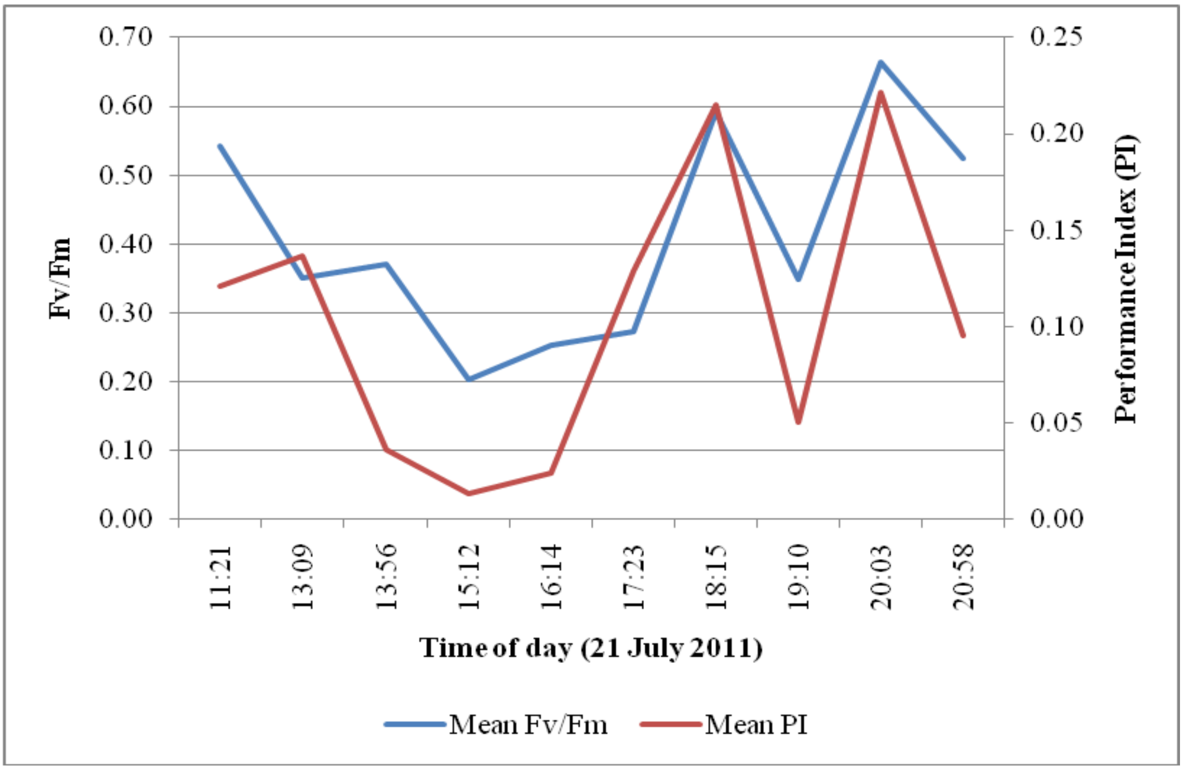


3.4.2 *Rhizoclonium riparium* and other filamentous green algae

The filamentous green alga *Rhizoclonium riparium* was present in a narrow band on the upper shore at Site 14 (see Figure 16 for location). On the day of the survey the zone of *Rhizoclonium riparium* was only just reached by the morning high tide, and on a neap tide would not have been covered. This suggests that this species would be tolerant of the trial high tide exclusion. The results from the Pocket PEA meter (Figure 12) show that Fv/Fm values fell to a mean value of approx 0.2 at 15:12 but then recovered strongly as humidity increased, then recovered more strongly when the algae were in shade from about 17:30. By 20:00 Fv/Fm values were similar to those at the start of the day.

The combination of the location on the upper intertidal, where it is only covered by some high tides, and its ability to recover quickly from desiccation stress when humidity rises and/or the plants are in shade, mean that this species is unlikely to be affected by a single tidal exclusion. We would expect other filamentous green algae such as *Ulva* spp. (previously mainly in *Enteromorpha*) to respond well to humidity and shading, but in case this is not correct we will monitor the large areas of filamentous green algae (mainly *Ulva* spp.) near the low water pool during the tidal exclusion.

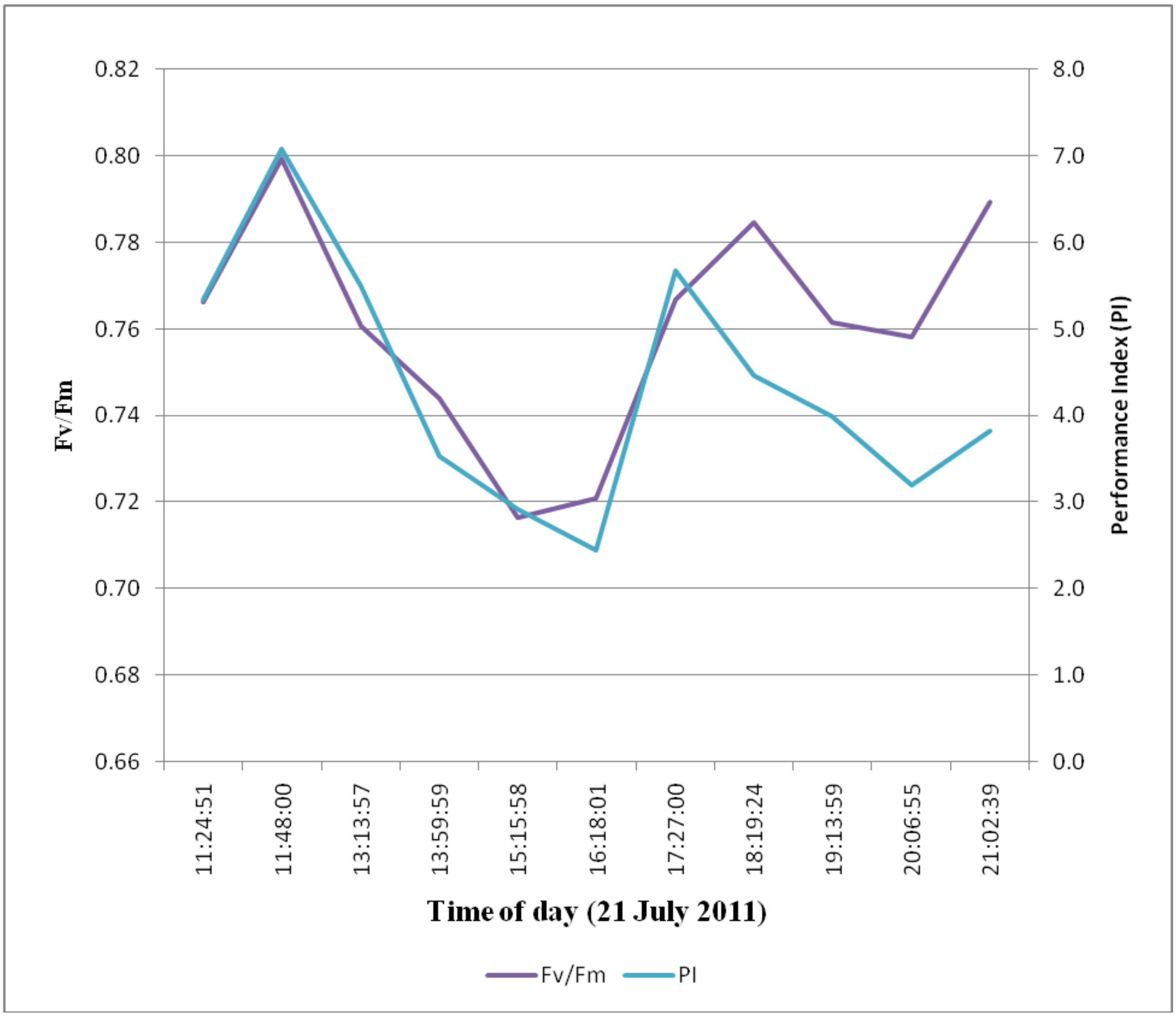
Figure 12. Response of *Rhizoclonium riparium* to a normal tidal cycle.



3.4.3 Cord grass (*Spartina anglica*) and glasswort (*Salicornia* spp.)

The *Spartina anglica* monitoring site is shown in Figure 16 (Site 13). Compared to bladder wrack (*Fucus vesiculosus*) and *Rhizoclonium riparium*, Fv/Fm and PI values did not fall very low during the tidal cycle, reaching minimum values around 15:30 (Figure 13). This is a normal response of plants to the highest levels of sunlight. After 16:00 both parameters increased rapidly until about 18:20, presumably due to the normal daily cycle and the increased humidity. By 16:20 Fv/Fm ratios were only slightly lower than those at the start of the study. Fv/Fm and PI values then fell again until 20:06, when they showed a slight increase, possibly due to the clump of *Spartina* being monitored being in the shade from 19:35 onwards. The final reading was taken before the *Spartina* was inundated and both Fv/Fm and PI values would be expected to increase further during the short period when the plants would have been covered by the tide.

Figure 13. Response of cord grass (*Spartina anglica*) to a normal tidal cycle.



3.5 Invertebrates – Activity and Toxicity

3.5.1 Ragworm, *Nereis diversicolor*

We were not able to locate any sites where there were ragworm on the surface during the normal low water period. We think that a baseline density of zero per square metre would be suitable for monitoring the effects of the trial tidal exclusion on ragworm activity. We expect ragworm to be very tolerant of a single day of tidal exclusion, but repeated tidal exclusions on successive days could affect reproduction and feeding.

3.5.2 Lugworm, *Arenicola marina*

Lugworm casts at two sites close to the low water pool were monitored soon after they were uncovered by the ebb tide (Table 8). The counts in the area furthest upstream (Site 4) were consistently lower than those in the area close to the low water pool (Site 5). In the less dense area the counts remained stable throughout, although this area was were not monitored immediately after it was uncovered by the ebb tide.

The minor variations in the density of lugworm cast throughout the day at a particular site suggests that this parameter could be monitored less frequently during the trial exclusion. We do not expect lugworm to be sensitive to a single tidal exclusion.

For the proposed exclusion we propose monitoring lugworm casts at 3 locations in 1 m^2 quadrats at the predicted time of low water (when numbers have peaked) on the day before exclusion, the day of exclusion and the following day.

Table 8. Lugworm (*Arenicola marina*) casts at two locations in Copperhouse Pool over the tidal cycle. Counts were made in four 0.25 m^2 quadrats to cover an area of 1.0 m^2 at each location.

Site 4 SW55953 37766 Time	**1**	**2**	**3**	**4**	**Total**
12:20	5	6	5	3	19
14:14	5	6	4	3	18
16:05	5	6	5	3	19
18:25	5	6	5	3	19
Site 5 SW55889 37718 Time					
12:50	5	6	7	4	22
13:50	5	5	6	9	25
16:00	6	6	7	8	27
18:20	7	6	6	7	26

3.5.3 *Corophium volutator* (an amphipod crustacean)

Densities of *Corophium volutator* were extremely low on all occasions they were monitored. The typical density was 0 in five 10 x 10 cm squares. The maximum density was just after the tide had receded, when 3 individuals were noted in the 5 combined 10 x 10 cm squares. We monitored the Corophium quadrats as they were being covered by the flood tide and expected an increase in activity, but this did not occur.

We do not expect *Corophium volutator* to be affected by a single tidal exclusion, but have retained the proposed monitoring for this species.

3.5.4 Rough periwinkle, *Littorina saxatilis*

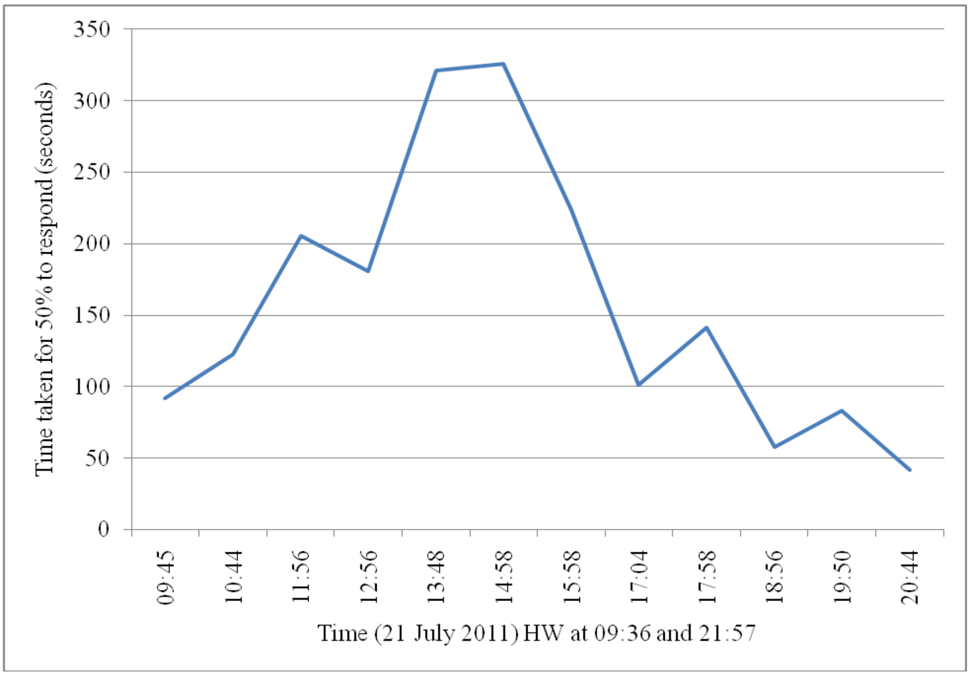
There were marked differences in the time taken for 50% of rough periwinkles to become active when placed in water (Figure 14). The quickest response times were when the tide had either just receded or was about to cover the zone from where the rough periwinkles were obtained. We interpret these results as showing a clear tidal rhythm, and it is possible that this method would be useful for long term monitoring of the activity of rough periwinkles. However, further monitoring of this species is probably not needed as we found that many of the rough periwinkles were at a level above the tidal limit on 21 July.

We brought back some specimens to the laboratory to determine their ability to survive extended desiccation followed by a high temperature (30°C for 20 minutes). Their response time was 3 minutes 58 seconds, indicating their very high tolerance to desiccation. We also assessed their ability to withstand the low water channel salinity (3.9 psu). The specimens did not move during an exposure of 4.5 hours, but when placed in 24 psu water they became active after 4 mins 18 seconds. Overall, we assess this species as being very tolerant of desiccation, low salinities (eg from heavy rain) and the relatively high metal concentrations in the low water channel. It is probably not necessary to monitor rough periwinkles during the trial exclusion.

3.5.5 Shore crab, *Carcinus maenas*

Moderately high numbers of juvenile shore crabs were seen on the upper intertidal, especially in shallow water at high tide. Larger crabs were found beneath stones. We did not do any assessment of their tolerance in the field, as crabs can hide under stones and damp seaweed during very dry conditions. We did assess their ability to tolerate the low salinity and moderately high metal concentrations in water from the low water channel. The specimens tested were extremely tolerant and survived for approximately 1 day.

Figure 14. Time taken for 50% of *Littorina saxatilis* to become active.



3.5.6 Brown shrimp, *Crangon crangon*

The metal content of the low water channel water sample was analysed by Chemtest. Cadmium concentrations (dissolved and total) and total lead were higher than samples from the low water pool or harbour, suggesting that the low water channel may be an important source of cadmium and lead. Other metals were below the mean values for the range of water samples taken from the harbour and low water pool.

The toxicity tests using brown shrimps that had been held in 24 psu water before transferring to either 3.9 psu (low water channel water) or harbour water (34 psu) showed some mortalities in the 3.9 psu water. As it was not clear whether these were due to the salinity or the metal content we carried out further tests. The conclusion was that it was the sudden transfer from 25 psu to 3.9 psu which caused the mortalities. Brown shrimp from Copperhouse Pool were then tested after allowing adaptation to decreasing salinities. No mortalities occurred down to 2 psu (approximately 6% seawater). At 1 psu the smallest brown shrimp started to die after 30 minutes. Half the specimens (mainly the smallest ones) were dead after 3 hours 15 minutes. The lethal time (LT50) for 50% of the specimens at 1 psu is therefore 3:15. The lethal time (LT25) for 25% of the specimens was >24 hours. These are important results as they suggest that brown shrimp mortalities would probably not occur in the low water channel during the tidal exclusion. However, very heavy rain during the tidal exclusion could result in a salinity of <2 psu and this would be expected to result in some mortality. There is little likelihood of a mass mortality of brown shrimp provided that the trial exclusion does not occur after heavy rain or when heavy or persistent rain is forecast.

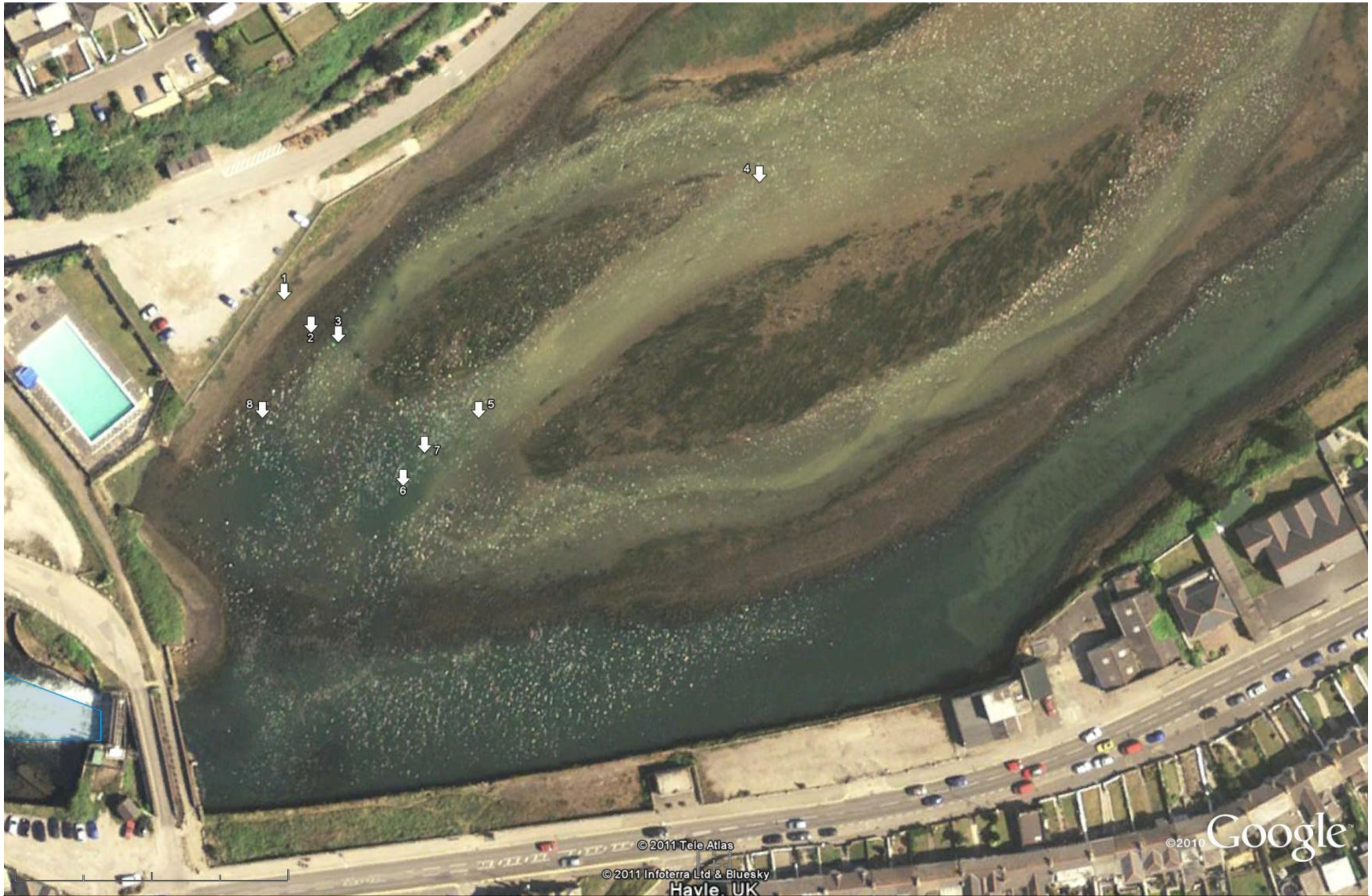


Figure 15. Water quality sampling sites near the low water pool (1 - 3 and 6 - 8) and study sites for *Arenicola* casts (4 & 5).

Figure 16. Study sites for *Littorina saxatilis* (11), *Salicornia* spp. (12), *Spartina anglica* (13), *Rhizoclonium riparium* (14), *Fucus vesiculosus* (15) and *Corophium volutator* (16 & 17).