Sydney Desalination Plant

Marine & Estuarine Monitoring Program

Recruitment and Salinity Studies

Final Report

November 2013

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Executive Summary

This report summarizes the Recruitment and Salinity Studies, conducted as part of Sydney Desalination Plant's Marine and Estuarine Monitoring Program. These studies were designed to assess impacts of desalination brine effluent on (i) the salinity of waters surrounding the desalination outfall, and (ii) the recruitment of sessile marine invertebrates around the outfall.

Potentially impacted locations were positioned at three distances from the outfall (20, 40, and 100 m), and four reference locations were positioned between 1.5 and 8.5 km north and south of the outfall. Data were analysed with a Multiple Before-After Control-Impact (MBACI) design. Both the Recruitment and Salinity Studies had 9 rounds of sampling data (5 pre-commissioning and 4 post-commissioning) to test for impacts. The Recruitment Study continued monitoring for an additional two rounds after the plant entered a period of shutdown in order to test for recovery from any impacts.

The brine effluent caused an average increase in salinity of approximately 1 psu at the seafloor (28 m depth), at a distance of 20 m north and south of the outfall. Salinity was lower at shallower depths, and decreased with distance away from the outfall as the brine mixed with surrounding seawater. Elevation in average salinity was 0.8 psu 40 m from the outfall, and 0.6 psu 100 m from the outfall. The plume was approximately symmetrical, extending similarly in north and south directions. There was no evidence that the brine effluent affected salinity at Boat Harbour Aquatic Reserve, or affected temperature at any location.

There were clear but spatially-restricted impacts of plant operation on recruitment assemblages. Recruitment of polychaetes, bryozoans and sponges all decreased near the outfall, and effects tapered off with distance in both north and south directions. Impacts were most severe for polychaetes (e.g. *Pomatoceros taeniata*), which showed heavily reduced abundance as far as 100 m from the outfall. In contrast, barnacles and hydroids increased in abundance around the outfall during plant operation. The most conspicuous of these was the pink barnacle *Megabalanus coccopoma*, which occurred in large, dense aggregations.

Given that elevation in salinity near the outfall was not excessively high (1 psu) compared to the natural range (0.3 to 0.4 psu annually), it is possible that mechanisms other than salinity toxicity are contributing to the observed change in recruitment. In particular, increased flow near the outfall diffusers may have impeded larval mobility and/or settlement in some taxa, and facilitated the settlement of others. Less likely impact pathways include change in pH, which may interfere with the calcification of exoskeletons, and toxic effects of antiscalants or other contaminants.

Continued monitoring after the plant was shut down found that recruitment assemblages fast recovered once desalination operations ceased. After two rounds of post-operational sampling, taxa that were previously impacted showed few signs of impact relative to background variation. In summary, impacts of plant operation on the recruitment of sessile marine invertebrates were spatially and temporally restricted. Impacts declined with distance from the outfall, and rapidly diminished once the plant ceased operation.

List of Acronyms and Abbreviations

ANOVA	Analysis of variance
DF	Degrees of freedom
F	F value
IWWS	Illawarra Waste Water Strategy study
km	Kilometre
m	Metre
MBACI	Multiple Before-After Control-Impact
MEMP	Marine and Estuarine Monitoring Program
ML	Mega litres
MS	Mean squares
ms^{-1}	Metres per second
NA	Not analysed
ND	No data
NS	Not significant
NMDS	Non-metric multidimensional scaling plot
P	Probability
PERMANOVA	Permutational multivariate analysis of variance
PSU	Practical salinity units
ROV	Remotely operated vehicle
SS	Sum of squares
UNSW	The University of New South Wales

1. Description of Recruitment and Salinity Studies

1.1 General background

Sydney Desalination Plant operates a desalination plant on the coast at Kurnell in southern Sydney. The plant was constructed and previously operated by Sydney Water Corporation. It has a daily capacity of 250 ML of freshwater and when working at full capacity the plant discharges between 125 and 250 ML of brine effluent per day into the ocean. The discharge point is located between Long Nose Point and Cape Bailey on the Kurnell Peninsula (Fig. 1.1) at a depth of between 25 and 30 m and approximately 300 m from the coastline (GHD 2006). The predominant habitat in this area is rocky reef (GHD 2006). The effluent discharged from the plant has a salinity of ~ 65 psu, which is approximately double that of background seawater (i.e. ~35 psu). When working at full capacity, effluent is discharged from the outlet at high velocity (~ 5.5 ms^{-1}) and mixes rapidly with the surrounding waters. The plume was initially predicted to be diluted to within 1 psu of background levels within 25 m of the outlet (Miller et al. 2007).

1.2 Marine and estuarine monitoring program (MEMP)

Together with the regulatory authorities Department of Planning, The Office of Environment and Heritage (OEH) and Department of Primary Industries (DPI), Sydney Desalination Plant created the Marine and Estuarine Monitoring Program (MEMP, Sydney Water Corporation 2006) to test for impacts of desalination discharge on the salinity, algae, invertebrate communities and fish off the coast of Kurnell. The effects of the discharge are assessed by monitoring salinity, and the abundance and diversity of organisms at sites near the outfall and at reference locations. Monitoring was conducted across a 20 km section of coastline, before and after commissioning of the plant. Sampling locations for all components of the MEMP are shown in Figures 1.1 and 1.2.

1.3 Recruitment and Salinity Studies

The Recruitment and Salinity Studies are components of the MEMP aimed at detecting change in salinity due to the desalination outfall, and associated change in the recruitment of sessile marine invertebrates. They were designed to be complementary: sampling for each was conducted at similar points in space and time, such that impacts on recruitment can be directly compared to change in salinity.

1.4 Sampling locations

Positions of sampling locations along the coast are shown in Figure 1.3a, and the positions of potentially impacted locations in Figure 1.3b.

The reference locations were:

- “North Reference” at Cape Solander (approximately 1.5 km north of the outfall)
- “South Reference” at Voodoo Point (approximately 2 km south of the outfall)
- “Far North Reference” between Cape Banks and Little Bay (approximately 5.5 km north of the outfall)
- “Far South Reference” near Jibbon Head (near Bundeena, approximately 8.5 km south of the outfall)

Potentially impacted, or ‘test’ locations were:

- “20 m test location”, located within the predicted discharge plume (sites 20 m from the outfall, north and south)
- “40 m test location”, located within the predicted mixing zone (sites 40 m from the outfall, north and south)
- “100 m test location”, located outside the mixing zone to the north (sites 100 m from the outfall, north and south)
- “Boat Harbour Aquatic Reserve”, located at the northern end of Cronulla Beach (~3 km SW of the outfall)

Salinity was measured at Boat Harbour Aquatic Reserve due to it being a designated area of special interest. Recruitment was not measured at Boat Harbour.

The 100 m test locations were introduced to the sampling program from Round 3 onwards, following a revision of the sampling design.

2. Effects of the desalination outfall on the salinity of surrounding waters

2.1 Introduction

Desalination plants are becoming increasing common worldwide as a means of meeting potable water demands (Roberts et al. 2010). The demand for fresh water is increasing globally with human population growth, climate change, and growing industrial and agricultural needs. Historically, most desalination plants were built on the shores of the Arabian Gulf, but plants are now appearing in major cities worldwide, particularly in California, China and Australia. These provide the primary freshwater supply in areas of acute water shortage, or serve as a secondary supply to safeguard against periodic water shortages such as droughts. In 2008 it was estimated that worldwide, desalination produces approximately 24.5 million m^3 of fresh water per day (Lattemann & Hopner 2008).

Simplistically, the desalination process involves drawing large volumes of seawater from the ocean, removing the salt content to obtain freshwater, and releasing a brine effluent containing the excess salt back into the ocean. In some plants salt is harvested from the concentrate instead of being released to the ocean, but this is rarely economically feasible. The desalination effluent (or 'brine') is piped to a discharge outfall, where it is released and mixes with ambient seawater. Most modern outfalls are fitted with diffuser caps at the release points, which are designed to increase the velocity of the discharge and facilitate mixing.

The discharge effluent can impact the waters surrounding the outfall in several ways, but most often by changing salinity. Elevated salinity can have a toxic effect on marine organisms, particularly in sustained exposures (Neupath et al. 2002). Thermal stress can also occur around plants that discharge heated effluent, and some effluent can increase the acidity (i.e. reduce pH) of surrounding water (Ahmed and Anwar 2012). Brine effluent can also contain antiscalants, metals, and other contaminants used in water treatment to maintain pipes free of fouling (Lattemann & Hopner 2008). These contaminants can be toxic in the water column when initially released, and can accumulate in sediments near the outfall to cause ongoing disturbance.

The spatial extent of ecological impacts is intrinsically dependent upon the size of the brine effluent plume. A recent review found that the size of plumes varies dramatically between plants, ranging from metres (e.g. Raventos et al. 2006) to kilometres (e.g. Fernandez-Torquemeda et al. 2005). In most cases salinity returns to within 1-2 psu of background levels within tens of meters from the outfall, and within 0.5 psu hundred of metres from the outfall (Roberts et al. 2010). See Table 1 in Roberts et al. (2010) for a list of plume sizes from published studies.

Plume size is determined by the capacity of the plant, diffuser design, and the hydrology of the environment to which effluent is discharged (Roberts et al. 2010). In low energy environments the brine effluent will take longer to mix with ambient seawater, and therefore extend further from the outfall. Hence, it is preferable for discharge points to be located in high-energy environments when possible.

Hypersaline water is denser than ambient seawater, so sinks to the seafloor as it disperses from the outfall. This difference in density can also result in effluent sinking into depressions or cavities in the seafloor, potentially increasing residence time (Roberts et al. 2010) and impacting a more specific habitat – crevices in the seabed. Modelling studies have found that plumes often extend alongshore (as opposed to offshore) from the outfall (Shao and Law 2009), although plume direction will also depend on seabed topography and the direction of prevailing currents.

Here we describe changes in salinity associated with the outfall of the Sydney Desalination Plant, on the coast at Kurnell in southern Sydney. The Sydney Desalination Plant management group aimed for change in salinity to be less than 1 psu within 75 m of the outfall. We conducted a monitoring study to test for change in salinity before and after plant commissioning, at various distances (20 m, 40 m and 100 m) from the outfall. This enabled an MBACI (Multiple Before-After, Control-Impact) analysis to test the statistical significance of change in salinity caused by plant operation, relative to background variation (Keough and Mapstone 2002). Salinity at test locations was compared to that at four reference locations which were assumed to be unaffected by the plume. This study was designed to complement the Recruitment Study, which measured the recruitment of sessile marine invertebrate at the same locations and time periods. To further monitor the plume we measured continuous time series of salinity and temperature around the outfall with moored CTD units, and measured temperature at each location with continuous temperature loggers (TidbiTs).

2.2 Materials and Methods

2.2.1 CTD casts

In each sampling round, salinity was measured at (i) four reference locations, (ii) three test locations 20 m, 40 m, and 100 m either side of the outfall area (test locations), and (iii) in Boat Harbour Aquatic Reserve. Measurements were made by Oceanographic Field Services using a Seacat Profiler and a Sea-bird SBE19 conductivity-temperature-depth meter (CTD).

Within each round, two replicate salinity measurements were taken at each site and time. Salinity was recorded as the probe descended to the seafloor. Since the vessel drifted during the cast, the vessel motored to its original position before taking the second replicate measurement. Replicates were averaged to obtain a single value for each one-metre interval per site.

Each site was close to the recruitment plates deployed for the Recruitment Study, with the exception of Boat Harbour, which was not sampled in the Recruitment Study. Sampling dates for each round are given in Table 2.1.

2.2.2 Moored CTD

Moored CTDs were deployed at each of the outfall locations (Fig. 1.3b), in rounds when the plant was operational. At each location, one CTD was moored midway between the two sites used for settlement plates and CTD casts. These were

Falmouth NXIC-CTD-BIO-AUTO CTDs, except in Round 8 when two of the four CTDs were Seabird SBE37SM CTDs. Routine maintenance and service, including chlorine disinfection and screen replacement, was conducted prior to deployment and twice during deployment.

2.2.3 Temperature loggers (TidbiTs)

TidbiTs (temperature loggers) were attached to settlement panel arrays at each location, in each round when the plant was operational. TidbiTs recorded temperature at 5 min intervals throughout the deployment period.

2.2.4 Statistical analyses

Salinity data from CTD casts were analysed at 5 m depth increments (1, 5, 10, 15, and 25 m) and at the seafloor (24 – 30 m). Boat Harbour was shallower than other locations so salinity these was analysed to a depth of 15 m and the seafloor.

We used an MBACI design to test for change in recruitment at potentially impacted (or 'test') locations before and after plant commissioning, relative to change at reference locations (Keough and Mapstone 1997). Period (Before-During) and Test (Control-Impact) were fixed factors, while Round, Time and Location were given random intercepts (Zurr et al. 2009).

Statistical inference was based on linear mixed models, hereafter LMM (Bolker et al. 2011). LMM incorporate random intercepts to account for spatial and temporal autocorrelation between replicates. An observational-level random effect was included to account for over-dispersion. Parameters were estimated with Laplace approximations (Breslow and Clayton 1993), and *P*-values for the Period x Test interaction term were obtained with Chi-square tests (Zurr et al. 2009). We used the 'lme4' package (Bates et al. 2011) in R v.2.15.0 (R Development Core Team 2012).

For each depth we first tested for impacts at the 100 m test location. When this test was conservatively non-significant ($P > 0.25$), we considered 100 m test sites as reference locations (100 m North and 100 m South) in tests for impacts at locations nearer the outfall. This increased the power of the tests near the outfall by increasing the number of reference locations.

We calculated the change in average salinity at each potentially impacted location before and after plant commissioning, relative to average change at reference locations for each depth. This was calculated as:

$$\Delta S = (\hat{s}_{i,A} - \hat{s}_{r,A}) - (\hat{s}_{i,B} - \hat{s}_{r,B}) \qquad \text{(Eq. 1)}$$

where S^ denotes average salinity, subscripts i and r denote potentially impacted and reference locations, and A and B denote During and Before periods, respectively. Moored CTD and TibiT data are presented graphically but were not subject to statistically analysed.

2.3 Results

2.3.1 Salinity: CTD casts

At the 20 m test location, salinity during plant operation was significantly elevated above background levels from depths of 15 m down to the seabed (Table 2.2). At the 40 m and 100 m test locations, salinity was significantly elevated above background levels from depths of 20 m to the seabed (Table 2.2).

Low background variation provides high power to detect even small differences in salinity, so the magnitude of change in salinity is more important than the significance of impacts. Salinity was most elevated at the seabed and decreased with distance from the outfall (Table 2.3). Elevation in salinity was slightly greater than 1 psu at the seabed at the 20 m test location, and well below 1 psu at the 40 m test location (Table 2.3).

The elevation in salinity at depths below 15 m changed through time (Figs. 2.2 and 2.3), but interestingly the direction of change varied with depth. Salinity peaked at the seabed in Round 6 (the first sampling round during plant operation), peaked at 25 m in Round 7, at 20 m in Round 8, and at 15 m depth in Round 9 (Figs. 2.2 and 2.3). The plume reduced in average magnitude and extent in Round 9, presumably due to intermittent operations in preparation for shutdown.

There was little indication of effects of the hypersaline plume on salinity at Boat Harbour (Fig. 2.2, Tables 2.2 and 2.3). Salinity was significantly different at 15 m in Boat Harbour relative to the same depth at reference locations, but the difference in salinity was of low magnitude (-0.08 psu) and in the opposite direction to that expected due to the desalination discharge.

2.3.2 Salinity: Moored CTD

Data from the moored CTD show average salinity per day, both near the outlet (~ 30 m the diffuser) and 100 m north and south (Fig. 2.4). Salinity was higher nearer the outfall, and there was no consistent bias in the north or south direction (Fig. 2.4).

Salinity fluctuated around steady means in Rounds 6 to 8, when it was mostly between 35.5 and 36.5 psu. In Round 9 however, salinity underwent large fluctuations through time that presumably resulted from change in plant operations.

One CTD recorded an anomalous drop in salinity in Round 8 (Fig. 2.4). This likely reflects CTD malfunction, because a similar anomaly was seen in the temperature measurements of that CTD (Fig. 2.5) but not in the TidbiT temperature measurements collected simultaneously (Fig. 2.6).

2.3.3 Temperature: Moored CTD and Tidbits

Temperature measurements from moored CTD (Fig. 2.5), and TidbiTs (Fig. 2.6) are plotted for each round while the plant was operational (Rounds 6 to 9). There was no indication of differences in temperature between outfall and reference locations, and both groups followed similar trajectories in the moored CTD and TidbiT data. There was an anomalous deviation in temperature recorded by the

CTD north of the outfall in Round 8 (Fig. 2.5), but as stated above this was likely due to a CTD malfunction as it was not reflected in the TidbiT measurements.

2.4 Discussion

2.4.1 Changes in salinity around the outfall

Elevation in salinity around the outfall while the plant was operational was within the aims of the program. The program aimed for the elevation in salinity to be less than 1 psu within 75 m from the outfall, and this benchmark salinity was generally reached within 40 m from the outfall.

At the seabed, salinity steadily decreased with distance from the outfall. Salinity was elevated by 1.0 psu 20 m from the outfall, 0.8 psu 40 m from the outfall, and 0.62 psu 100 m from the outfall. The hypersaline plume was small to moderate compared to plumes in published studies elsewhere in the world (Roberts et al. 2010). Most other plumes extend between several hundred metres, with some having 0.5 psu distances at much further than 100 m.

Salinity at depths of 15 m and below changed considerably between pre- and post-commissioning rounds, but the timing of change depended on depth. At the seabed salinity peaked in Round 6 – the first round post-commissioning – then one round later at each 5 m depth increment towards the surface. This trend probably reflects improvement of diffuser effectiveness throughout the post-commissioning period as well as inter-annual or seasonal differences in currents within the recipient environment. There were known problems with diffuser seals in Round 6 (the first sampling round post-commissioning) which increased salinity at the seabed. The problems were rectified in subsequent rounds and likely resulted in improved performance as brine was released higher in the water column as originally planned.

These analyses include data from the Round 9 because the Recruitment Study uses data over this same period. However, Round 9 is not representative of normal operating conditions as the plant was operating below normal capacity on three of the four CTD cast dates. Estimates here are therefore conservative, and average salinity should be slightly higher if Round 9 was excluded or sampled under normal operating conditions.

2.4.2 Boat Harbour Aquatic Reserve

Salinity at Boat Harbour was lower than at reference sites at 15 m depth. However, the direction of change was opposite to what would be expected if caused by the brine effluent. Instead it likely reflects a difference in oceanographic processes at the seabed (at Boat Harbour) vs. midwater (at Reference locations). Effects of the plume were generally confined to depths greater than 20 m and in close proximity to the outfall. The shallow depth of Boat Harbour (15m) and its distance from the outfall means that dense hypersaline water was unlikely to extend to this area.

2.4.3 Temperature

Temperature was similar at test and reference locations in all rounds of sampling while the plant was operational. This is consistent with the expectation that the reverse osmosis plant does to expel heated effluent.

2.4.4 Conclusions

The brine effluent increased salinity around the outlet, but the magnitude of change was similar to or less than that predicted. Elevation in salinity changed through time – presumably due to change in the efficiency of diffusers – highlighting the importance of proper diffuser function. There were no detectable effect of the plume of salinity at Boat Harbour, nor at temperature at any location.

3. Impacts of the desalination outfall on marine invertebrate recruitment

3.1 Introduction

Desalination plants impose a range of stressors on the environment. Many of these stressors are associated with the brine effluent – a by-product of the desalination process that is often released from an outfall directly into the marine environment (Roberts et al. 2010). The effluent contains excess salt that remains after freshwater extraction, as well as contaminants that are either deliberately added or accumulate as water travels through the plant. Brine leaving the outfall creates a plume of altered water quality (the 'mixing zone') before it is sufficiently diluted by surrounding seawater. Within and near the mixing zone there are several potential pathways through which marine ecosystems might be impacted.

The most obvious impact pathway to the marine environment is through change in the salinity of water surrounding the outfall. The salinity of brine exiting the outfall is typically 60-75 psu, approximately double that of background water (Roberts et al. 2010). Hypersalinity can be toxic to some marine organisms by interfering with osmotic processes and causing physiological damage (Santos-Gouvea and Freire 2007). It can also increase the toxicity of other stressors, such as heavy metals (McLusky et al. 1986). Hypersaline brine is denser than ambient seawater, so typically sinks to the seafloor and can accumulate in depressions. Impacts are therefore most likely on the seabed, and benthic communities may be more vulnerable than pelagic communities. Exceptions might include pelagic fauna in the immediate vicinity of the outfall, since high velocity diffusers propel the effluent tens of meters from the seabed before it mixes or sinks to the seafloor.

Some desalination plants produce heated effluent, adding a temperature stress. This is mainly the case for distillation plants, and is less common in reverse osmosis plants. In addition to direct effects of increased temperature on metabolism, reproduction and survivorship (Eriksson Wiklund and Sundelin 2001); increasing temperature and salinity also decrease oxygen solubility. Oxygen depletion is deliberately achieved in distillation plants to reduce corrosion, and sometimes occurs in reverse osmosis plants when sodium bisulphate is added to neutralize chlorine (Lattemann and Hopner 2008).

Desalination effluent can contain a suite of potentially toxic contaminants. Many desalination plants add chlorine (a strong oxidant and effective biocide) to the water to prevent biofouling on internal surfaces (Lattemann and Hopner 2008). In reverse osmosis plants chlorine is often neutralized, but brine effluent may still contain residual amounts. Chlorination can also produce to oxidation by-products such as halogenated organics, which can persist in the marine environment for long periods and be carcinogenic to some organisms. Other contaminants commonly associated with desalination effluent include heavy metals, antiscalants, coagulants and coagulant aids, antifoaming agents and cleaning chemicals (Lattemann and Hopner 2008).

Change in the flow or hydrodynamics around the outfall is a less discussed but potentially important impact pathway. Many plants discharge effluent at high

velocities through diffuser valves to facilitate mixing and dispersal. The Sydney Desalination Plant, for example, discharges effluent at a rate of 5.5 ms^{-1}. High flow could affect larval mobility and their ability to settle. Some larvae may have difficulty swimming and settling in high flow (Chia et al. 1984), while others preferentially settle in high flow (Abelson and Denny 1997, Koehl 2007). Elevated flow might also attract fish or other predators that could affect the abundance of lower trophic groups, via indirect effects.

Indirect effects are when direct effects of the plume on one species subsequently influences another, by changing the interaction between those two species (Menge 1995). For example, increased fish abundance in response to the plume might decrease the abundance of sessile invertebrates that are preyed upon by fish. Similarly, direct effects of the plume on some sessile invertebrates may affect the abundance of others, by altering competitive interactions (Johnston and Keough 2002).

Despite the number of desalination plants worldwide, there is a severe lack of knowledge regarding the nature, magnitude and extent of their ecological impacts. The primary reason for this knowledge gap is the scarcity of studies that provide robust and powerful tests for impacts. A review of published literature found that most studies are descriptive in nature, and most quantitative studies are small in scope (Roberts et al. 2010). This may be because historically, the primacy of the need for freshwater has outweighed potential environmental concerns. Additionally, commercial sensitivity of environmental impacts may have restricted publication or relegated reports to grey literature, largely inaccessible to the scientific community. There is a clear need for well-designed studies of ecological impacts of desalination plants to be published in the scientific literature. Such information is crucial for predicting future impacts of a plant, and in planning other plants elsewhere around the world.

Here we present a test for impacts of plant operation on the recruitment of sessile marine invertebrates in the vicinity of the Sydney Desalination Plant. These fauna provide an ideal study system with which to test for impacts of the desalination effluent. Larvae are typically more sensitive to change in water quality than adults, so toxic effects of the hypersaline plume are first likely to occur in the water column. Moreover, sessile invertebrates are unable to escape disturbance once settled, in contrast to mobile fauna (e.g. fish and mobile invertebrates) that can exhibit avoidance behaviour.

We test for impacts with an MBACI (Multiple Before-After-Control-Impact) design (Keough and Mapstone 1995), sampling at multiple times before and during plant commissioning, at multiple test and reference locations. MBACI designs partition natural variation from variation attributable to a disturbance. The power of these tests (i.e. the ability to detect impacts) is proportional to the number of sampling sites and times. This study sampled 3 test and 5 reference locations over 9 sampling rounds, providing one of the most powerful and robust studies of the ecological effects of brine effluent to date.

3.2 Materials and Methods

3.2.1 Recruitment plates and deployment

Recruitment plates were deployed at two sites per location (excluding Boat Harbour) in each sampling round. All sites were at a depth of approximately 21 to 28 m and on rocky reef. Recruitment plates (roughened black Perspex, 11 x 11 cm; Plates 1 and 2) were deployed using a mooring system (Fig. 3.1). Two recruitment plates were attached to a PVC backing panel (30 x 30 cm). The PVC panel was attached to a foam float and faced downward towards the reef to encourage invertebrate settlement (Plate 2). An array of four panels was deployed at each site.

All of the panels at each site were separated by approximately 1.5 m and were tethered to a mooring line which stretched from one site to the other. Sites were separated by approximately 20 m. The plates and moorings were deployed by boat by Oceanographic Field Services in all rounds of sampling. Dates of panel deployment and collection in each sampling round are given in Table 3.1.

3.2.2 Inspection of recruitment plates and locations

To check that the recruitment plates had been deployed appropriately, a remotely operated vehicle (ROV) was used by Oceanographic Field Services to inspect the plates at each site in each round.

3.2.3 Collection of recruitment plates

Oceanographic Field Services collected recruitment panels after 12 to 16 weeks of deployment. Floats attached to the ends of the moorings were located and used to winch the mooring lines and attached panels to the surface.

At the surface, the floats were cut away from the mooring lines and brought onto the deck of the boat. The panels, with attached recruitment plates, were removed from the floats and immersed in a container of local seawater by UNSW staff within 3 minutes of emersion (Plate 3 and 4). Specially designed frames protected the assemblages from abrasion during transport.

Plates were removed from their backing panels at Fisheries Wharf, Cronulla, and taken to a UNSW laboratory in water-tight containers filled with fresh, cool seawater (Plate 5). The plates were secured on lengths of stainless steel all-thread and separated with plastic tubing to avoid physical abrasion of the assemblages (Plate 5). Assemblages were preserved in 7% formaldehyde buffered with seawater prior to sampling.

3.2.4 Sampling and identification of species

We too a photograph of each settlement plate assemblage, for reference purposes, within 24 h of collection of the samples (e.g. Plate 6). Each assemblage was sampled live under a microscope, which involved identifying, counting and measuring the cover and density of taxa on each plate. Sampling was limited to the inner 10 x 10 cm section of the plate, excluding the including the area around the centre hole or bolt head (approximately 4 cm^2). This avoided areas on the plates that may have been disturbed during the collection procedure.

The cover of each species was estimated (i.e. percentage cover) by counting the number of times it occurred under each of 49 regularly spaced points superimposed over the plate (a 7 x 7 grid). Taxa which were in the quadrat but not found under a point were recorded as having a nominal cover of 0.5 %. Percentage cover is a useful measure for colonial species, as indeterminate growth means that the area they cover can greatly differ from the density of individuals.

The densities of taxa were estimated by counting the numbers of individuals that occurred within twelve 1 x 1 cm squares on each plate. Very abundant species (i.e. small barnacles, amphipod tubes) were sub-sampled to increase sampling efficiency.

Photographs of species and morpho-species were taken and a voucher specimen was collected and preserved in 80% ethanol. Bryozoans were identified with the assistance of taxonomic expert Dr. Dennis Gordon (National Institute of Water and Atmospheric Research, New Zealand).

Each recruitment assemblage was sampled by a suitably trained marine ecologist in the Subtidal Ecology and Ecotoxicology (SEE) laboratory at UNSW. Data were collected on specially designed data sheets, which once completed were photocopied, and copies stored in separate locations (on and off UNSW campus). Data were entered into Microsoft Excel spreadsheets. The electronic copy was checked against the original data sheet and corrected if any transcriptional errors had occurred. The checked electronic data sheets were copied and stored at two separate locations (on and off UNSW campus).

3.2.5 Statistical analyses

MBACI analyses were conducted to test for change in recruitment at potentially impacted locations before and after plant commissioning, relative to change at reference locations (Keough and Mapstone 1997).

3.2.6 Multivariate analyses

Permutational Multivariate Analysis of Variance (PERMANOVA) was used to test for significant change in community structure at potentially impacted locations (Anderson 2001). Since there was a single impact location per analysis, we used an asymmetrical design in which the ‘Test’ term (Impact vs. Control) was a planned comparison nested within ‘Location’ (Glasby 1997). Fixed effects were Period (Before vs. During) and Test, and random effects were Round (nested in Period) and Location.

Canonical Analysis of Principle Coordinates (CAP) was used to visualize the multivariate structure of data and to identify taxa contributing to differences (Anderson and Willis 2003). This routine is similar to a Principle Coordinate Analysis (PCO) but rotates the ordination to maximize differences between levels of a factor of interest, in this case the Period x Test interaction.

Prior to analysis, multivariate data were square-root transformed to reduce the influence of abundant taxa, and similarity matrices used the distance measure of Bray-Curtis dissimilarity.

3.2.7 Univariate analyses

Inference for univariate response variables was based on generalized linear mixed models (Bolker et al. 2009), hereafter GLMM. These models are suitable for non-normal data and unbalanced designs, and incorporate random effects to account for spatial and temporal autocorrelation between samples. Period and Test were fixed effects, and Round, Location, Site and Panel were treated as random effects.

For percent cover data we assumed a binomial distribution with a log-link for variance, and for density data we assumed a Poisson distribution with a log-link for variance. We fit an observational-levels random effect to account for over-dispersion. Parameters were estimated with Laplace approximations (Breslow and Clayton 1993), and *P*-values for the Period x Test interaction term were obtained with Chi-square tests. We used the 'lme4' package (Bolker et al. 2009) in R v.2.15.0 9 (R Core Team 2012).

For each response variable we first tested for impacts at the 100 m test location. When this test was conservatively non-significant ($P>0.25$) we considered 100 m test sites as reference locations (100 m North and 100 m South) in tests for impacts at locations nearer the outfall. This increased the power of tests near the outfall by increasing the number of reference locations.

Type I errors are of potential concern when conducting a large number of tests (Quinn and Keough 2002). However, we do not consider them problematic here since we are interpreting tests across the range of potentially impacted locations within rounds, rather than interpreting tests individually. We expect systematic trends with distance from the outfall, so are mainly interested in patterns found at multiple potentially impacted locations.

3.3 Results

3.3.1 Multivariate analysis

PERMANOVA detected significant impacts of plant operation on assemblage structure at all three potentially impacted locations (Table 3.2). Impacts were strongest 20 m and 40 m from the outfall, but were still significant at 100 m (Table 1).

Figure 4 shows Canonical Analysis of Principle Coordinates (CAP) ordinations illustrating similarity between assemblages. Symbols close together indicate that assemblages were similar to one another, while those further apart were less similar. Adjacent vectors diagrams show the strength and direction of Pearson correlation between individual taxa and CAP axes.

Impacts to assemblage structure at 20 m and 40 m from the outfall appear similar in nature and extent, and are correlated with change in a similar suite of species (Fig. 3.2). Most assemblages at the 100 m test location in the post-commissioning period were segregated into a distinct group, but some sites from Round 9 (intermittent plant operation) were similar to those at reference locations (Fig. 3.2).

3.3.2 Summary variables

Changes described below refer to near the outfall from pre- to post-operational, relative to change at reference locations. Bare space decreased in assemblages at the 100 m test location, but not at the 20 m or 40 m test locations (Fig. 3.3, Table 3.3). Species richness (the number of species per plate) increased at potentially impacted locations, except for at the 20 m location (Fig. 3.3, Table 3.3). Neither Shannon-Wiener diversity (a diversity index that considers both species richness and evenness) nor species evenness changed in response to plant operation (Figs. 3.3, Table 3.3).

3.3.3 Major taxonomic groups

Several major taxonomic groups showed strong response to plant operation. Cover of polychaetes decreased at all potentially impacted locations. Average polychaete cover reduced by ~ 70% at the 20 m location, and effects decreased in magnitude but were still significant 40 and 100 m from the outfall (Fig. 3.4, Table 3.3). This was in contrast to increased polychaete cover at the reference locations from before the plant operation.

Bryozoan cover was reduced at the 20 m and 40 m test locations relative to reference locations, but the apparent reduction at 100 m from the outfall was marginally non-significant (P = 0.087) (Fig. 3.4, Table 3.3). Sponge cover was heavily reduced 20 m and 40 m from the outfall, but not at 100 m (Fig. 3.4, Table 3.3).

In contrast, barnacles and hydroids increased at test locations relative to reference locations (Fig. 3.4, Table 3.3). Impacts on barnacles were significant at the 20 m and 40 m test locations, and for hydroids at 40 m and 100 m test locations (Table 3.3). Colonial ascidians, solitary ascidians and bivalves did not show significant change in response to plant operation (Fig. 3.4).

3.3.4 Cover of individual taxa

Several species significantly decreased in percent cover around the outfall during operation, relative to change at reference locations (Fig. 3.5, Table 3.3). These included three polychaete (*Pomatoceros taeniata*, *Salmacina australis* and *Hydroides elegans*) and two bryozoan species (*Microporella* sp. and *Smittina* sp.). *P. taeniata*, *Microporella* sp. and *S. australis* were decreased at all test locations (Table 3.3).

Specific taxa that increased in cover around the outfall post-commissioning included three barnacle species (*Balanus trigonus*, *Megabalanus coccopoma*, and *Amphibalanus amphitrite*) and an unidentified hydroid (Fig. 3.6, Table 3.3). Of these, only the hydroid significantly increased in cover 100 m from the outfall. Change in two of the barnacle species was significant at both 20 m and 40 m from the outfall.

3.3.5 Density of individual taxa

Density results were generally similar to those analyses of percent cover. The densities of many taxa were significantly impacted by plant commissioing. Taxa affected at either the 20 m or 40 m test locations are shown in Figs. 3.7 and 3.8, and Table 3.3.

Some species that decreased in cover near the outfall also decreased in density. These included three polychaete (*Pomatoceros taeniata*, *Salmacina australis* and *Hydroides elegans*) and two bryozoan species (*Microporella* sp., *Smittina* sp.) (Fig. 3.7, Table 3.3). Amphipod tubes decreased in density (Fig. 3.7, Table 3.3) but not in cover. Taxa that increased in density around the outfall were the barnacle *Amphibalanus imperator*, the bryozoan *Arachnopusia unicornis* and an unidentified hydroid (Fig. 3.8, Table 3.3).

3.4 Discussion

We detected strong impacts of plant operation on the cover and density of sessile invertebrates recruiting near the outfall. Some impacts extended 100 m from the outfall, beyond the predicted mixing zone. We detected impacts at three levels of biological organisation: whole communities, major taxonomic groups, and individual species.

3.4.1 Nature of impacts

Impacts of the brine effluent can be categorised as decreases or increases in abundance or diversity. Decreases are usually of greater concern as they may lead to reduced biodiversity (Erlich 1988) and impaired ecosystem function (Hillebrand and Matthiessen 2009). Most decreases were detected for the major taxonomic groups of polychaetes, bryozoans and sponges, and species within these groups. Impacts were highest in magnitude and spatial extent for polychaetes, and appeared proportional to distance from the outfall. This suggests that recruitment is tightly linked to the extent of the outfall plume.

Increases in abundance around the outfall were mainly seen for barnacles and hydroids. Increase in the cover of barnacles was seen for three species, indicating that the mechanism of impact is operating similarly within this taxonomic group.

3.4.2 Potential impact pathways

Impacts of plant operation could reflect (i) direct responses to environmental conditions, or (ii) indirect responses that are mediated by a third variable. Direct and indirect effects cannot be distinguished without experimental manipulations, and multiple potential pathways may be contributing to impacts.

Toxicity of the hypersaline plume is generally considered the most important impact pathway of ecological effects of the brine effluent. Larval stages of marine organisms are typically more sensitive to toxicants and stressors than adults (Wisely 1963), although the susceptibility of larvae to stress will depend upon their behaviour. Larvae of some taxa are photopositive (attracted to light) when first spawned, then become photonegative (attracted to darkness) over time (Jékely et al. 2008). Phototaxis causes vertical migration through the water, meaning some larvae may approach the seafloor where observed salinity increases were greatest. Species differ in their extent of vertical migration, which should influence the probability of encountering hypersaline patches. Phototactic behaviour might contribute to the differences in impacts between species. However, changes in salinity due to the brine effluent were relatively minor in the context of natural

variation, particularly 100 m from the outfall (Section 2). It is therefore likely that factors other than salinity are contributing to impacts.

Increases in flow, turbulence and shear stress caused by the plume might also result in impacts. Productivity and diversity of sessile marine invertebrate assemblages can be strongly regulated by flow (Palardy and Witman 2011), which mediates the delivery of propagules and food. Species differ in their larval mobility (Chia et al. 1984), settlement preferences relative to flow, and susceptibility to shear stress. Barnacle cyprids (larvae) are known to preferentially settle in high flow and can actively swim against strong current (DiBacco et al. 2011) – a behavioural trait that may explain their increased abundance near the outlet during plant operation. Studies of larval settlement behavior demonstrate that optimal flow rates for barnacles are higher than those for serpulids and arborescent bryozoans (Crisp 1955, Mullineaux and Garland 1993, Qian et al. 2000, Qian et al. 1999). This may explain differential responses of taxonomic groups to the plume.

Change in pH, trace levels of anti-scalant, or anti-fouling compounds may be physiologically stressful and may be contributing to difference in species distributions. Calcium carbonate-forming marine organisms find it more difficult to form their skeletons in acidified water, and desalination plumes can have lower pH than surrounding waters. Both serpulid polychaetes and bryozoans form calcium carbonate skeletons, so may be affected by changes in pH. Bryozoans can be particularly sensitive, as some species contain a higher proportion of aragonite in their skeletal composition (Smith 2009). Aragonite is more prone to dissolution under low pH than other skeletal compounds, making these species particularly vulnerable.

Indirect effects may have contributed to impacts if direct impacts on some taxa had flow-on effects to others (Kneib 1991, Menge 1995). Examples of indirect effects are increased predation by fish around the outfall, and change in inter-specific competition between sessile invertebrates. Barnacles are common early colonizers (Dean and Hurd 1980) and were often the space-dominating species on settlement plates. Serpulids on the other hand are known to be poor competitors for space (Jackson 1977, Unabia and Hadfield 1999) and may have been excluded by high densities of barnacles. Fish and barnacles also prey on the larvae of other sessile invertebrates, including polychaetes, and their prevalence around the outfall may have to the reduction in some taxa. Round 9 incorporated a predator exclusion (caging) test to determine whether apparent effects are due to increased predation by fish on the plates, and the preliminary results of this experiment suggest that increased fish predation around the outfall does not explain the assemblage differences (unpublished data).

3.4.3 Conclusions

The MBACI analyses found strong and significant impacts of commissioning of the desalination plant of the recruitment of sessile invertebrates around the outfall. Impacts on some taxa extended 100 m from the outfall, which is beyond the predicted mixing zone. The lessening of some impacts in Round 9 suggests that assemblages may recover when plant operation is reduced for a sufficient length of time. The rate and extent of ecological recovery can be assessed with further sampling, which will assist in predicting ecological impacts under variable plant operating regimes.

4. Recovery of marine invertebrate recruitment following impacts of the desalination outfall

4.1 Introduction

Ecological recovery is the return of an ecosystem to its pre-disturbance state (Bullock et al. 2011). Since emerging in the 1980's, the study of ecological recovery – also an aspect of 'restoration ecology' – has grown rapidly and now includes a substantial body of literature (Wortley et al. 2013). Ecologists and managers are increasingly charged with the task of restoring systems to their former states, or monitoring and assessing natural recovery once a disturbance is removed.

Sydney Desalination Plant was operational for approximately two years. Following this, the water supplied by the desalination plant was temporarily unnecessary to meet city needs and the plant entered a 'shutdown' mode. In this mode, operations focused on maintaining the integrity of plant equipment (e.g. the reverse osmosis membranes), and very little effluent was released from the outfall.

Given the impacts on marine invertebrate recruitment during plant operation (see Section 3), it was pertinent to assess recovery after the plant was turned off. This study examines the recovery of recruitment assemblages proximal to the desalination outfall, once the plant had ceased operation and the potential disturbance was removed.

Recovery can be assessed by monitoring a disturbed site after the disturbance has ceased, and comparing measurements to the pre-disturbance or post-disturbance states (Downes 2002). Common subjects to monitor include species or morphological group abundance, diversity indices, or ecological function. The present studies use taxonomic abundance, species diversity, and the amount of bare space (a signal of disturbance) as the primary indicators.

BACI (Before-After Control-Impact) style statistical analyses can be used to formally test whether an ecosystem has recovered (Downes 2002). Designs vary according to the data available, which in this study include 'before', 'during', and 'recovery' (post-disturbance) periods. These data allow tests for change (i) from the during to the recovery period, to assess change towards a recovery state, and (ii) from the before to recovery period, to test whether impacts are still detectable relative to background variation.

The trajectory of recovery of recruitment assemblages from the impacts detected during commissioning should allow some inference about the impact pathways. If recovery occurs rapidly, we could infer that the impact pathway is related to larvae in the water column rather than damage to source populations. Alternatively, slow recovery could imply that source populations have suffered significantly and are no longer producing the same numbers of larvae to seed recruitment.

The speed and extent to which recruitment assemblages recover from the impact of the brine effluent is relevant to the ongoing management of the desalination plant. As the plant alternates between operational and post-operational periods in response to water needs, it is important to understand how environmental impacts

vary with this regime. Persistent effects mean that consecutive operational periods could compound impacts, whereas rapid recovery implies that impacts of each operational period are temporally independent.

4.2 Materials and Methods

4.2.1 Recruitment panel deployment and collection

Monitoring for recovery was conducted over Rounds 10 and 11 of the sampling program. The deployment and retrieval of settlement panels followed methods described in Section 3.2. The dates of panel deployment and collection are given in Table 3.1.

4.2.2 Statistical analyses

Two MBACI analyses were conducted to test whether recruitment assemblages recovered from the impact of plant operation. These assessed change in recruitment at potentially impacted locations relative to change at reference locations:

1. before plant operation vs. the recovery period
2. during plant operation vs. the recovery period

The first of these tests addressed whether the impact of plant operation was still detectable in the recovery period, relative to the baseline period. Whether the direction of change is towards recovery or further impact can then be determined from the graphs. The second test addresses whether recruitment has significantly changed from the impacted state since the plant became post-operational. Methods for multivariate and univariate analysis follow those in Sections 3.2.6 and 3.2.7.

4.3 Results

4.3.1 Baseline vs. Post-operational

Multivariate MBACI analyses (PERMANOVA) did not detect a significant difference between potentially impacted and reference locations in the recovery period, relative to the before period (Table 4.1). Community-level impacts of the brine effluent had sharply diminished after approximately one year of the plant becoming post-operational, to the point that they were no longer detectable.

There were very few significant differences in the cover of major taxonomic groups, or individual taxa identified as impacted in the previous MBACI (Table 3.3). Out of 63 tests only 5 (8%) were significant, which is only marginally higher than the accepted Type I error rate (5%) that might be expected to occur by chance. In Rounds 10 and 11, almost all response variables showed little difference between Test and Reference locations (Figs. 3.3 to 3.8).

Significant changes were declines in species richness, and the cover of polychaetes, bryozoans, *Pomatoceros taeniata* and *Microporella* sp. at the 100 m test location (Table 4.2). Some taxa near the outfall also showed impacts in their densities (Table 4.2). *Smittina* sp. was not found in density counts at near outfall

locations in the recovery period (Fig. 3.7), but was noted in rare species counts for percent cover (Fig. 3.5). *Salmacina australis* occurred in very low densities in the before period (Fig 3.7), so the significance of change in this taxa is not meaningful.

4.3.2 During vs. Post-operational

PERMANOVA found that community-level change from the during to recovery period was significant at the 40 m test location, and marginally non-significant at the 20 m test location (P=0.78) (Table 4.3). It was not significant at the 100 m test location – presumably due to the smaller magnitude of impact at this distance.

Polychaetes showed a significant increase from during plant operation to the post-operational period, at all three distances from the outfall (Table 4.4). Polychaetes were almost absent at test locations during plant operation, but by Round 11 all locations had between 10 and 25 % cover (Fig. 4.2). Bryozoans also showed significant recovery at the 20 m test location (Table 4.4), which had amongst the highest bryozoan cover of all locations in Round 11 (Fig. 4.2). The increase in barnacles observed during plant operation significantly declined at the 20 m and 40 m test locations (Table 4.4), until barnacle cover at the test locations was within the range of reference locations (Fig. 3.4).

The only indicators that did not show significant change in percent cover from the impacted to recovery period were *Hydroides elegans* (Table 4.4, Fig. 3.5) and *Amphibalanus amphitrite* (Table 4.4, Fig. 3.6). More taxa failed to show recovery in their density (abundance counts), including *Smittina* sp., *Hydroides elegans, Microporella* sp., and amphipod tubes (Table 4.4, Fig. 3.7). *Arachnopusia unicornis* and an unidentified hydroid continued to be more abundant near the outfall in the post-operational period.

4.4 Discussion

4.4.1 Recovery from impacts

Most taxa showed significant recovery from impacts caused by operation of the desalination plat (Section 3). In the two rounds of sampling conducted in the year following plant shutdown, the signal of the impact from the brine effluent had diminished and was undetectable for most taxa. Some taxa have been slower to respond and do not yet show full recovery, but most are trending towards recovery. Monitoring during the recovery period indicates that impacts of the brine effluent on sessile marine invertebrates are spatially and temporally limited.

We did not detect a signal of impact on most taxa relative to the baseline period. Some exceptions were taxa or indices that were biased in the baseline period due to varying deployment periods or natural spatial variability in recruitment. These differences between outfall and reference locations lessened in the recovery period, causing a significant ‘impact by period’ interaction that is often indicative of an impact. For example, when averaged across rounds, species richness was higher near the outfall than at reference locations due to a staggered sample collection in Round 4. In this round panel collection was interrupted by inclement weather, and samples near the outfall were deployed for weeks longer than those at reference locations. Period by Impact interactions that arise from an increasing similarity of outfall and reference locations through time are not interpreted as true

impacts. Most taxa that experienced true impacts in the operational period did, however, show significant recovery.

Tests for change from the impacted to recovered state mostly indicated recovery in a direction more similar to the natural state. The strongest recovery was seen in the most impacted taxa – polychaetes, particularly *Pomatoceros taeniata.* These tubeworms were almost absent around the outfall while the plant was operational, then returned to a relatively equal distribution between outfall and reference locations when then plant was shutdown. Other taxa to show strong recovery were the tubeworm *Salmacina australis*, and the barnacles *Balanus trigonus* and *Megabalanus coccopoma*.

For some taxa, change from the impacted to recovery period was not statistically significant, although recovery may still be occurring. Some taxa showed trends towards recovery, but may require more sampling rounds before there is sufficient power to detect change. Other taxa, such as the encrusting bryozoan *Smittina* sp., showed little evidence of recovery after one year, although recovery may occur over a longer time scale. *Smittina* sp. was impacted by plant operation and remained in low abundance around the outfall in the recovery period. However, it was also relatively rare at reference locations in the recovery period, so more sampling may be needed to better estimate its spatial distribution.

Trends of impact and recovery should be interpreted in the context of the specific disturbance that occurred: 2 years of plant operation followed by one year of recovery. Longer operational periods might have more substantial impacts that take longer to recover. Alternatively, the rate of recovery could be largely independent of the duration of disturbance if the mechanism of impact is transient. An exception would be if recruitment failure close to the outfall causes a reduction in self-seeding adult populations. Given the small spatial extent of the impacts (< 100 m north and south of the outfall) however, even more persistent impacts should not pose a major ecological concern.

4.4.2 Insight into impact pathways

The recovery trajectory provides some insight into the pathways of initial impact. Persistent impacts, for example, suggest that the effluent has harmed source populations that seed recruitment, whereas transient impacts suggest that impacts directly harmed larvae in the water column. The rapid recovery of most taxa implies that source populations were not heavily impacted, and that decline in recruitment during plant operation was primarily due to disturbance to larvae in the water column. The disturbance may have caused larval mortality, or simply impeded larval settlement (see discussion in Section 3.4.2).

Recovery may have been aided by the limited spatial extent of the impacts. Impacts were mainly found with 40 m of the outfall, and few extended to 100 m. Even if source populations near the outfall were damaged, recruits may still have arrived from further away to seed recruitment panels. The relationship between impact size and recovery rate may be non-linear due to scale-dependent ecological processes, such as thresholds in connectivity between impacted and unaffected areas. Larger areas of disturbance may therefore take disproportionately longer to recover.

Some taxa were more similar between test and reference locations in the recovery period than in previous rounds. While this is probably sign of recovery, there is a possibility that increased similarity between test and reference locations indicates damage to source populations. Recolonization of disturbed areas from nearby populations would increase biotic homogenization, causing test and reference locations to converge in species composition. Homogenization of recruitment could also emerge if damage to local source populations causes a larger proportion of recruitment to be drawn from the regional species pool. Further studies would be needed to test these hypotheses.

4.4.3 Conclusions

Together, the impact and recovery analyses suggest that intermittent operation of the desalination plant is likely to cause spatially and temporally restricted impacts to marine invertebrate recruitment. Impacts will occur over a small area (~ 100 m radius from the outfall), but will soon disappear when the plant is turned off. Most impacts were undetectable after one year of plant shutdown, although may be longer lasting if the plant is operated for a longer period.

5. Acknowledgements

We are grateful to Dr Clive Holden of Oceanographic Field Services for carrying out the salinity measurements. Nathan Knott had a primary role in the design of this study and project management during the first three sampling rounds. We thank past and present members of the SEE lab at UNSW for assistance with panel collection and sample processing. In particular, David Roberts, Michael Black, Halley Durrant, Mailie Gall and Valeriya Komyakova made substantial contributions. Eloise Henderson and Susan Trousdale coordinated and provided advice on various aspects of the MEMP.

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Tables

Table 2.1 Sampling dates for salinity measurements

Round	Time 1	Time 2	Time 3	Time 4
1	24/07/2007	29/08/2007	27/09/2007	-
2	27/02/2008	11/03/2008	26/03/2008	10/04/2008
3	3/09/2008	17/09/2008	1/10/2008	17/10/2008
4	11/03/2009	9/04/2009	14/05/2009	3/06/2009
5	27/08/2009	16/09/2009	13/10/2009	28/10/2009
6	30/06/2010	23/07/2010	11/08/2010	26/08/2010
7	3/03/2011	7/04/2011	11/05/2011	6/06/2011
8	6/09/2011	28/09/2011	2/11/2011	22/11/2011
9	15/03/2012	17/04/2012	17/05/2012	30/05/2012

Table 2.2 MBACI tests for change in salinity at test locations

P-values, estimates and standard errors and for the Period x Impact term in the MBACI model, at each depth. This infers change in salinity at potentially impacted locations pre- and post-commissioning, relative to change at reference locations. Statistically significant *P*-values (p<0.05) are in bold.

	20 m			**40 m**			**100 m**			**Boat Harbour**		
Depth	*P*	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE
1 m	0.536	-0.021	0.035	0.416	-0.028	0.035	0.496	-0.028	0.041	0.289	0.046	0.043
5 m	0.634	-0.003	0.006	0.503	-0.004	0.006	0.563	-0.004	0.007	0.301	0.008	0.008
10 m	0.238	-0.006	0.005	0.052	-0.01	0.005	0.583	-0.003	0.006	0.148	0.01	0.007
15 m	**0.002**	-0.045	0.015	0.495	-0.004	0.006	0.417	-0.005	0.006	**<0.001**	0.041	0.009
20 m	**<0.001**	-0.187	0.024	**0.022**	-0.032	0.014	**0.001**	-0.028	0.009	NA	NA	NA
25 m	**<0.001**	-0.582	0.033	**<0.001**	-0.413	0.026	**<0.001**	-0.237	0.02	NA	NA	NA
Seabed	**<0.001**	-1.033	0.042	**<0.001**	-0.823	0.033	**<0.001**	-0.615	0.025	0.823	-0.003	0.015

Table 2.3 Average change in salinity pre-and post-commissioning at test locations, relative to change at reference locations

Differences in salinity (psu) between each potentially impacted location and the average salinity across reference locations, at each depth. Elevations in salinity greater than 1 psu are in bold. Grey rows are the average differences for Near Outlet (20m and 40m), 100m Outlet, and all potentially impacted locations.

Test Location	1m	5m	10m	15m	20m	25m	Seabed
20 m	-0.06	-0.04	-0.03	0.12	0.16	0.56	1.01
40 m	-0.03	-0.04	-0.01	-0.03	0.01	0.39	0.80
100m	0.03	0.00	0.00	0.00	0.02	0.24	0.62
Boat Harbour	-0.05	-0.02	-0.02	-0.08	NA	NA	0.00

Table 3.1 Dates of panel deployment and collection in each sampling round

Round	Deployed	Collection	Period
1	28/07/2007	23/10/2007	Before
2	12/02/2008	15/05/2008	Before
3	25/07/2008	29/10/2008 - 6/11/2008	Before
4	5/03/2009	4/06/2009 - 26/06/2009	Before
5	11/08/2009	25/11/2009	Before
6	30/06/2010	26/08/2010	During
7	1/03/2011	21/06/2011	During
8	29/08/2011	21/12/2011	During
9	13/03/2012	20/06/2012	During
10	19/12/2012	8/4/2013 – 11/4/2013	Recovery
11	25/4/2013	7/8/2013	Recovery

Table 3.2 Multivariate test for impacts of plant commissioning on sessile invertebrate assemblages (before vs. during)

Permutational multivariate analysis of variance (PERMANOVA) testing for change in assemblage structure at potentially impacted locations before and after plant commissioning, relative to change at reference locations. *Period* is a fixed effect, and *Round* and *Location* are random effects. *Test* is a planned comparison (fixed effect) between levels of *Location*. The term is interest (*Period* x *Test* interaction) is shaded grey. Significant *P*-values for fixed effects are in bold.

	20 m				40 m				100 m			
Source	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)
Period	1	9407.3	0.893	0.588	1	14012	1.378	0.167	1	15052	1.480	0.143
Test	1	2633.7	3.075	0.012	1	3149.8	4.073	0.002	1	1734.2	1.904	0.093
Period x Test	1	3976.8	4.641	**0.006**	1	3813.8	4.931	**0.002**	1	2595.9	2.851	**0.020**
Round (Period)	6	9878.2	14.420	0.001	7	9315	14.053	0.001	5	9713.8	15.156	0.001
Location	4	1964.7	2.881	0.001	4	2315.2	3.520	0.001	5	1638.5	2.569	0.001
Period x Location	4	1530.3	2.244	0.001	4	1486.7	2.260	0.001	5	1007.6	1.580	0.008
Ro(Period) x Location	24	690.28	2.632	0.001	28	666.74	2.311	0.001	25	649.82	2.109	0.001
Ro(Period) x Test	6	851.93	1.785	0.003	7	773.95	1.583	0.006	5	936.88	1.936	0.002
Residual	38	262.24			43	288.49			39	308.11		

Table 3.3 Univariate tests for impacts of plant commissioning (before vs. during)

P-values, parameter estimates and standard errors for the Period x Test interaction term in MBACI analyses. Tests were performed separately for each potentially impacted location. *P*-values interpreted as significant (*P*<0.05) are in bold.

Response variable	Test location	*P*	Estimate	SE
Summary variables				
Bare space	20m	0.212	0.517	0.411
	40m	0.290	0.401	0.375
	100m	**0.003**	1.069	0.350
Species richness	20m	0.137	-0.238	0.153
	40m	**0.032**	-0.308	0.140
	100m	**0.006**	-0.348	0.125
Shannon-Wiener diversity	20m	0.680	-0.071	0.171
	40m	0.378	-0.138	0.157
	100m	0.761	0.043	0.143
Evenness	20m	0.894	0.033	0.249
	40m	0.755	-0.071	0.229
	100m	0.499	0.141	0.210
Major taxonomic groups				
Polychaetes	20m	**<0.001**	-3.678	0.389
	40m	**<0.001**	-2.320	0.361
	100m	**<0.001**	-1.691	0.287
Bryozoans	20m	**0.014**	-0.731	0.276
	40m	**0.008**	-0.718	0.257
	100m	0.087	-0.425	0.243
Sponges	20m	**0.020**	-0.794	0.316
	40m	**0.011**	-0.801	0.299
	100m	0.394	-0.239	0.277
Barnacles	20m	**<0.001**	1.633	0.402
	40m	**0.008**	0.947	0.344
	100m	0.490	-0.232	0.336
Hydroids	20m	0.096	1.714	1.095
	40m	**0.002**	2.932	0.906
	100m	**<0.001**	2.090	0.872
Colonial ascidians	20m	0.182	0.974	0.710
	40m	0.441	0.475	0.601
	100m	0.494	0.402	0.575
Solitary ascidians	20m	0.883	-0.090	0.601
	40m	0.776	-0.146	0.504

	100m	0.710	-0.191	0.507
Bivalves	20m	0.661	-0.249	0.561
	40m	0.210	0.572	0.458
	100m	0.493	0.300	0.413
Taxa that decreased in cover around the outlet				
Pomatoceros taeniata	20m	**<0.001**	-4.005	0.441
	40m	**<0.001**	-2.262	0.384
	100m	**<0.001**	-1.680	0.310
Microporella sp.	20m	**<0.001**	-2.119	0.678
	40m	**<0.001**	-2.084	0.687
	100m	**<0.001**	-2.682	0.501
Salmacina australis	20m	**<0.001**	-3.409	1.176
	40m	**<0.001**	-4.025	1.225
	100m	**<0.001**	-1.524	0.473
Smittina sp.	20m	**0.020**	-1.894	0.634
	40m	**<0.001**	-2.815	0.601
	100m	0.071	-0.754	0.408
Hydroides elegans	20m	**0.031**	-1.714	0.731
	40m	**0.008**	-2.022	0.702
	100m	0.052	-1.098	0.547
Taxa that increased in cover around the outlet				
Balanus trigonus (live)	20m	**0.001**	1.822	0.530
	40m	**0.013**	1.276	0.494
	100m	0.147	0.622	0.425
Hydroid	20m	0.096	1.714	1.095
	40m	**0.002**	2.932	0.906
	100m	**<0.001**	2.090	0.872
Megabalanus coccopoma	20m	**0.035**	6.959	1.632
	40m	**0.042**	6.007	1.629
	100m	0.755	0.633	5.282
Amphibalanus amphitrite (live)	20m	0.132	1.613	0.819
	40m	**0.045**	1.647	0.800
	100m	0.827	0.167	0.753
Taxa that decreased in density around the outlet				
Pomatoceros taeniata	20m	**<0.001**	-5.399	0.420
	40m	**<0.001**	-3.590	0.454
	100m	**<0.001**	-2.369	0.435
Smittina sp.	20m	**<0.001**	-5.429	0.933
	40m	**<0.001**	-3.818	0.695
	100m	**<0.001**	-3.242	0.729
Salmacina australis	20m	**<0.001**	-8.631	1.686

	40m	**<0.001**	-4.607	0.992
	100m	**0.032**	-2.299	1.051
Hydroides elegans	20m	**0.010**	-2.371	0.881
	40m	**0.008**	-2.045	0.767
	100m	0.288	-1.116	1.029
Microporella sp.	20m	**0.014**	-2.465	1.008
	40m	**0.003**	-2.723	0.911
	100m	0.394	12.853	1623.887
Amphipod tube	20m	**0.010**	-1.649	0.618
	40m	0.290	-0.611	0.575
	100m	0.101	0.979	0.585
Taxa that increased in density around the outlet				
Amphibalanus imperator (live)	20m	0.590	0.739	1.432
	40m	**0.007**	3.412	1.247
	100m	**0.009**	2.698	1.007
Arachnopusia unicornis	20m	**0.011**	2.506	0.968
	40m	0.121	1.631	1.030
	100m	0.153	1.662	1.109
Hydroid	20m	0.824	0.394	1.777
	40m	**0.004**	3.612	1.248
	100m	0.070	2.549	1.426

Table 4.1 Multivariate test for impacts of plant commissioning on sessile invertebrate assemblages (before vs. recovery)

Permutational multivariate analysis of variance (PERMANOVA) testing for change in assemblage structure at potentially impacted locations before plant commissioning vs. the recovery period, relative to change at reference locations. *Period* is a fixed effect, and *Round* and *Location* are random effects. *Test* is a planned comparison (fixed effect) between levels of *Location*. The term is interest (*Period* x *Test* interaction) is shaded grey. Significant *P*-values for fixed effects are in bold

	20 m				40 m				100 m			
Source	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)
Period	1	14003	1.5322	0.13	1	13800	1.5354	0.154	1	14808	1.6727	0.1
Test	1	328.31	0.48762	0.815	1	469.54	0.65776	0.661	1	925.63	1.1732	0.377
Period x Test	1	603.89	0.87769	0.539	1	922.72	1.2926	0.303	1	1322.9	1.6712	0.179
Round (Period)	5	8750.8	14.245	0.001	5	8666.2	13.854	0.001	5	8082.4	13.742	0.001
Location	4	750.01	1.2078	0.211	4	785.31	1.2554	0.158	5	836.66	1.4253	0.049
Period x Location	4	649.33	1.0462	0.396	4	729.04	1.1655	0.245	5	758.05	1.2914	0.119
Ro(Period) x Location	20	617.35	2.4737	0.001	20	625.54	2.4631	0.001	21	589.02	2.1687	0.001
Ro(Period) x Test	5	681.11	1.5675	0.024	5	713.86	1.645	0.009	3	779.56	1.7708	0.019
Residual	34	249.57			35	253.96			36	271.6		

Table 4.2 Univariate tests for impacts (before vs. recovery)

P-values, parameter estimates and standard errors for the Period x Test interaction term in MBACI analyses. Tests were performed separately for each potentially impacted location. *P*-values interpreted as significant (*P*<0.05) are in bold.

Response variable	Test location	*P*	Estimate	SE
Summary variables				
Bare space	20m	0.722	0.178	0.500
	40m	1.000	0.670	0.494
	100m	1.000	0.592	0.589
Species richness	20m	0.419	-0.146	0.180
	40m	0.117	-0.278	0.175
	100m	**0.001**	-0.558	0.156
Shannon-Wiener diversity	20m	0.727	-0.068	0.195
	40m	0.562	-0.112	0.193
	100m	0.118	-0.272	0.174
Evenness	20m	0.936	0.025	0.315
	40m	0.937	-0.025	0.322
	100m	0.853	-0.047	0.256
Major taxonomic groups				
Polychaetes	20m	0.294	-0.278	0.263
	40m	0.125	-0.429	0.278
	100m	**0.004**	-0.671	0.222
Bryozoans	20m	0.281	-0.315	0.284
	40m	0.054	-0.587	0.296
	100m	**0.013**	-0.640	0.247
Sponges	20m	0.416	-0.333	0.395
	40m	0.396	-0.339	0.385
	100m	0.056	-0.874	0.441
Barnacles	20m	0.303	0.491	0.474
	40m	0.685	0.173	0.426
	100m	0.831	0.087	0.407
Hydroids	20m	0.169	1.488	1.083
	40m	0.082	2.018	1.159
	100m	0.096	2.028	1.181
Colonial ascidians	20m	0.267	0.705	0.624
	40m	0.789	-0.172	0.628
	100m	0.574	-0.329	0.565
Solitary ascidians	20m	0.345	0.572	0.598
	40m	0.129	0.793	0.513

	100m	0.645	-0.228	0.496
Amphipod tubes	20m	0.685	0.259	0.631
	40m	0.932	-0.057	0.651
	100m	0.908	0.072	0.613
Taxa that decreased in cover around the outlet				
Pomatoceros taeniata	20m	0.283	-0.324	0.299
	40m	0.144	-0.458	0.310
	100m	**0.015**	-0.627	0.252
Microporella sp.	20m	0.073	-1.082	0.588
	40m	0.087	-1.284	0.733
	100m	**0.002**	-1.579	0.480
Salmacina australis	20m	0.965	0.023	0.512
	40m	0.435	-0.420	0.517
	100m	0.071	-0.789	0.419
Smittina sp.	20m	0.212	1.206	0.932
	40m	0.514	0.646	0.970
	100m	0.383	-0.849	1.034
Hydroides elegans	20m	0.134	-1.034	0.679
	40m	0.410	-0.539	0.650
	100m	0.229	-0.754	0.608
Taxa that increased in cover around the outlet				
Balanus trigonus (live)	20m	0.276	0.607	0.550
	40m	0.816	0.129	0.553
	100m	0.245	0.540	0.459
Hydroid	20m	0.169	1.488	1.083
	40m	0.082	2.018	1.159
	100m	0.096	2.028	1.181
Megabalanus coccopoma	20m	0.443	1.448	3.554
	40m	0.885	-0.360	6.094
	100m	0.836	-0.440	2.953
Amphibalanus amphitrite (live)	20m	0.945	0.088	1.292
	40m	0.845	-0.315	1.708
	100m	0.102	-2.330	1.661
Taxa that decreased in density around the outlet				
Pomatoceros taeniata	20m	0.969	-0.014	0.353
	40m	0.288	0.388	0.362
	100m	0.190	0.436	0.330
Smittina sp.	20m	**0.004**	14.936	708.126
	40m	**0.010**	14.851	807.494
	100m	0.180	1.168	0.891
Salmacina australis	20m	**0.020**	1.313	0.524

	40m	**0.031**	1.262	0.555
	100m	**0.048**	1.145	0.565
Hydroides elegans	20m	0.809	0.174	0.677
	40m	0.301	0.662	0.623
	100m	0.644	0.416	0.863
Microporella sp.	20m	0.425	0.655	0.795
	40m	**0.044**	1.651	0.778
	100m	0.245	-14.816	2511.802
Amphipod tube	20m	0.072	1.518	0.822
	40m	0.234	0.892	0.736
	100m	0.014	2.007	0.800
Taxa that increased in density around the outlet				
Amphibalanus imperator (live)	20m	0.687	-0.371	0.906
	40m	0.970	-0.032	0.851
	100m	0.983	0.023	1.029
Arachnopusia unicornis	20m	0.314	0.968	0.851
	40m	0.757	0.271	0.861
	100m	**0.012**	2.503	0.854
Hydroid	20m	0.072	-2.502	1.422
	40m	0.692	-0.525	1.329
	100m	0.121	-2.715	1.757

Table 4.3 Multivariate test for impacts of plant commissioning on sessile invertebrate assemblages (during vs. recovery)

Permutational multivariate analysis of variance (PERMANOVA) testing for change in assemblage structure at potentially impacted locations during plant operation vs. the recovery period, relative to change at reference locations. *Period* is a fixed effect, and *Round* and *Location* are random effects. *Test* is a planned comparison (fixed effect) between levels of *Location*. The term is interest (*Period* x *Test* interaction) is shaded grey. Significant *P*-values for fixed effects are in bold.

	20 m				40 m				100 m			
Source	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)	df	MS	Pseudo-F	P(perm)
Period	1	14459	1.5646	0.16	1	14618	1.5236	0.171	1	18115	1.629	0.147
Test	1	2523.5	3.5922	0.061	1	2324.3	4.0073	0.022	1	2078.6	2.5215	0.064
Period x Test	1	2050.7	2.9192	0.078	1	1753.4	3.0236	**0.032**	1	1148.5	1.3943	0.263
Round (Period)	4	8421.8	14.515	0.001	4	8968.5	16.084	0.001	4	10655	17.798	0.001
Location	4	1205.3	2.0435	0.002	4	1145.1	2.0317	0.003	5	1019.1	1.687	0.004
Period x Location	4	931.26	1.5798	0.022	4	848.34	1.5061	0.03	5	683.87	1.1331	0.235
Ro(Period) x Location	15	585.44	2.2961	0.001	16	560.25	2.0216	0.001	20	601.36	2.0439	0.001
Ro(Period) x Test	3	702.48	1.7642	0.005	4	578.64	1.4154	0.046	4	821.28	1.9496	0.003
Residual	28	254.97			29	277.13			35	294.22		

Table 4.4 Univariate tests for recovery (during vs. recovery)

P-values, parameter estimates and standard errors for the Period x Test interaction term in MBACI analyses. Tests were performed separately for each potentially impacted location. *P*-values interpreted as significant (*P*<0.05) are in bold.

Response variable	Test location	*P*	Estimate	SE
Summary variables				
Bare space	20m	**<0.001**	0.264	0.503
	40m	0.094	0.874	0.480
	100m	1.000	-0.153	0.387
Species richness	20m	0.324	0.111	0.111
	40m	0.516	0.073	0.110
	100m	0.119	-0.168	0.105
Shannon-Wiener diversity	20m	0.982	0.004	0.193
	40m	0.974	-0.006	0.194
	100m	0.248	-0.189	0.164
Evenness	20m	0.829	0.067	0.308
	40m	0.867	0.053	0.316
	100m	0.620	-0.119	0.241
Major taxonomic groups				
Polychaetes	20m	**<0.001**	2.224	0.544
	40m	**0.016**	1.274	0.516
	100m	**0.021**	0.792	0.334
Bryozoans	20m	**0.045**	0.642	0.310
	40m	0.470	0.236	0.324
	100m	0.320	-0.253	0.247
Sponges	20m	0.081	0.700	0.336
	40m	0.093	0.648	0.342
	100m	0.195	-0.526	0.402
Barnacles	20m	**0.001**	-1.644	0.474
	40m	**0.010**	-1.147	0.431
	100m	0.843	0.070	0.353
Hydroids	20m	0.923	-0.110	1.137
	40m	0.186	-1.187	0.873
	100m	**0.037**	-0.314	1.195
Colonial ascidians	20m	0.619	-0.359	0.694
	40m	0.333	-0.638	0.649
	100m	0.280	-0.608	0.537
Solitary ascidians	20m	0.400	0.621	0.721
	40m	0.175	0.948	0.688

	100m	0.786	-0.169	0.623
Amphipod tubes	20m	0.150	1.424	0.955
	40m	0.820	-0.215	0.916
	100m	0.880	-0.122	0.759
Taxa that decreased in cover around the outlet				
Pomatoceros taeniata	20m	**<0.001**	2.349	0.565
	40m	**0.026**	1.206	0.529
	100m	**0.022**	0.825	0.351
Microporella sp.	20m	**0.045**	1.437	0.672
	40m	0.129	1.065	0.681
	100m	0.116	0.788	0.505
Salmacina australis	20m	**0.011**	2.174	0.858
	40m	**0.003**	2.546	0.878
	100m	0.559	0.266	0.447
Smittina sp.	20m	0.072	2.232	1.015
	40m	**0.013**	3.216	1.097
	100m	0.856	-0.173	1.074
Hydroides elegans	20m	0.382	0.729	0.820
	40m	0.082	1.510	0.811
	100m	0.876	0.096	0.608
Taxa that increased in cover around the outlet				
Balanus trigonus (live)	20m	**0.005**	-1.471	0.502
	40m	**0.005**	-1.375	0.473
	100m	0.751	-0.123	0.387
Hydroid	20m	0.923	-0.110	1.137
	40m	0.186	-1.187	0.873
	100m	0.037	-0.314	1.195
Megabalanus coccopoma	20m	**0.001**	-4.528	1.073
	40m	**0.005**	-5.640	1.697
	100m	0.776	-0.642	5.771
Amphibalanus amphitrite (live)	20m	0.512	-0.861	1.310
	40m	0.276	-1.654	1.563
	100m	0.077	-2.360	1.539
Taxa that decreased in density around the outlet				
Pomatoceros taeniata	20m	**<0.001**	-5.963	0.615
	40m	**<0.001**	-3.783	0.715
	100m	**<0.001**	-2.084	0.533
Smittina sp.	20m	0.384	-1.959	6.457
	40m	0.382	-1.963	6.474
	100m	0.373	-1.973	6.289
Salmacina australis	20m	**0.043**	-2.061	1.010

	40m	0.073	-1.619	0.885
	100m	0.301	-1.064	1.001
Hydroides elegans	20m	0.138	-1.853	1.215
	40m	0.387	-0.948	1.049
	100m	0.936	-0.096	1.120
Microporella sp.	20m	0.480	-0.947	3.761
	40m	0.627	-0.694	3.987
	100m	0.737	-0.491	4.011
Amphipod tube	20m	0.568	-0.699	1.186
	40m	0.799	-0.306	1.154
	100m	**<0.001**	3.575	0.956
Taxa that increased in density around the outlet				
Amphibalanus imperator (live)	20m	0.312	-2.158	2.056
	40m	**0.025**	-5.464	2.021
	100m	**0.001**	-4.782	1.291
Arachnopusia unicornis	20m	0.340	1.943	5.673
	40m	0.534	1.237	5.362
	100m	0.207	2.619	4.545
Hydroid	20m	0.999	0.001	4.346
	40m	0.712	0.519	4.289
	100m	0.903	0.189	4.696

Figures

Figure 1.1 Satellite image showing sampling locations for MEMP components

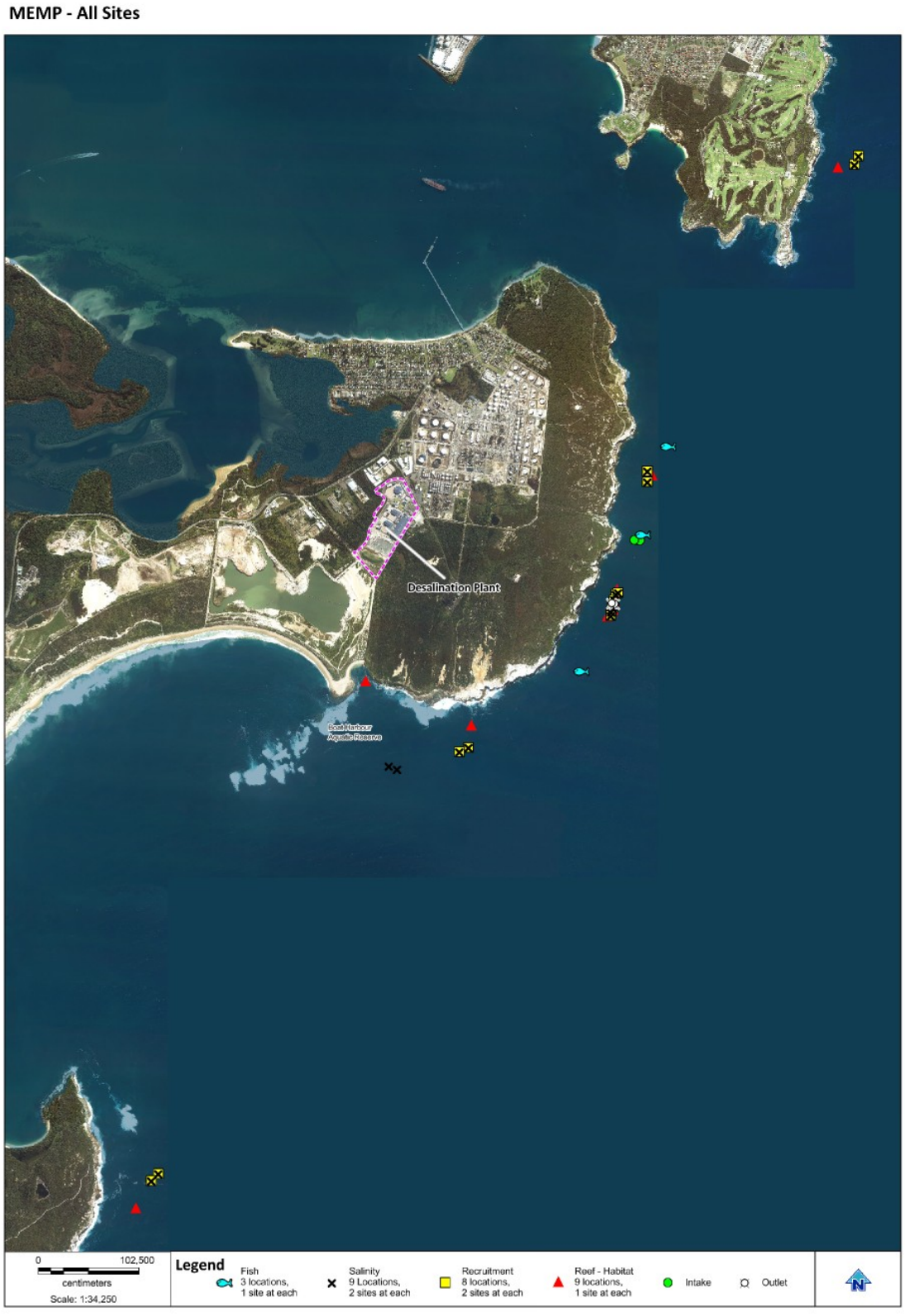


Figure 1.2 Satellite image showing sampling locations for MEMP components

Figure 2.1 Map of sampling locations used in the Recruitment and Salinity Studies

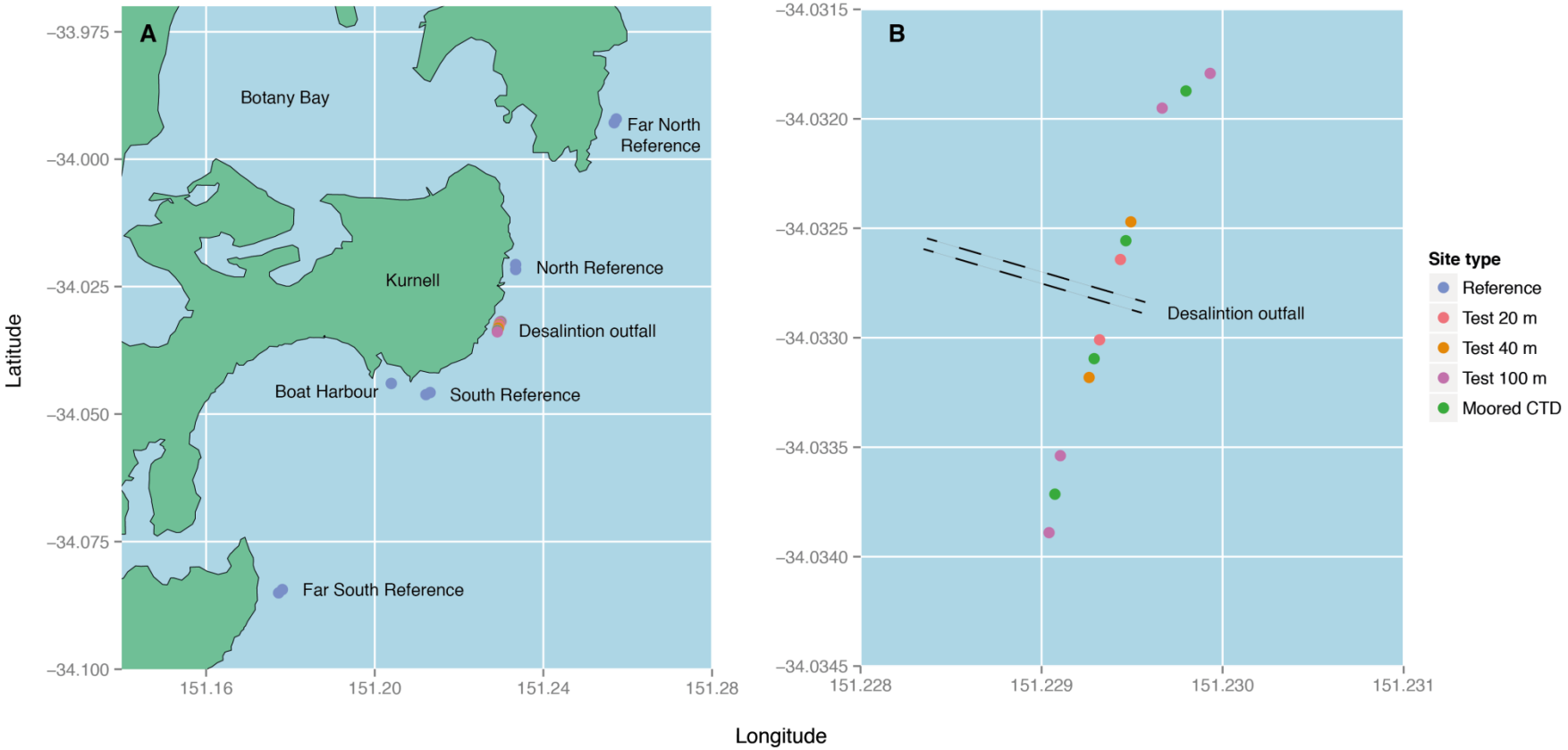


Figure 2.2 Schematic diagram of salinity profiles

Schematic diagram showing positions of salinity profiles around recruitment panels. Spacing of the arrays at the reference locations is 20 m; while the immediate and near outlet arrays are separated by 40 and 80 m respectively. Two salinity profiles are taken at each array of panels (i.e. sites); one as the probe descends to the seafloor and one as the probe returns to the surface.

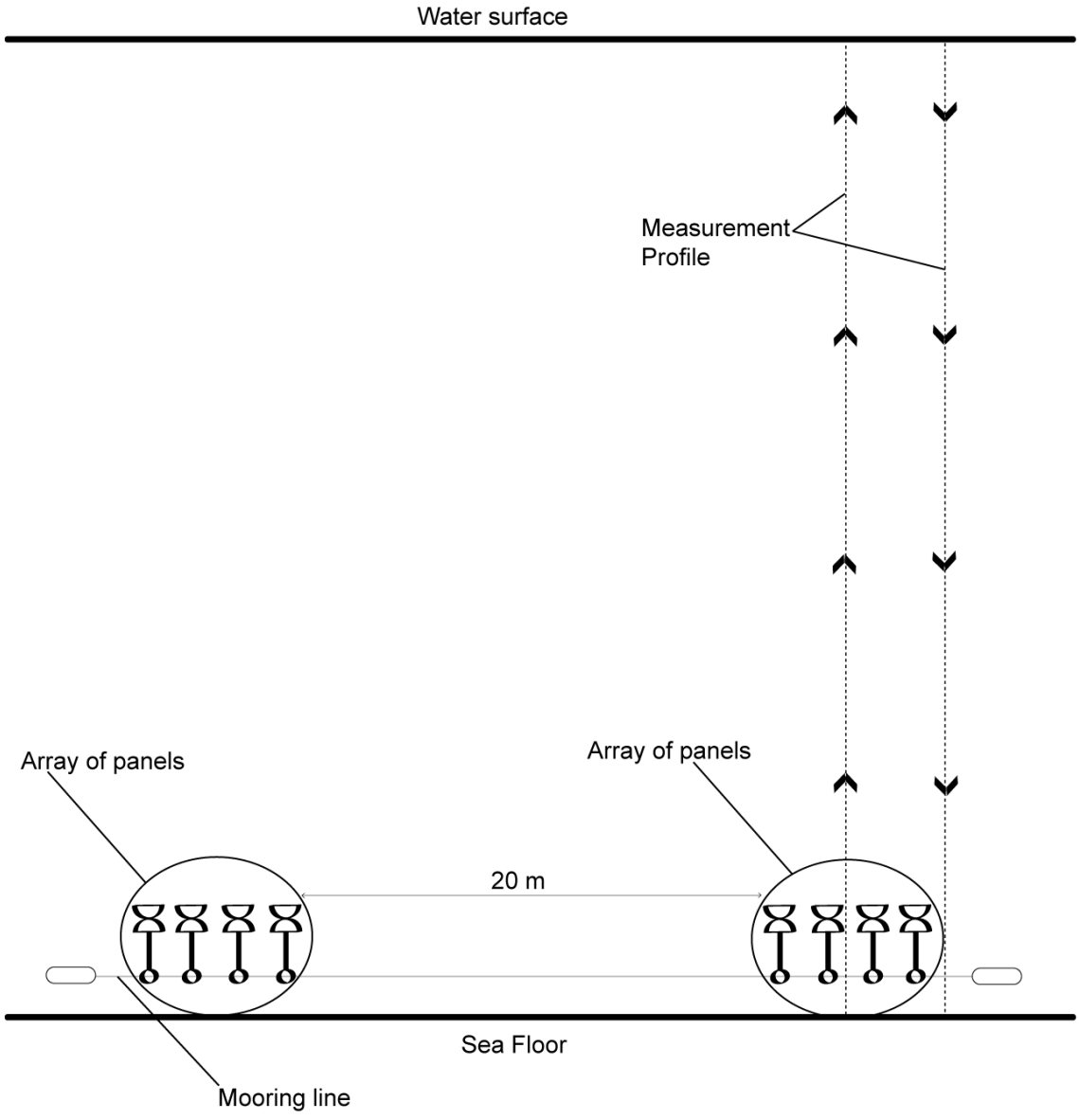


Figure 2.3 Salinity at potentially impacted and reference locations

Line graphs showing average salinity at each location in each round. Dashed red line indicates the time at which the plant became operational.

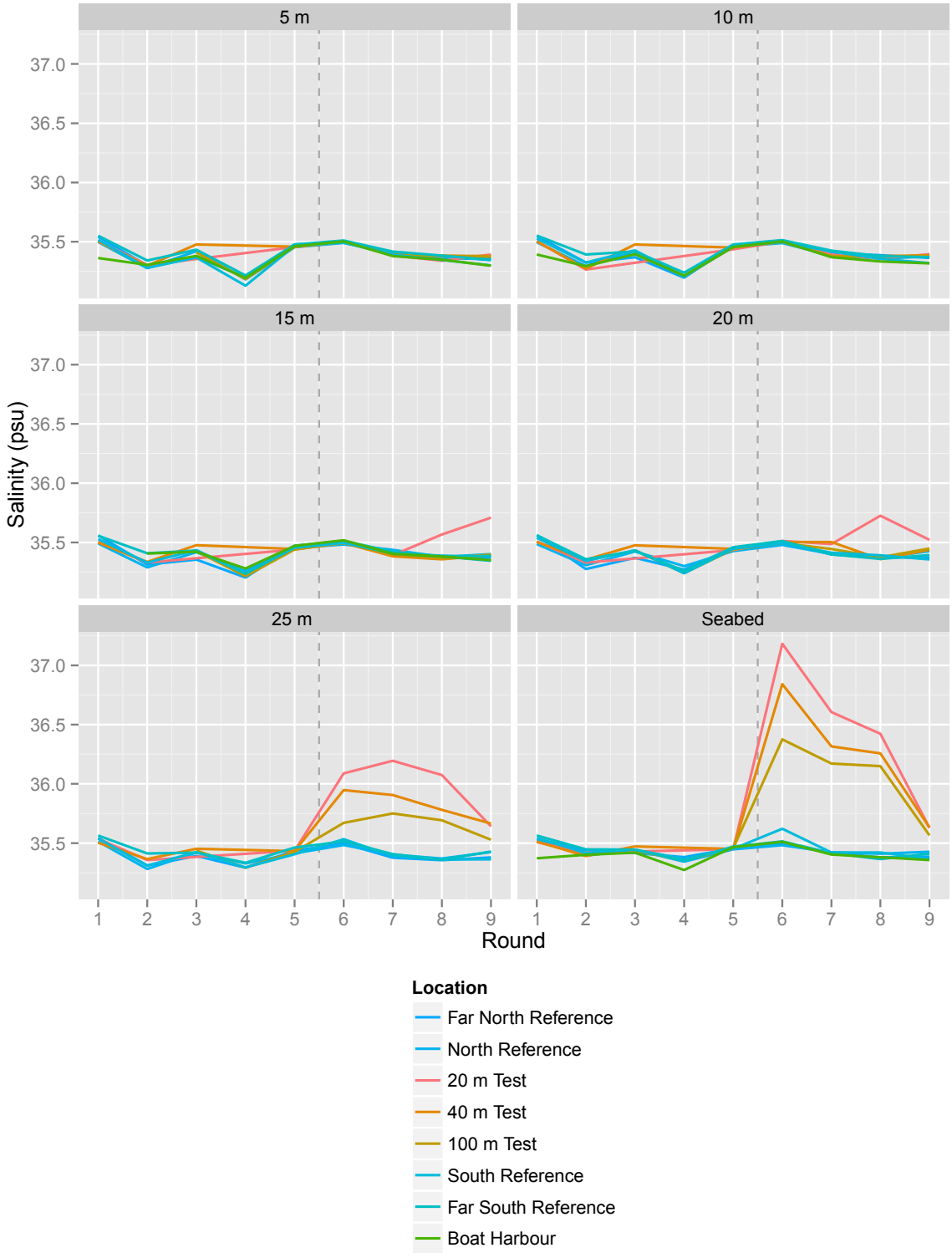


Figure 2.4 Depth profiles of salinity at each location in Rounds 1 to 9

Depth profiles showing vertical change in salinity at each location, in each round. Locations are shown as coloured lines, and rounds appear as subplots. Within each round data are averaged across three or four sampling times. Plant operation commenced between rounds 5 and 6.

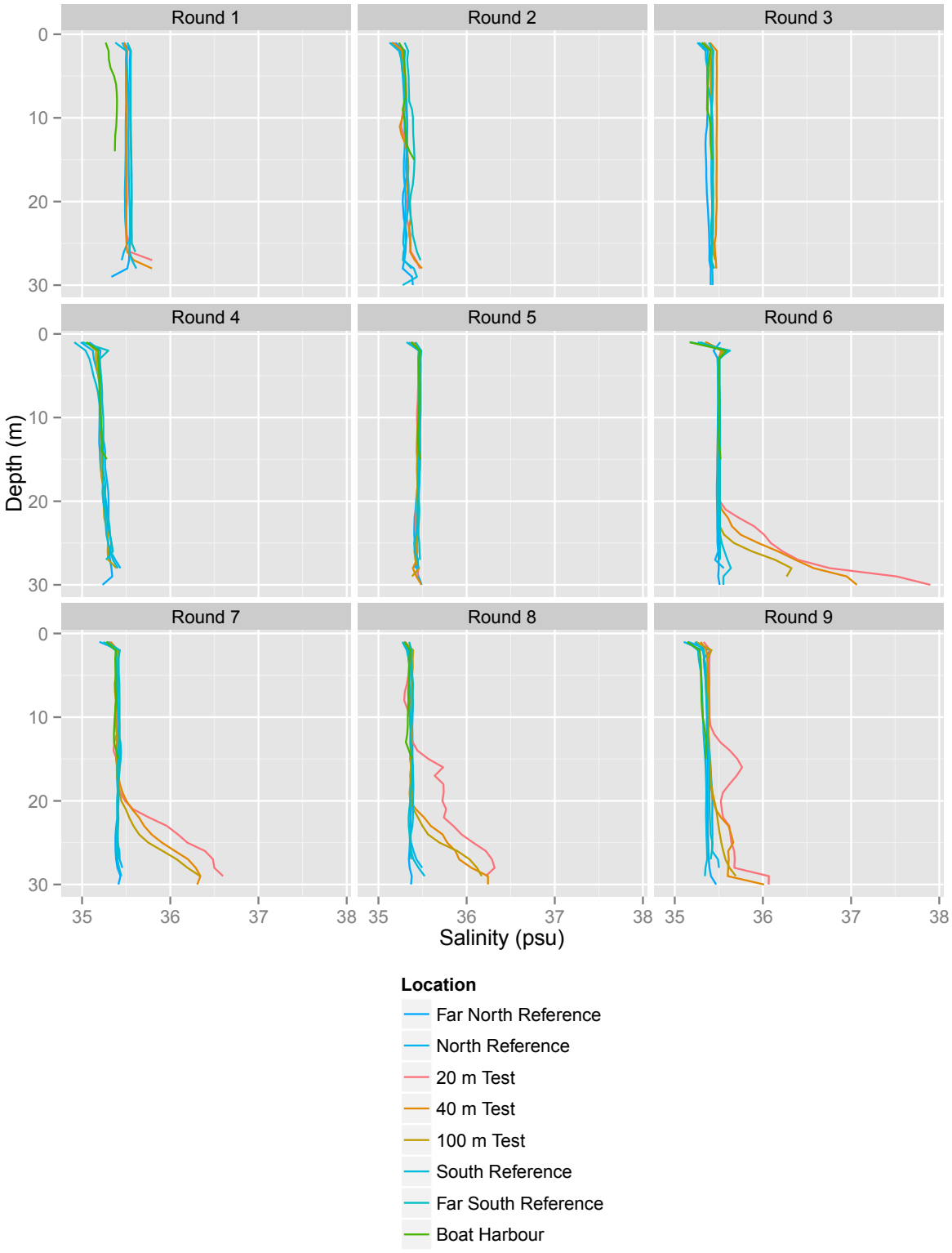


Figure 2.5 Moored CTD: Salinity

Continuous salinity measurements from moored CTDs at test locations during plant commissioning.

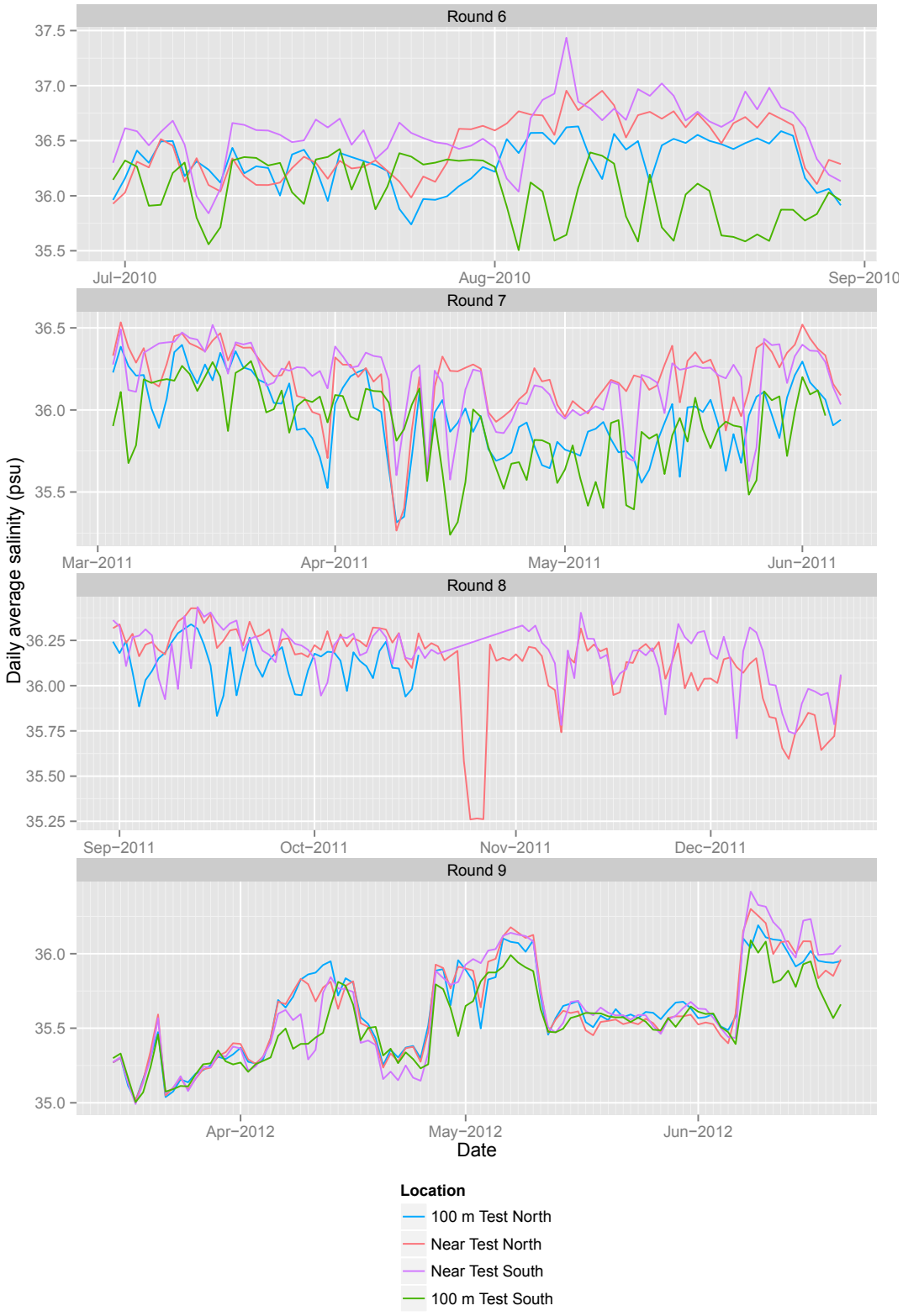


Figure 2.6 Moored CTD: Temperature

Continuous temperature measurements from moored CTDs at test locations during plant commissioning.

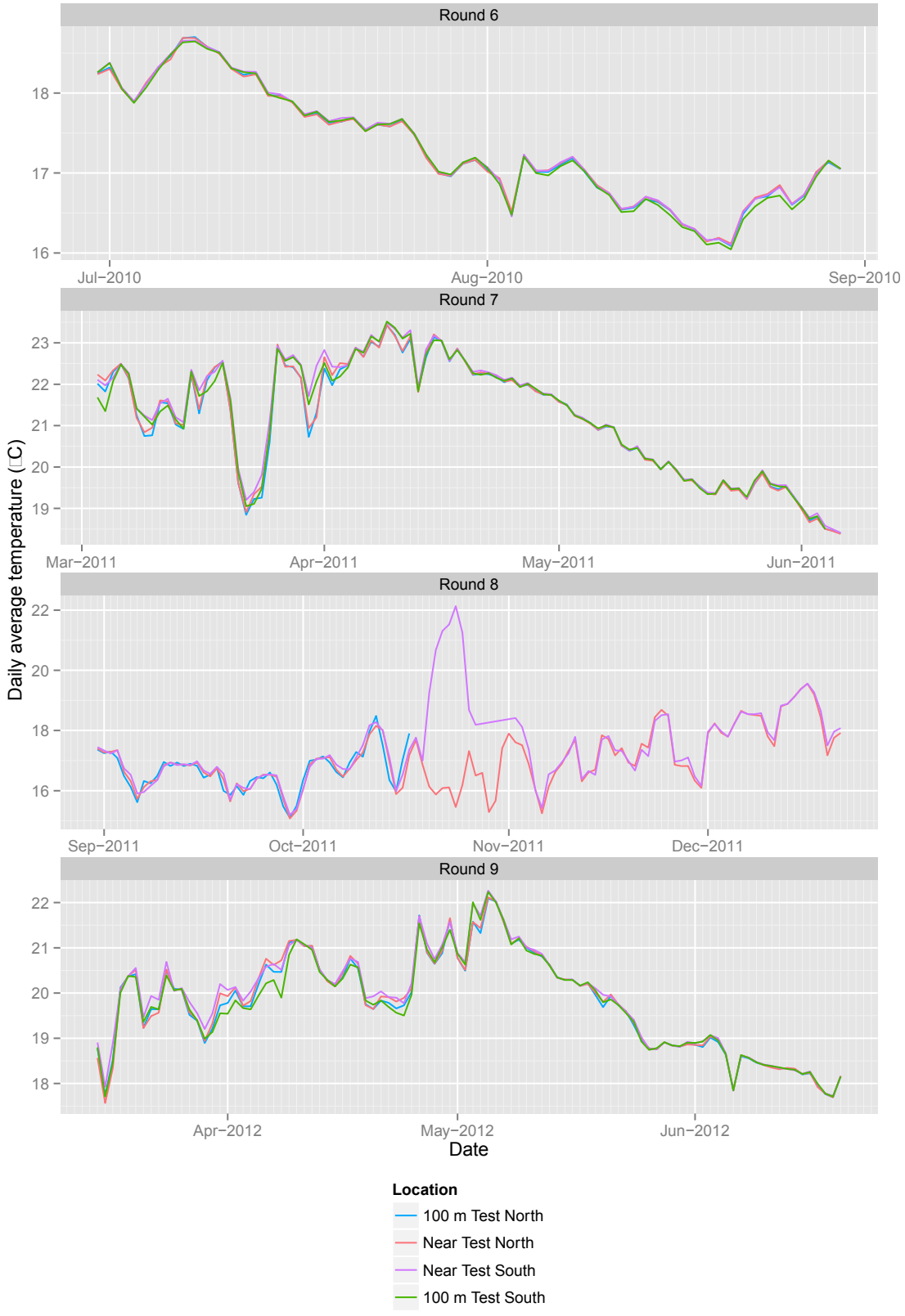


Figure 2.7 TidbiT temperature loggers

Continuous temperature measurements from Tidbit loggers at all locations during plant commissioning.

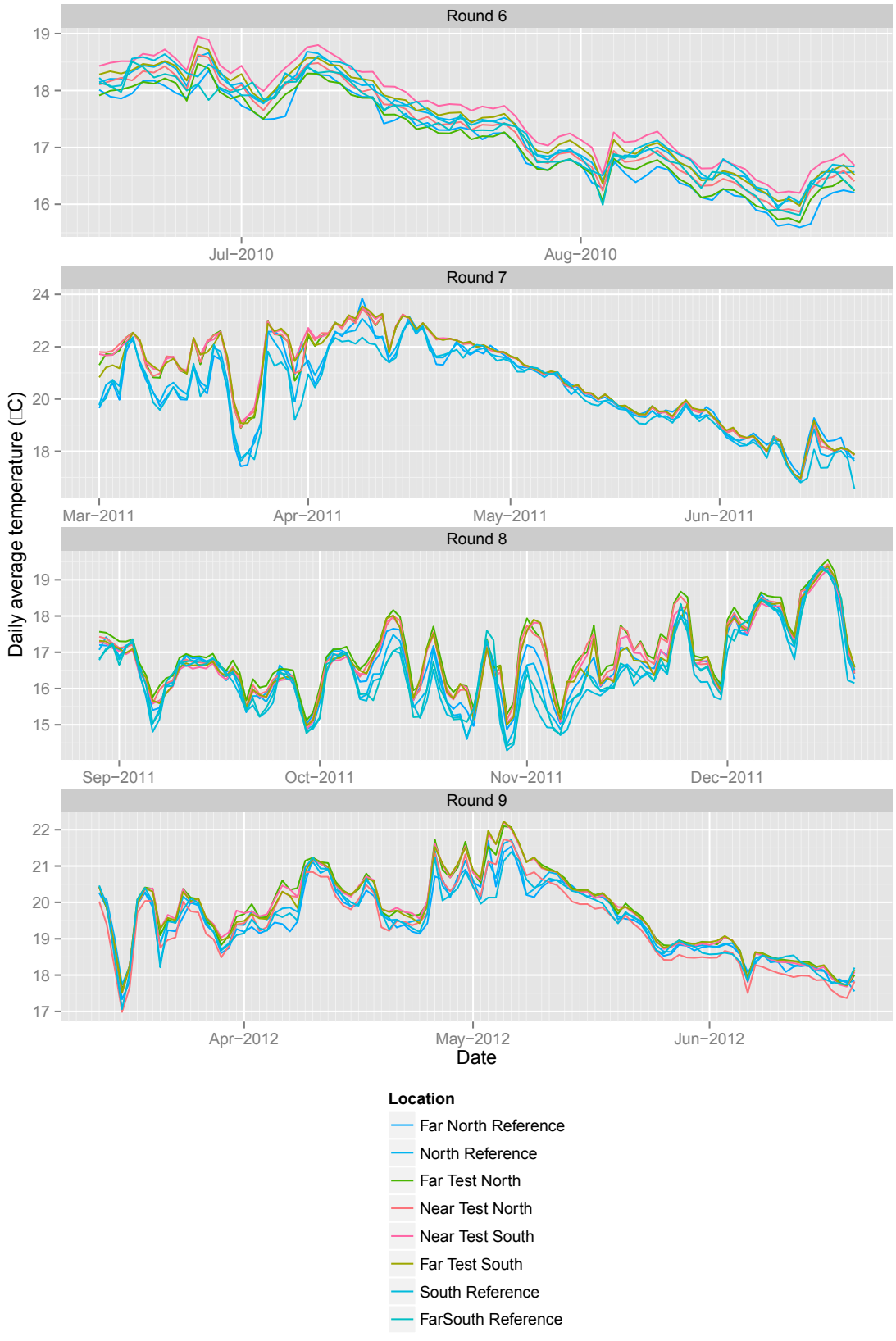


Figure 3.1 Schematic diagram of deployment of recruitment plates

A schematic diagram showing the deployment of the recruitment plates. A 100 kg weight is lowered into position to anchor the mooring line. This weight is connected to the first array of panels (i.e. site 1). These panels are connected to the next array of panels (i.e. site 2) by a 20 m length of mooring line. A final length of mooring line attaches to the final 100 kg anchor. Each panel is itself also weighted to help it stay in place on the reef.

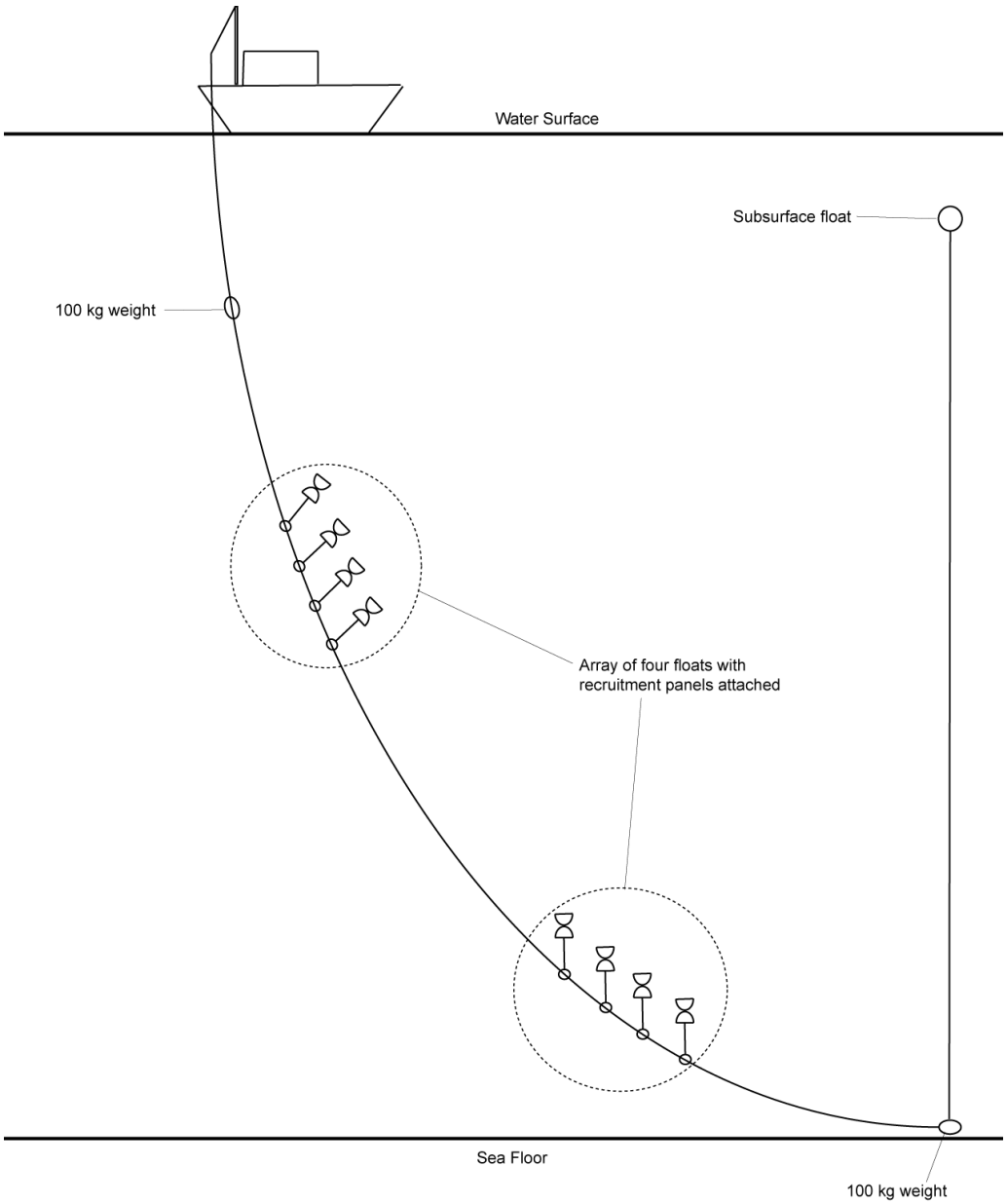


Figure 3.2 Canonical Analysis of Principle Coordinates (CAP)

Canonical Analysis of Principle Coordinates (CAP) ordination showing multivariate differences in recruitment assemblages. CAP maximises differences according to Period (Before and During) and site Status (Impact and Reference). Points represent sites within rounds, and increasing distance between points indicates increasing dissimilarity. Vector diagrams indicate Pearson correlations (>0.4) between taxa and CAP axes. The circle is a correlation of 1.

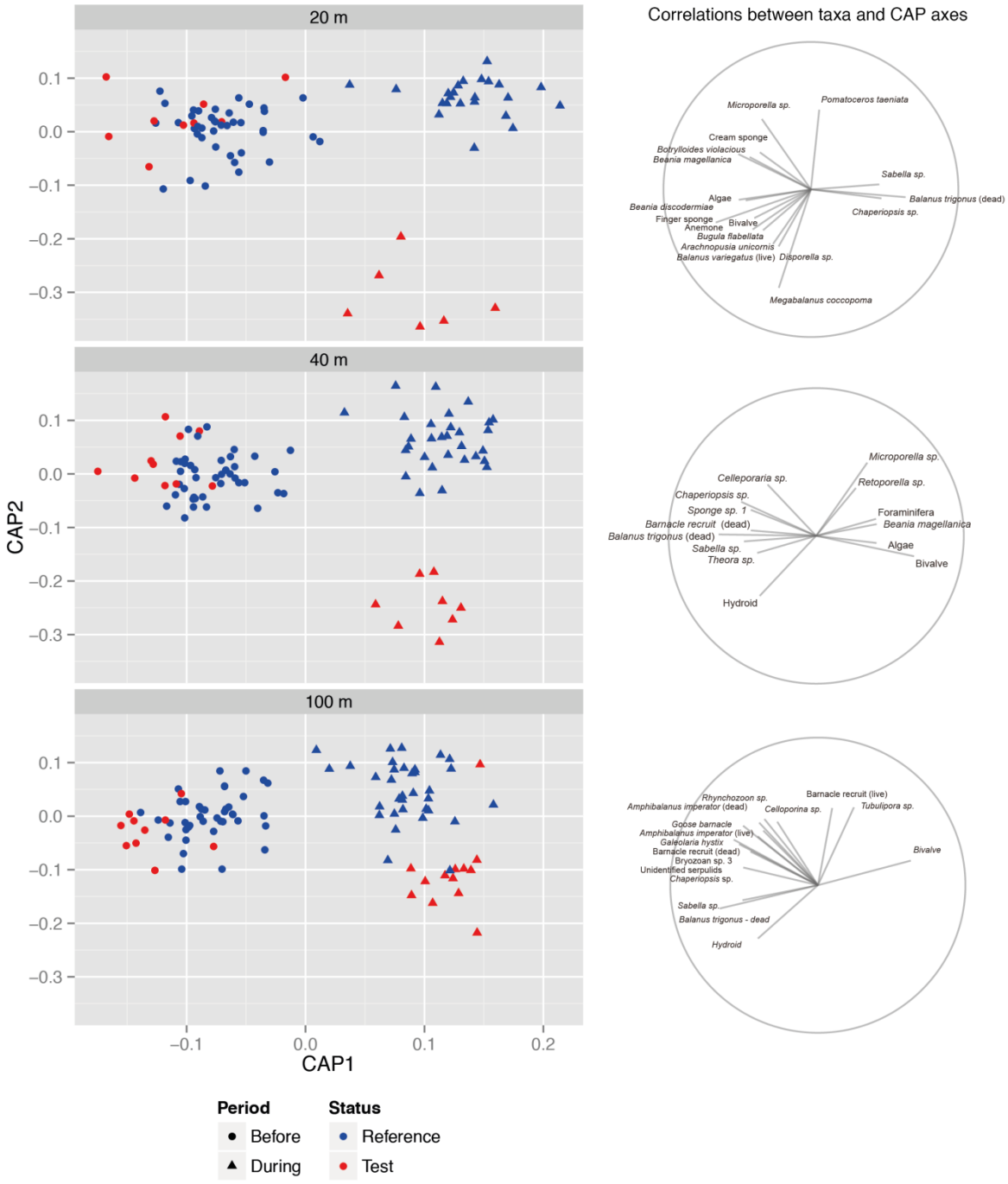


Figure 3.3 Summary variables

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

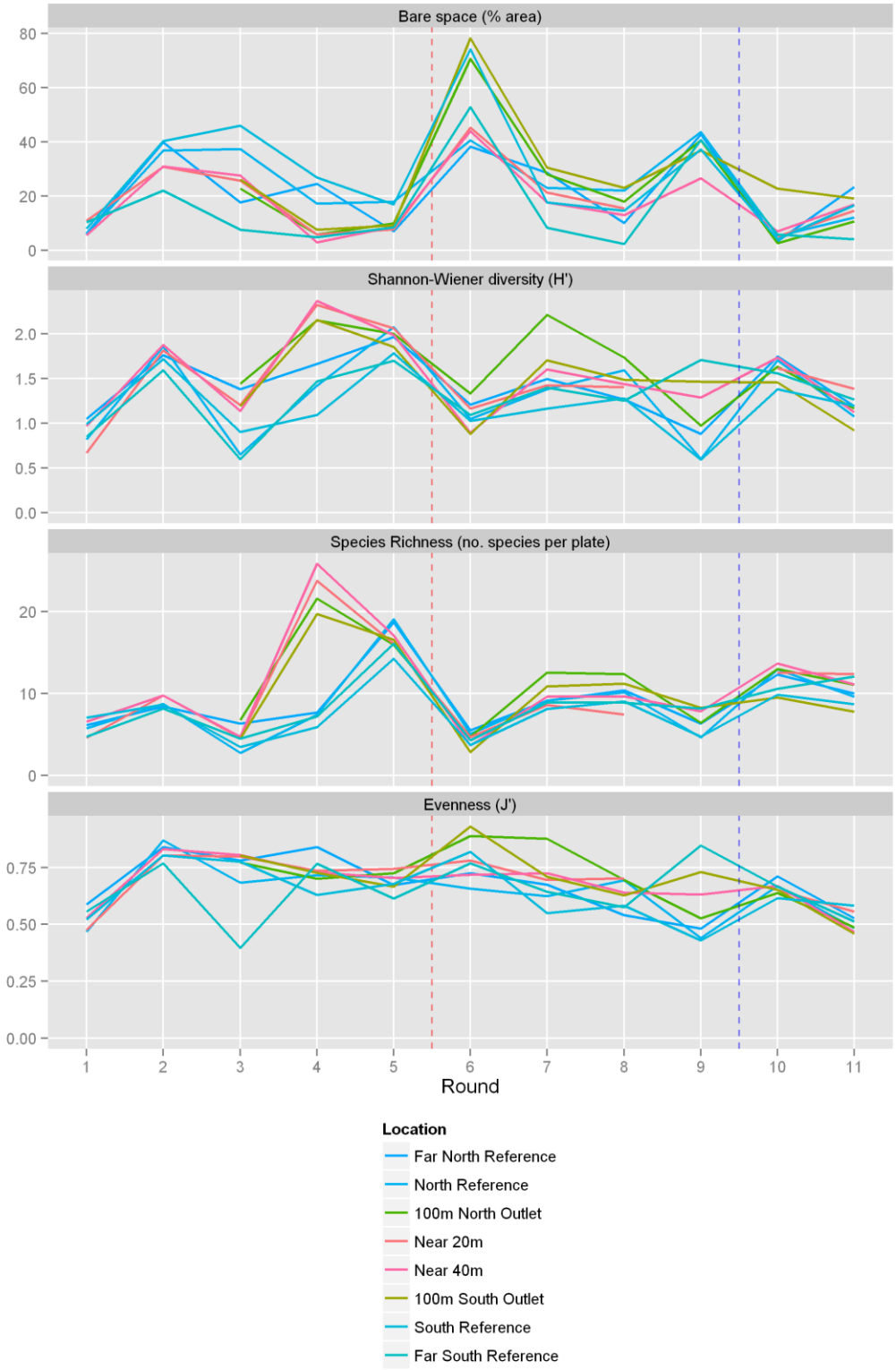


Figure 3.4 Major taxonomic groups

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

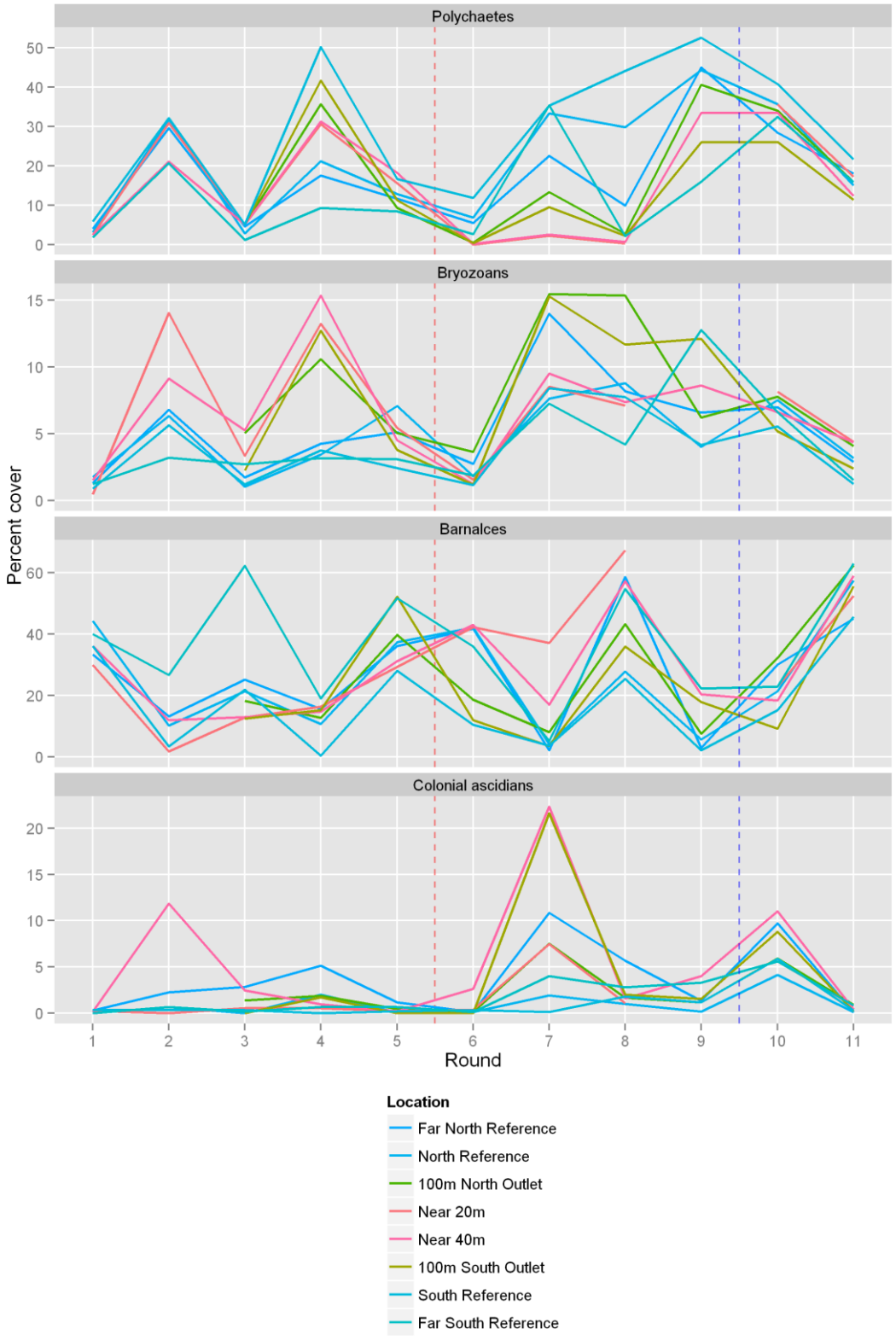


Figure 3.4 Major taxonomic groups (continued)

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

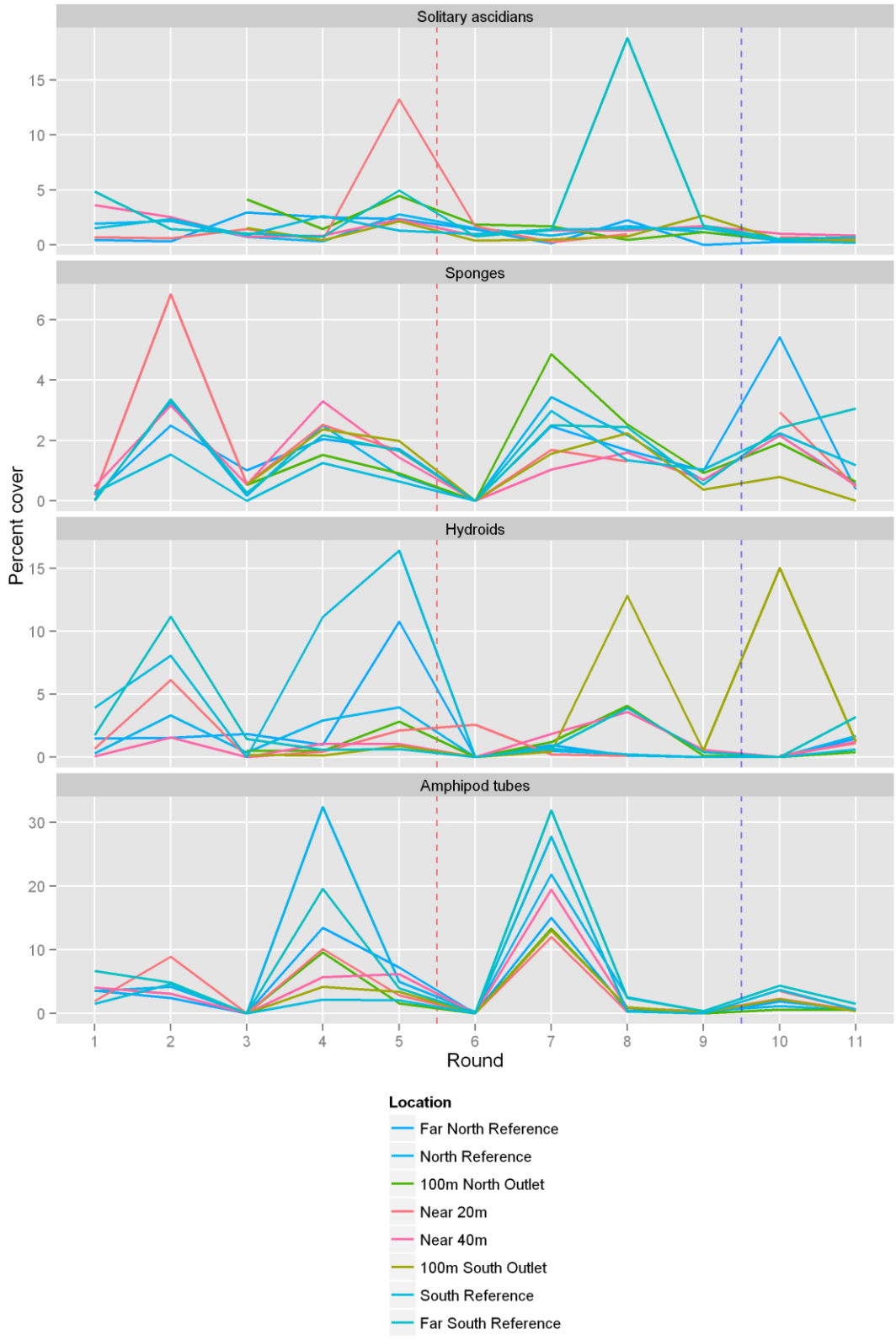


Figure 3.5 Taxa that decreased in cover around the outlet during plant commissioning

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

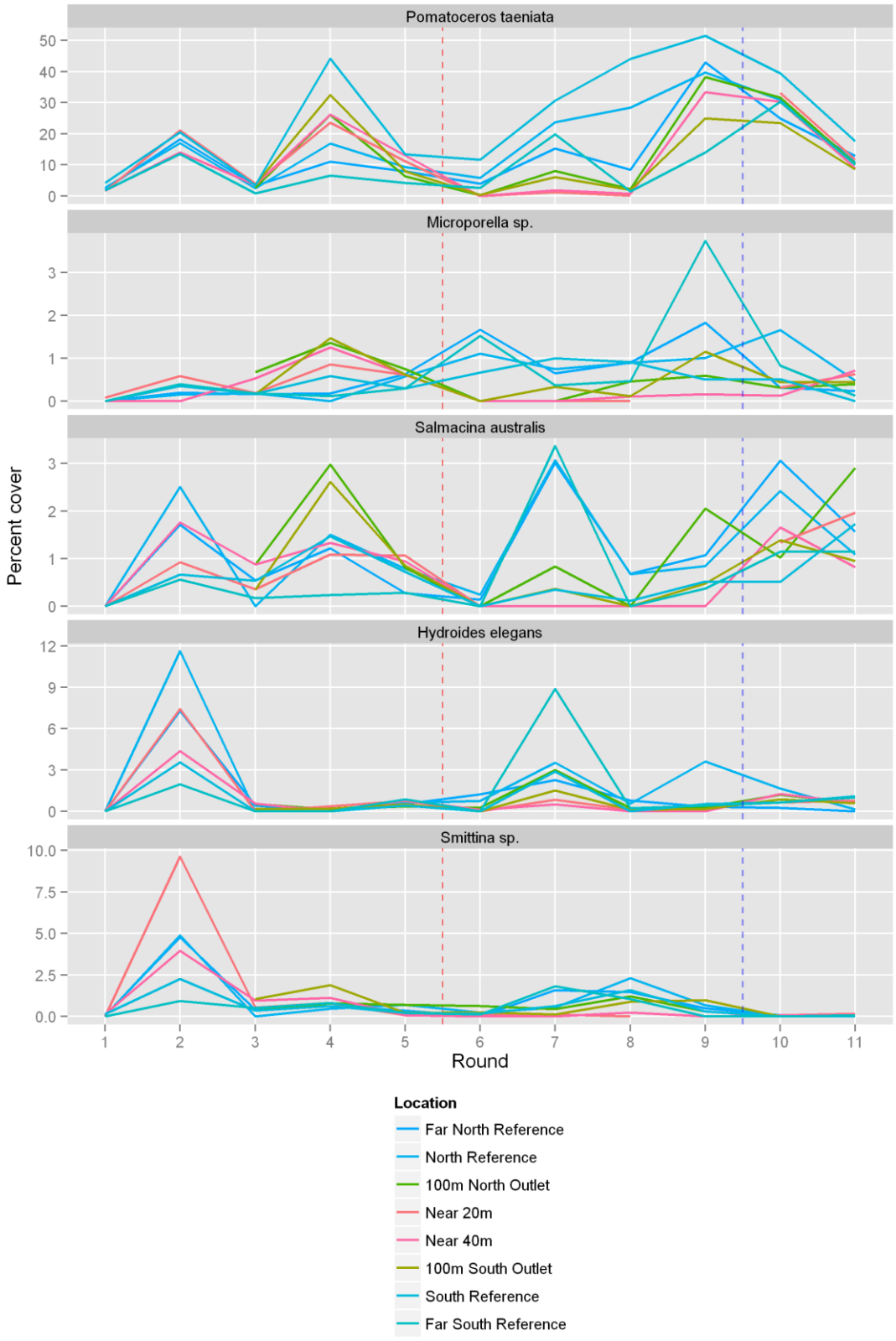


Figure 3.6 Taxa that increased in cover around the outlet during plant commissioning

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

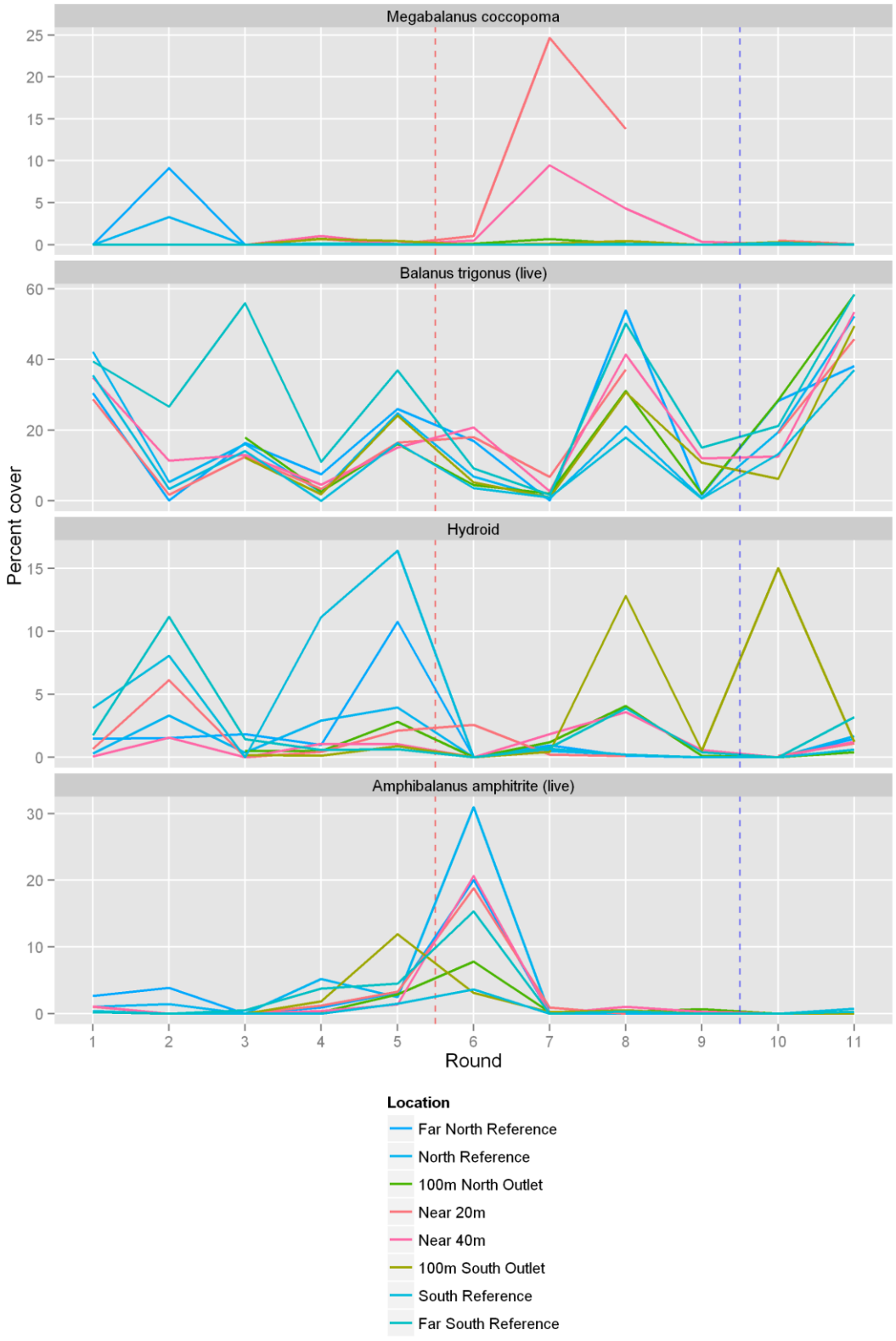


Figure 3.7 Taxa that decreased in density around the outlet during plant commissioning

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.

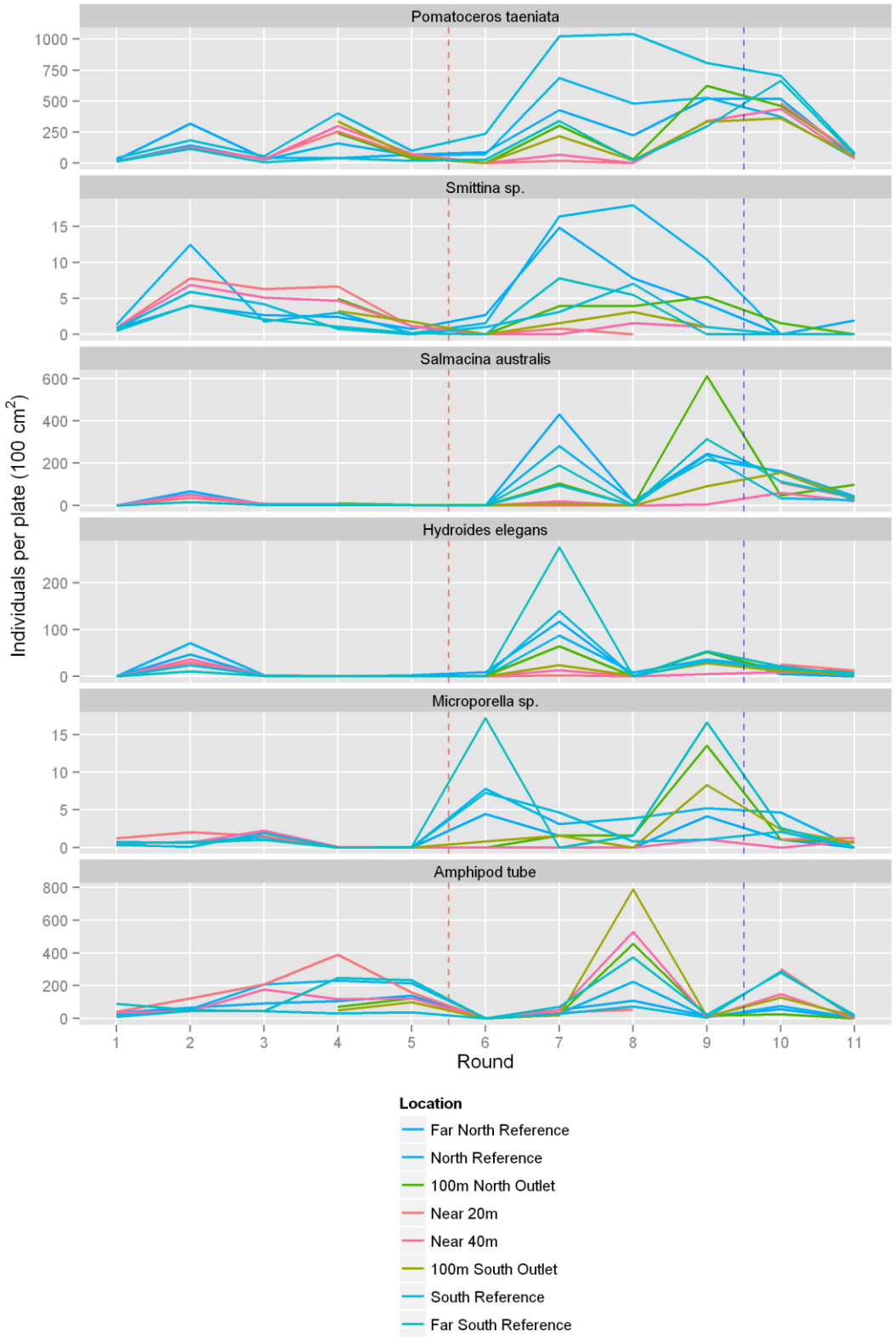
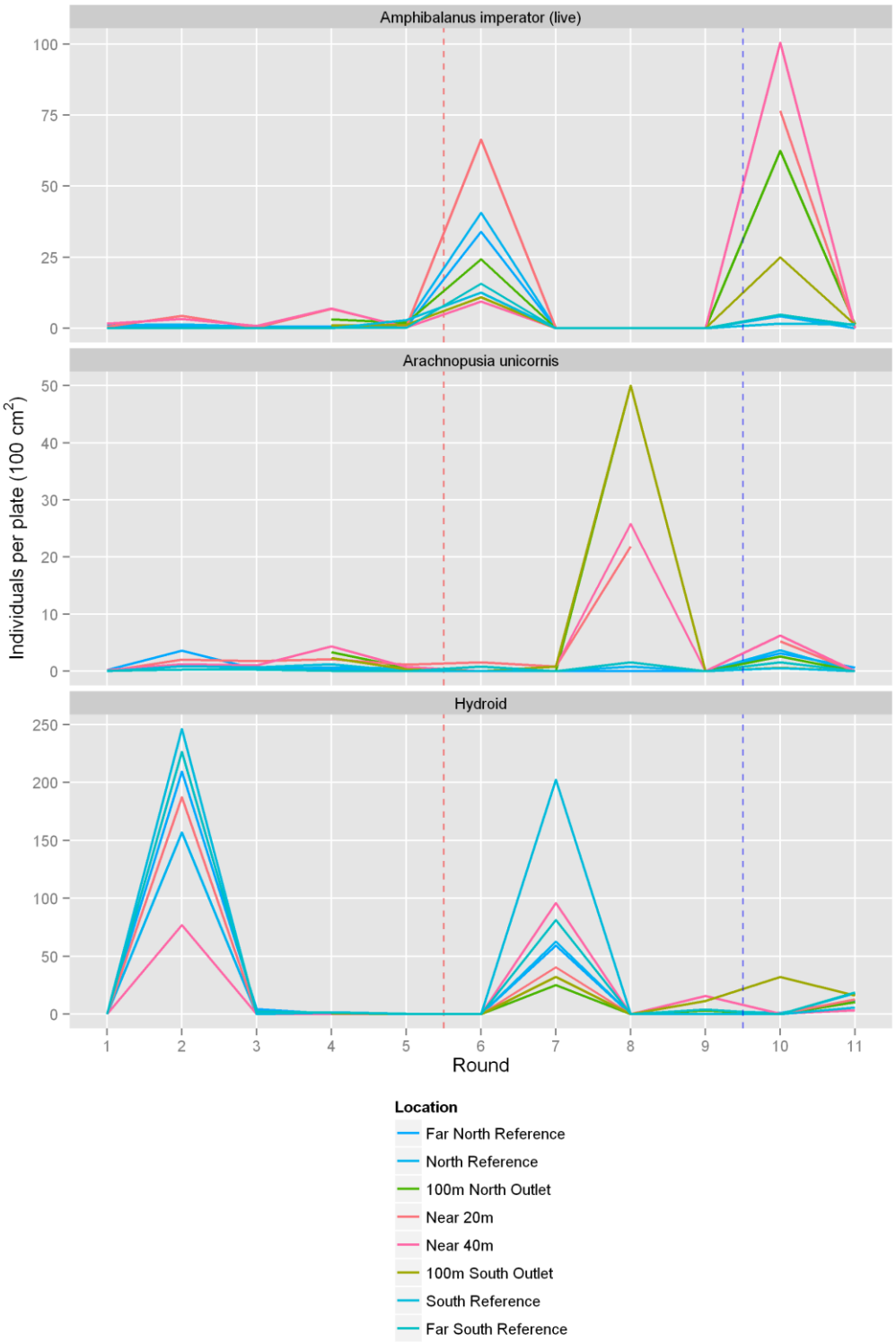


Figure 3.8 Taxa that increased in density around the outlet during plant commissioning

Dashed red line indicates the time at which the plant became operational, and dashed blue line when the plant entered shutdown mode. No data were collected from the Near 20 m location in Round 9, which is represented as a broken line.



7. Plates

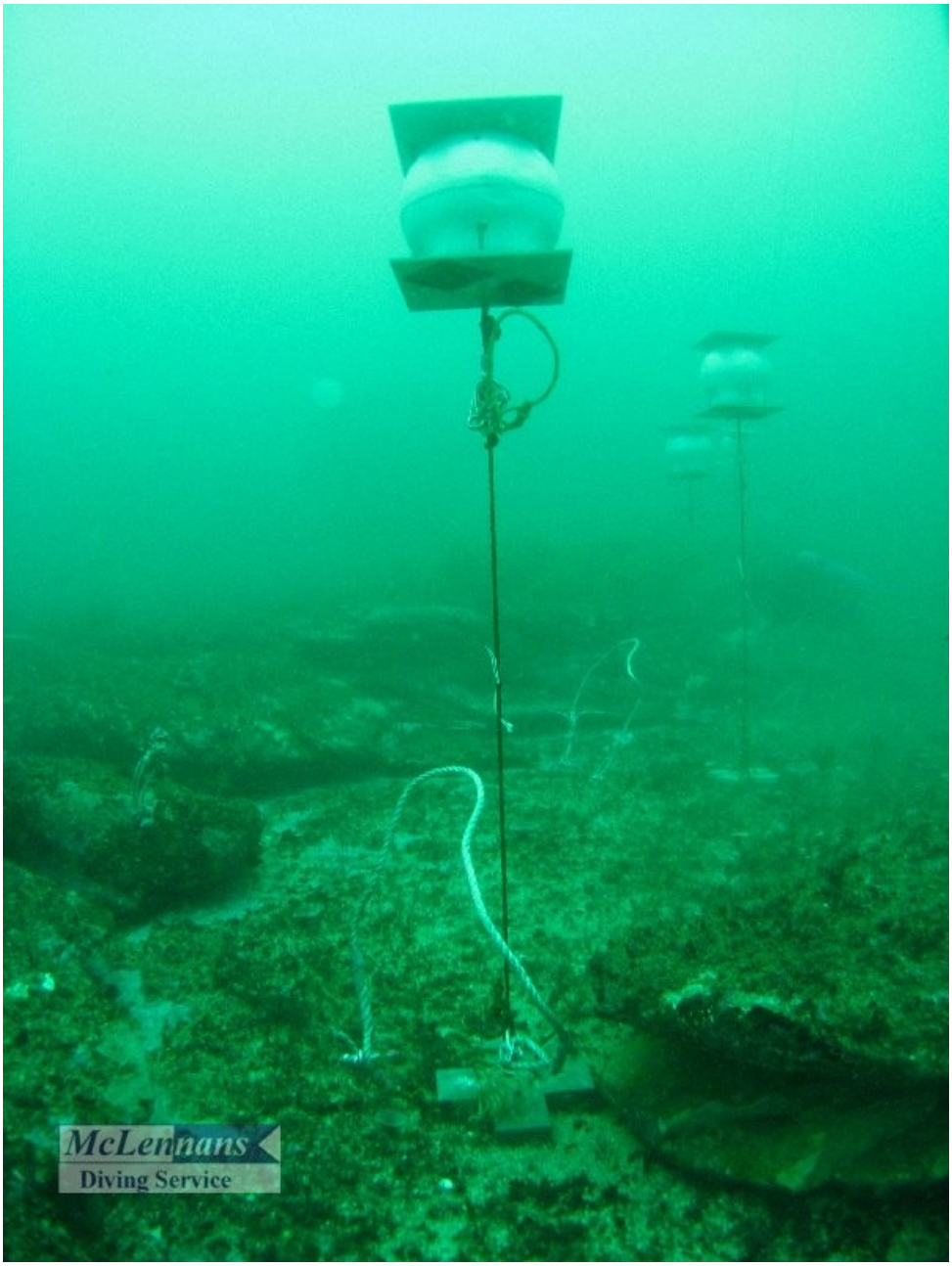


Plate 1. An array of recruitment panels on a mooring. Each recruitment panel has two downward facing recruitment plates which will be sampled. (Photograph courtesy of McLennans Diving Services)

Plate 2. Two recruitment plates (roughened Perspex) attached to the downward surface of a panel/float. Four panels are set up in an array (a site) with 2 sets of arrays at each location (Photograph courtesy of McLennans Diving Services).

Plate 3. Recruitment plates attached to PVC backing panel just after removal from the holding float.

Plate 4. Recruitment plates attached to PVC backing panels held in specially designed frames to safely hold the samples during collection at sea.

Plate 5. Recruitment plates held on stainless steel allthread with plastic tubing spacers to keep each set of plates separate. PVC tubing is used to separate the three allthreads of plates and the perfectly fitting container also holds them in place. Using this holding system enables the plates to be brought from the field by vehicle to the laboratory without any damage occurring to the recruitment assemblages. Plates were removed from the backing panels at Fisheries Wharf, Cronulla.

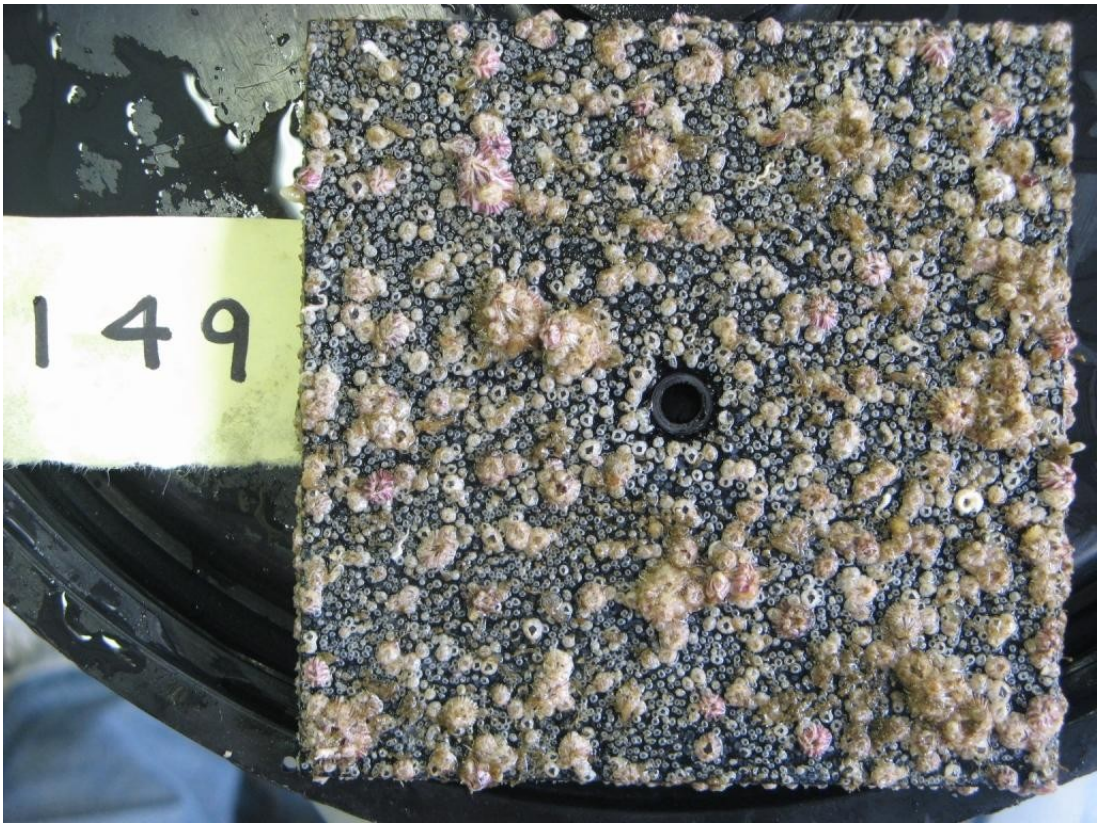


Plate 6. A recruitment plate dominated by barnacles from the Far North Reference Location. The barnacles are predominately *Balanus trigonus* (identified by the irregular rays down the plates of the barnacle and erosions on the operculum plates) with some *Amphibalanus amphitrite* (purple/pink coloured barnacle). These barnacles cover the four size classes recruit (< 0.3 cm), small (< 0.5 cm), medium (< 1 cm) and large (> 1 cm). With a microscope numerous other sessile invertebrates can also be observed e.g. small solitary and colonial ascidians, encrusting bryozoans, polychaete worm tubes, bivalves and amphipod tubes.

Document Status

Rev No.	Author	Reviewer		Approved for Issue	
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2	Emma Johnston				
3					