Report to:

URS Australia

Estuarine Ecological Monitoring
Botany Groundwater Cleanup Project

First Annual Report

FINAL

June 2006

The Ecology Lab Pty Ltd

Marine and Freshwater Studies

Estuarine Ecological Monitoring
Botany Groundwater Cleanup Project

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Report Number – 04/0506 B
Report Status – Final June 19, 2006

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SUMMARY

Orica Australia has begun a long-term program to cleanup contaminated groundwater in the vicinity of their facility at Broadmeadow, near Penrhyn Estuary in northern Botany Bay. Cleanup methodology involves the extraction of groundwater along a series of pumps, and treatment of the extracted groundwater. The extraction of groundwater will lead to an almost complete reduction in the volume of groundwater reaching Penrhyn Estuary and Botany Bay, downgradient of the hydraulic containment line, potentially affecting estuarine and marine habitats and biota. This document reports on the results of the first three surveys undertaken during 2005 and 2006 to monitor potential effects on marine and estuarine habitats and biota, including seagrass beds, mangroves and saltmarsh communities. During this period, the maximum pumping rate achieved was in the order of 2 ML/day, less than the 8 to 10 ML/day predicted in the Groundwater Treatment Plant (GTP) EIS (URS, 2004).

The aim of the monitoring program is to determine whether the extraction of groundwater is impacting on estuarine communities. The components of the monitoring program include:

- Seagrass habitats in Penrhyn Estuary –spatial extent of seagrass beds, density and health of seagrass plants
- Saltmarsh habitats – spatial extent of habitat, species composition (focussed on potential dominance of *Sarcocornia quinqueflora* and health of dominant species
- Mangrove habitats – spatial extent of habitat, focussed on their potential intrusion into seagrass habitats

Three surveys have been completed:

- Survey 1: 19 – 23 July 2005
- Survey 2: 31 October - 3 November 2005
- Survey 3: 31 May – 12 April 2006.

Groundwater extraction began in October 2004 with an extraction rate of between 0.6 and 1.0 ML/day until February 2006. Following commissioning of the Groundwater Treatment Plant, the extraction rate for both Foreshore Road and Southlands reached a maximum of 2.0 ML/day in April 2006. This decreased to approximately 0.8 ML/day in May during maintenance shutdown of the GTP.

Spatial Extent of Estuarine Habitats

The spatial extent of estuarine habitats was determined initially by mapping habitats based on an aerial photograph captured in April 2005. Preliminary mapping was refined during each survey by traversing the habitats on foot and recording boundaries of habitat types using a DGPS unit. For the third survey, mapping was done on an aerial photograph captured on 21 April, 2006, and refined by ground truthing as described above. Mapping was done at the scale of 1:1500.

Seagrass area within Penrhyn Estuary increased nearly threefold was due to the appearance of two new beds of *Zostera* sp. in Survey 2 that were not present in Survey 1 (Figure 2). The larger of these beds appears to have expanded in extent by Survey 3, with the smaller of the two beds having disappeared by Survey 3. In addition, the bed in the southern section of the inner estuary increased in extent from Survey 1 to Survey 3.

A small decrease in the spatial extent of seagrass within mangrove pneumatophore habitat was likely due to natural variations in the size of these beds, and the difficulty in defining their boundaries and therefore measured differences are likely due to variability in the monitoring methodology.

Small changes in saltmarsh cover observed were considered to be within the boundaries of the error of measurements and do not indicate any change in spatial extent of this habitat at Penrhyn Estuary.

Mangrove habitat appears to have increased through time, probably due to the expansion of the seaward edge of the main stand of mangroves in the southeastern section of the estuary. Changes in the seaward boundaries of mangrove stands were also evident in several other locations within the estuary. These changes were consistent with an expansion of mangroves in Penrhyn Estuary in recent times.

Seagrass Habitat

In addition to determining changes in the spatial extent of seagrass beds by mapping from aerial photographs, finer scale changes in the nature of seagrass beds were monitored. Seagrass density, leaf length and width and the number of leaves per shoot were recorded at Penrhyn Estuary and two control locations (South Towra and Quibray Bay) within a 5 x 5 m study area. The majority of seagrass at Penrhyn Estuary was found growing among pneumatophores at the margins of mangrove habitat. Hence, control locations were chosen where *Zostera* was observed in similar habitats. The density of seagrass shoots was counted in five haphazardly placed, 30 x 30 cm quadrats and the number of pneumatophores was also counted and recorded. In addition, measurements of *Zostera* leaf length, width and the number of leaves per shoot within quadrats were recorded. In each of the five quadrats, the length and width of four haphazardly chosen leaves were measured to the nearest 0.5 cm and 1 mm, respectively. A photograph was taken of each quadrat sampled in Penrhyn Estuary to provide a permanent visual record of seagrass.

The density of *Zostera* at Penrhyn Estuary was within the range of densities observed at the controls and increased between surveys. In the second survey the density of *Zostera* within Penrhyn Estuary varied considerably within and between study areas. Leaf width varied little between surveys, while there was no apparent pattern in the variation observed in leaf length and number of leaves per shoot.

Zostera at all locations was short and generally the top of the leaves was brown in colour, while at the base of the shoots all leaves were green in colour.

Overall, changes in seagrass beds monitored indicate an increase in seagrass extent during the monitoring period which varied greatly between surveys.

Saltmarsh Habitat

In addition to determining changes in the spatial extent of saltmarsh habitat by mapping from aerial photographs, finer scale changes in the nature of saltmarsh communities were monitored. Percentage cover, species composition, number of epifaunal invertebrates and condition of saltmarsh were recorded at Penrhyn Estuary and two control locations (Woolooware Bay and Quibray Bay). The condition of saltmarsh plants was categorised using three condition categories outlined below:

1 Good condition – greater than 50 % of the plant fleshy, growing tips

2 Poor condition - less than 50 % of the plant fleshy, growing tips

3 Dead – no growing tips on plant

In each survey the percentage cover, species composition and condition of saltmarsh was recorded along three permanent transects at four sites within Penrhyn Estuary and two sites at each of the controls for a total of 24 transects. Transects began low on the shore (close to the water) and ran perpendicular to the shore to the landward margin of the saltmarsh habitat. Data recorded included percentage cover, species composition, condition of saltmarsh, abundance of epifaunal invertebrates, number of mangrove seedlings and pneumatophores and height of plants.

The dominant species of saltmarsh recorded at all locations were *Sarcocornia quinqueflora, Suaeda australis* and *Sporobolus virginicus. S. quinqueflora* was absent from two of the four transects at Penrhyn Estuary, and overall there were more *S. quinqueflora* plants in control locations than at Penrhyn Estuary, as well as a trend for plants to be taller at control locations.

No significant temporal changes in the height of *Sarcocornia quinqueflora* plants or % cover of dead *S. quinqueflora* plants were detected at the scale of transects, sites or locations at Penrhyn Estuary. Changes in the % cover of plants in poor condition were evident at the scale of sites and locations, and in % cover of plants in good condition at the scale of locations, however these changes were evident only in control locations.

When data were averaged across times, significant variation in the height of *Sarcocornia quinqueflora* plants and % cover of plants in good condition was evident among transects, but only within sites at Penrhyn Estuary. Significant variation in the % cover of plants in dead plants was also evident at the scale of transect, but in this case occurred only at the control locations. There was also significant variation in % cover of plants in poor condition among transects, and this was evident within both Penrhyn Estuary and control locations.

These results indicate no trend of increase or decrease of *Sarcocornia quinqueflora* compared to control locations, nor significant change in the condition of plants.

Conclusion

Monitoring data to date indicate no measurable impact of the extraction of groundwater on the spatial extent or condition of estuarine habitats in Penrhyn Estuary when compared to control locations. Seagrass beds and, to a much lesser extent mangrove habitats, have expanded, the latter continuing an existing trend. Changes attributable to natural variation have been observed in saltmarsh habitats. Continuation of the monitoring program is recommended, with an extension of seagrass sampling at control locations to balance the statistical design caused by the appearance of new seagrass beds in Penrhyn Estuary.

1.0 INTRODUCTION

1.1 Background and Aims

Orica Australia has begun a long-term program to cleanup contaminated groundwater in the vicinity of their facility at Broadmeadow, near Penrhyn Estuary in northern Botany Bay. Cleanup methodology involves the extraction of groundwater along a series of pumps, and treatment of the extracted groundwater. The extraction of groundwater will lead to an almost complete reduction in the volume of groundwater reaching Penrhyn Estuary and Botany Bay, potentially affecting estuarine and marine habitats and biota. This document reports on the results of the first three surveys undertaken during 2005 and 2006 to monitor potential effects on marine and estuarine habitats and biota, including seagrass beds, mangroves and saltmarsh communities.

The overall objective of the monitoring program is to quantify changes in components of the estuarine ecosystem at Penrhyn Estuary (Botany Bay) that may be associated with the withdrawal of contaminated groundwater upgradient of the estuary. The aquatic components assessed in this series of reports include seagrass, saltmarsh and mangrove habitats in Penrhyn Estuary and at control locations:

- Seagrass habitats –spatial extent of seagrass beds, density and health of seagrass plants
- Saltmarsh habitats – spatial extent of habitat, species composition (focussed on potential dominance of *Sarcocornia quinqueflora* and health of dominant species
- Mangrove habitats – spatial extent of habitat, focussed on their potential intrusion into seagrass habitats.

1.2 Existing Information

Groundwater extraction began in October 2004 with an extraction rate of between 0.6 and 1.0 ML/day until February 2006. Following commissioning of the Groundwater Treatment Plant, the extraction rate for both Foreshore Road (adjacent to Penrhyn Estuary) and Southlands reached a maximum of 2.0 ML/day in April 2006. This decreased to approximately 0.8 ML/day in May 2006 during maintenance shutdown of the GTP.

Over the period January - March 2006 the water table in monitoring well MWF15 located adjacent to the dune vegetation, dropped by 0.20 m from an average elevation of 0.40 m AHD in January to 0.20 m AHD in March. However, this elevation varied monthly, in the order of 0.15 m, and daily, in the order of 0.10 m, due to tidal fluctuations. It should also be noted that drought conditions were reported for the period January to March 2006 and in the absence of significant rainfall a drop of 0.20 m in groundwater elevation would be expected.

Prior to the first survey the extent of seagrass, saltmarsh and mangrove habitats in Penrhyn estuary had been mapped by The Ecology Lab (URS 2003). The seagrass bed now present in the southeastern section of the estuary was noted subsequently (URS 2004).

The Ecology Lab (URS 2003) also provided descriptions of community composition of saltmarsh, mangrove and soft sediment benthic habitats.

2.0 STUDY METHODS

2.1 Spatial Extent of Estuarine Habitats

Mapping of estuarine habitats was done using Geographical Information Systems (GIS), aerial imagery, and field validation. This standard method of mapping estuarine habitats allows accurate thematic mapping of coastal terrestrial and shallow sub-tidal habitats (Zharikov *et al.*, 2005).

Digital geo-referenced, ortho-rectified aerial images of the study site were imported into a GIS software package (MapInfo Professional V8). Ecology Lab staff with field experience in the identification and mapping of estuarine habitats interpreted these images and identified areas likely to contain mangrove, seagrass, and saltmarsh habitats. Habitat boundaries were digitized at a scale of 1:1500, with autonode feature enabled (5 pixel tolerance), to create a layer of non-overlapping, mutually exclusive polygons. Each polygon was labelled according to presumed habitat, as either mangrove, seagrass, or saltmarsh. This presumptive map was taken to the study site for field validation. For surveys 1 and 2 preliminary mapping was done from an aerial photograph capture in August, 2005. For Survey 3, preliminary mapping was done from an aerial photograph captured 21 April, 2006.

Field validation of habitats was done using a Differential Global Positioning System (DGPS) These systems are known to be spatially accurate to within ± 2 metres. Habitat boundaries were validated by navigating the boundaries of habitats whilst recording co-ordinates using a hand-held data logger. The species composition of each habitat was recorded during this process by means of visual assessment. In areas where a species boundary was present within habitats, the location of this boundary was also recorded.

Data collected during field validation was overlaid onto the presumptive map and aerial imagery. In areas where the presumed boundary was not accurate, habitat boundaries were altered based on data collected during field validation.

This process was repeated for all surveys. Following mapping, the total area of each habitat contained within the study site was determined using MapInfo. Area of each habitat at each sampling interval was calculated, allowing comparison of changes in habitat distribution and extent through time.

All geographic data in this study is in Geocentric Datum of Australia 1994 (MGA Zone 56).

2.2 Seagrass

In addition to determining changes in the spatial extent of seagrass beds by mapping from aerial photographs, finer scale changes in the nature of seagrass beds were monitored. Seagrass density, leaf length and width and the number of leaves per shoot were recorded at Penrhyn Estuary and two control locations (South Towra and Quibray Bay) within a 5 x 5 m study area. The majority of seagrass at Penrhyn Estuary was found growing among pneumatophores at the margins of mangrove habitat. Hence, control locations were chosen where *Zostera* was observed in similar habitats. The density of seagrass shoots was counted in five haphazardly placed, 30 x 30 cm quadrats and the number of pneumatophores was also counted and recorded (Plate 1). In addition, measurements of *Zostera* leaf length, width and the number of leaves per shoot within quadrats were recorded. In each of the five quadrats, the length and width of four haphazardly chosen leaves were measured to the

nearest 0.5 cm and 1 mm, respectively. A photograph was taken of each quadrat sampled in Penrhyn Estuary to provide a permanent visual record of seagrass.

2.3 Saltmarsh

In addition to determining changes in the spatial extent of saltmarsh habitat, fine scale measurements (percentage cover, species composition, number of epifaunal invertebrates and condition of saltmarsh) were recorded at Penrhyn Estuary and two control locations (Woolooware Bay and Quibray Bay). The condition of saltmarsh plants was categorised using three condition categories outlined below:

1 Good condition – greater than 50 % of the plant fleshy, growing tips (Plates 2 & 4)

2 Poor condition - less than 50 % of the plant fleshy, growing tips (Plates 3 & 5)

3 Dead – no growing tips on plant (Plate 6)

In each survey the percentage cover, species composition and condition of saltmarsh was recorded along three permanent transects at four sites within Penrhyn Estuary and two sites at each of the controls for a total of 24 transects. Transects began low on the shore (close to the water) and ran perpendicular to the shore to the top of the saltmarsh (Plate 7). The exception was at Woolooware Bay where transects stopped after 40 m as the saltmarsh habitat was too extensive to survey (~ 200 m). Four random (1 m^2) quadrats were sampled along each transect (for a total of 96 quadrats in each survey) to record the percentage cover, species composition, condition of saltmarsh, abundance of epifaunal invertebrates, number of mangrove seedlings and pneumatophores and height of plants (Plate 8). Data were entered into an Excel spreadsheet and checked.

Monitoring % cover and condition of plants present in saltmarsh transects allowed testing the hypothesis that the withdrawal of groundwater could result in conditions that would favour the dominance of *Sarcocornia quinqueflora* (The Ecology Lab in URS 2004).

2.4 Mangroves

Detailed recording of floristic composition in mangrove habitats was considered unnecessary because only two species occur in the Sydney area. The focus for the investigation of mangroves was on their aerial extent (Section 2.4 mapping), with the underlying null hypothesis stated as: there is no evidence of incursion of mangroves into seagrass habitats due to changes in groundwater flow. The indicator variable for this hypothesis was the density of mangrove pneumatophores in seagrass/mangrove habitats, recorded using the techniques outlined above in Section 2.2.

2.5 Statistical Methods

2.5.1 Univariate Analyses

ANOVAs were used to examine temporal and spatial variation in height and % cover of *Sarcocornia quinqueflora* plants. Separate analyses were done on plants that were healthy, dead and in poor condition. The factors of interest were:

- Survey (i.e. 1 vs 2 vs 3), which was a fixed and orthogonal factor;
- Location (i.e. Penrhyn vs Woolooware Bay vs Quibray Bay), which was a fixed and orthogonal factor;

- Site (i.e. 1 vs 2) , which was random and nested in Location; and
- Transect (i.e. 1 vs 2 vs 3), which was random and nested in Site and Location.

ANOVAs were done using the computer programme GMAV V.5 and are based on four replicate measures of each indicator per location and site combination. Prior to ANOVA, data were checked for homogeneity of variances using Cochran's C Test and data were transformed if their variances were heterogeneous. If transformation failed to homogenise the variances, the ANOVA was done with the data transform providing the smallest C value, and results interpreted conservatively (i.e. the significance level was reduced from $P < 0.05$ to 0.01 to reduce the likelihood of Type 1 error). Sources of variation that were not significant at $P \geq 0.25$ were pooled according to the *post hoc* pooling procedures in Winer (1971). This was done to strengthen the test of effects of other factors. If the factors examined in ANOVA showed significant variation, Student Newman Keuls (SNK) Tests were used to establish which pairs of surveys, locations or sites differed. Further details of these analytical procedures are available in Underwood (1997).

2.5.2 Multivariate Analyses

Multivariate procedures were used to examine differences in the number of types and relative abundances of organisms in saltmarsh assemblages. First, differences in the types and relative abundance of the taxa in each pair of replicates were estimated by calculating their respective Bray-Curtis dissimilarity coefficients after transforming abundance data to their square root. This transformation downweights the importance of the most abundant groups of organisms and thereby ensures that dissimilarities reflect groups of organisms with large and moderate abundances (Clarke 1993).

Two-way crossed ANOSIM, a non-parametric permutation test which compares the relative number and types of taxa present in the samples from each place or time, was used to examine differences in the structure of saltmarsh assemblages among Locations (averaged across surveys) and Surveys (averaged across Locations). If the results of these analyses were significant, pairwise comparisons were used to determine which particular surveys and/or locations differed. The ANOSIM statistic (*R*-value) provides an indication of the magnitude of differences between comparisons.

Temporal and spatial patterns in the composition of saltmarsh assemblages were also examined by means of non-metric Multi Dimensional Scaling (MDS) (Clarke 1993). MDS provides a graphical representation of assemblages based on their similarity within and among locations or times sampled. In MDS plots, samples which have similar sets of organisms are grouped closer together than ones containing different sets of organisms.

3.0 RESULTS

3.1 Timing of Surveys

Three surveys have been completed:

- Survey 1: 19 – 23 July 2005
- Survey 2: 31 October - 3 November 2005
- Survey 3: 31 May – 13 April 2006

Weather conditions were fine for all surveys, and no events occurred that would affect the quality or continuity of data.

3.2 Spatial Extent of Estuarine Habitats

Table 1: Spatial extent of estuarine habitats in Penrhyn Estuary, Surveys 1, 2 and 3. All units m^2.

Survey **Habitat type**	**Survey 1 –** **August 2005**	**Survey 2 –** **November 2005**	**Survey 3 –** **April 2006**
Seagrass beds	572	1,306	1,492
Seagrass in mangrove pneumatophore habitat	293	263	278
Saltmarsh	6,435	6,558	6,479
Mangrove	7,659	7,951	8,807

The increase in seagrass area within Penrhyn Estuary was due to the appearance of two new beds of *Zostera* sp. in Survey 2 that were not present in Survey 1 (Figures 1 and 2). The larger of these beds located on the northeastern section of the inner estuary expanded in extent by Survey 3, with the smaller of the two beds having disappeared by Survey 3 (Figure 3). The large seagrass bed in the southern section of the inner estuary covered 835 m^2 , was located among mangrove seedlings and pneumatophores and almost doubled in extent from Survey 1 to Survey 3. The net result was a nearly threefold increase in the spatial extent of seagrass in Penrhyn Estuary since August 2005.

The apparent decrease of seagrass within mangrove pneumatophore habitat was very small and likely due to natural variations in the size of these beds, and the difficulty in defining their boundaries. Sources of error in defining the boundaries of seagrass habitat include difficulty in detecting short, sparse, brown-coloured seagrass against the dark mud background. Sources of error in defining the boundaries of mangrove habitat include difficulties in accurately identifying the outermost edge of sparse mangrove pneumatophores.

Changes in saltmarsh cover were within the boundaries of the error of measurements and did not indicate any change in spatial extent of this habitat at Penrhyn Estuary.

Mangrove habitat appears to have increased through time, probably due to the expansion of the seaward edge of the main stand of mangroves in the southeastern section of the estuary. This expansion consisted of a patch of scattered juvenile grey mangroves (*Avicennia marina*).

Changes in the seaward boundaries of mangrove stands were also evident in several other locations within the estuary (Figures 1, 2, and 3).

3.3 Seagrass

3.3.1 Morphology

Zostera at all locations was short and generally the top of the leaves were brown in colour (Plates 9, 10 & 11), while at the base of the shoots all leaves were green in colour.

3.3.2 Seagrass Density

The density of *Zostera* at Penrhyn Estuary was within the range of densities observed at the controls and increased significantly between Survey 1 and Survey 2, indicating seasonal growth of seagrass (Figure 4, Appendix 1). This result was consistent with the finding of expansion in seagrass spatial cover as determined by mapping. In Survey 3 densities decreased in Penrhyn Estuary and at control locations, indicating seasonal variation (Figure 4).

3.3.3 Seagrass Leaf Length and Width

Substantial changes in the length of seagrass leaves through time were evident at Penrhyn Site 1 and Quibray Bay, but not at South Towra (Figure 5). The pattern of change at these two locations was not the same. Between Survey 1 and Survey 2 there was a marked decline in leaf length at Penrhyn, but no change at Quibray Bay. Between the Survey 2 and Survey 3 a substantial increase in leaf length was evident at both locations. The data from Survey 3 indicate marked differences in mean length of leaves among the three Penrhyn Estuary sites. There are insufficient data to comment on trends at the other locations. The change in leaf lengths observed at Penrhyn Site 1 and Quibray Bay were not mirrored by changes in leaf width. At Penrhyn, mean leaf width remained relatively stable throughout the three surveys, whereas at Quibray Bay it doubled between Survey 1 and Survey 2, and showed only a minor change thereafter. Leaf width at South Towra also remained relatively stable. During Survey 2 leaf width was similar at all the Penrhyn Estuary sites, but marked differences in width became apparent during the Survey 3 (Figure 5).

The pattern of change in number of leaves per shoot at Penrhyn Estuary Site 1 was similar to that observed at Quibray Bay. At these locations, the number of leaves per shoot was similar during the first two surveys, but declined between Survey 2 and Survey 3 (Figure 5).

3.4 Saltmarsh

3.4.1 Dominance

The dominant species of saltmarsh recorded at all locations were *Sarcocornia quinqueflora, Suaeda australis* and *Sporobolus virginicus. S. quinqueflora* was absent from two of the four transects at Penrhyn Estuary, and overall there were more *S. quinqueflora* plants in control locations than at Penrhyn Estuary, as well as a trend for plants to be taller at control locations.

3.4.2 Percentage Cover and Plant Height

No significant temporal changes in the height of *S. quinqueflora* plants or % cover of dead *S. quinqueflora* plants were detected at the scale of transects, sites or locations at Penrhyn Estuary (Table 3). Changes in the % cover of plants in poor condition were evident at the scale of sites and locations, and in % cover of plants in good condition at the scale of locations, however these changes were evident only in control locations.

When data were averaged across three surveys, significant variation in the height of *S. quinqueflora* plants and % cover of plants in good condition was evident among transects, but only within sites at Penrhyn Estuary. Significant variation in the % cover of plants in dead plants was also evident at the scale of transect, but in this case occurred only at the control locations. There was also significant variation in % cover of plants in poor condition among transects, and this was evident within both Penrhyn Estuary and control locations.

These results indicate no trend of increase or decrease of *S. quinqueflora* compared to control locations, nor significant change in the condition of plants.

3.4.3 Assemblages

The saltmarsh assemblages differed significantly among both locations and times. There were also significant differences in assemblages between each pair of locations and between two of the three pairs of surveys (Table 2). Assemblages averaged across locations, however, did not differ between surveys 2 and 3. The ANOSIM statistic indicated that differences in assemblages between locations (R = 0.366) were greater than those between times (R = 0.190). Differences in assemblages were greater between surveys 1 and 3 (R = 0.281*)* than between surveys 1 and 2 (R = 0.183). The assemblages at the control locations were more dissimilar to each other (R = 0.619) than the assemblages at Penrhyn Estuary were to Woolooware Bay (R = 0.388) and Quibray (R= 0.343).

The symbols representing the saltmarsh assemblages at Penrhyn are divided into two distinct groups: a tight cluster on the bottom left-hand side and a more diffuse group stretching across the upper section of the ordination (Figure 6a). The symbols representing Woolooware Bay form a tight cluster in the lower centre whereas those representing the assemblages at Quibray Bay are interspersed on either side of this group. The lack of overlap and degree of separation in the symbols representing the different sites at Penrhyn Estuary during each individual survey indicates that the assemblages at this location differ markedly across sites (Figure 6b). The tight clustering of the symbols representing Sites 3 and 4 relative to the symbols representing Sites 1 and 2 indicates that the former assemblages are less temporally variable than the latter. The symbols representing the assemblages at the sites in Woolooware Bay were more tightly clustered during the first and second surveys than in the third survey, thus suggesting that there has been an increase in the variability of these assemblages. The opposite trend was evident at Quibray Bay.

These patterns in time and space suggest that there were differences between saltmarsh assemblages at the three locations, and that these differences changed through time, but changes at Penrhyn Estuary were within the range of changes observed at control locations.

3.5 Mangrove Pneumatophores in Seagrass Habitats

The mangroves at Penrhyn Estuary were composed of predominantly the grey mangrove (*Avicennia marina)* with a few river mangroves (*Aegiceras corniculatum)* present. In Survey 2

several recently dead mangroves (i.e. leaves were still attached but dead) were recorded (Plates 12, 13 & 14).

The density of mangrove pneumatophores in the main seagrass bed in Penrhyn Estuary was greater during Survey 1 than at control locations. Density decreased during Survey 2 and was greater than densities recorded at South Towra and Quibray Bay during Survey 3 (Figure 7, Penrhyn Estuary Site 1). There were no pneumatophores in the two seagrass beds recorded during Survey 2, and none recorded in northwestern seagrass bed during Survey 3 (Figure 7). More monitoring events are required before an overall trend, if any, can be identified.

4.0 CONCLUSIONS

The timeframe covered in this report represents the early stages of the groundwater cleanup project. The maximum pumping rates for the GTP operation were not achieved within the timeframe of this report, and the small drop in groundwater levels recorded to date may be attributable to background drought conditions. Hence, this report covers a period in which the full impact of groundwater removal is not expected to have occurred. It also represents a point in time wherein responses of biological habitats and biota could be considered to be in their earliest stages. The data collected during this period are useful, however, because they provide an indication of natural levels of variation in the estuarine ecosystems and their components.

4.1 Spatial Extent of Estuarine Habitats

The greatest change in the spatial extent of seagrass habitats was due to the appearance of two new seagrass beds observed during monitoring in November 2005. The larger of these beds in the northwestern section of Penrhyn Estuary persisted and enlarged, while the smaller had disappeared by the April 2006 survey. These changes are a demonstration of the dynamic nature of seagrass habitats which is likely to be driven by a combination of factors including seasonality, seasonally related physico-chemical changes in seawater, and small scale local variations unique to Penrhyn Estuary. While increases in the extent of seagrass bed above background levels of variation would provide evidence to falsify the prediction that removal of groundwater could result in the reduction of seagrass beds in the estuary, full groundwater removal was not accomplished during the timeframe of this report, and it is likely to be too early to detect changes attributable to removal of groundwater.

There was no evidence of change in spatial extent of saltmarsh habitat. There was some evidence of expansion of mangroves into saltmarsh habitat in the eastern section of the study area, a finding consistent with previously observed trends (Figure 2.11 in URS 2003).

The small increase in the spatial extent of mangroves is likely due to changes in the seaward boundaries of these habitats and is confounded by the difficulty in defining the edge of the habitat. This difficulty arises because pneumatophores that mark the seaward boundaries in some locations become very gradually less dense, making the boundary difficult to define.

4.2 Seagrass Condition

Seagrass leaf length and number of leaves per shoot showed variability through time, but no pattern consistent with the hypothesis of declining seagrass health in Penrhyn Estuary compared to control locations. Leaf width varied little during the three surveys.

4.3 Saltmarsh Condition and Assemblages

Saltmarsh assemblages varied between locations and through time. No significant changes in condition of plants were detected during the three surveys. Hence, there is no evidence to date that the removal of groundwater could result in the reduction of saltmarsh plant condition, or significantly favour the dominance of the saltmarsh plant *Sarcocornia quinqueflora*.

4.4 Mangroves Pneumatophores in Seagrass Habitats

The density of pneumatophores in seagrass habitats can be compared only within the mangrove/seagrass habitat in the southeastern section of Penrhyn Estuary. Density varied greatly at the scale of 900 cm^2 and showed no clear pattern. These results provide no evidence to date that the removal of groundwater could result in the encroachment of mangroves into seagrass habitats. More monitoring events are required before an overall trend, if any, can be identified.

5.0 RECOMMENDATIONS

At the end of three monitoring events, no overall evidence of changes in estuarine habitats and biota in Penrhyn Estuary have been observed that can be attributabed to the removal of groundwater. The ability to detect changes will increase with the greater number of monitoring events. Hence the current monitoring program is recommended to continue, with minor modifications. The appearance of two new seagrass beds in Penrhyn Estuary has caused the sampling design examining changes in seagrass density and morphology to be unbalanced. That is, there is a lower level of sampling effort at control locations due to the increase in beds in Penrhyn Estuary, making a robust comparison to control seagrass beds impossible. This situation can be simply rectified by increasing the level of replication at the two control locations to match that in Penrhyn Estuary. This would require one additional day of field work to collect appropriate data. The increase in sampling effort would also allow more robust comparison of changes in the density of pneumatophores in seagrass habitats than can be achieved with the current design.

6.0 ACKNOWLEDGEMENTS

This report was written by Dr Peggy O'Donnell. Dr Theresa Dye completed statistical analyses and related figures. Joseph Neilson mapped data for Survey 3 and produced Figures 1, 2 and 3. Brendan Alderson, Belinda Parkes, Rick Johnson, Joanna Browne, Deirdre Foley, Craig Blount, Peggy O'Donnell and Kade Mills completed the field work.

7.0 REFERENCES

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18:** 117-143.

Underwood, A. J. (1997). *Experiments in Ecology, Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge University Press, UK, pp. 504.

URS Australia Pty Ltd (2004). *Botany Groundwater Cleanup Project - Environmental Impact Statement - Volume 3 - Appendices H-M.* Prepared for: Orica Australia Pty Ltd. URS Australia Pty Ltd, North Sydney NSW.

URS Australia Pty Ltd (2003). *Port Botany Expansion - Environmental Impact Statement - Volume 6 - Aquatic Ecology.* Prepared for: Sydney Ports Corporation. URS Australia Pty Ltd, North Sydney NSW.

Zharikov, Y., Skilleter, G.A., Loneragan, N.R., Taranto, T. and Cameron, B.E (2005). Mapping and characterising subtropical estuarine landscapes using aerial photography and GIS for potential application in wildlife conservation and management. *Biological Conservation* **125***:* 87-100.

TABLES

FIGURES

PLATES

APPENDICES

Appendix 1: Density of *Zostera* and pneumatophores in each of the 30 x 30 cm quadrats assessed per survey at each location.

Appendix 2: *Zostera* leaf length, width and number of leaves per shoot.

Appendix 3: Percentage cover of vegetation along saltmarsh transects.

Appendix 4: Percentage cover and abundances of organisms in saltmarsh quadrats.

Appendix 5: Heights (cm) of saltmarsh and mangrove plants in saltmarsh quadrats (1 x 1 m).