MEASURING SUCCESS OF ACTIVE SALTMARSH RESTORATION IN TUGGERAH LAKES

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Abstract

As part of the Tuggerah Lakes Estuary Management Plan, Wyong Council identified specific areas for re-establishment of saltmarsh to the shores of the Tuggerah Lakes Estuary. These locations were highly modified and elevated above the water level of the lake. In Tuggerah Lakes the minimal tidal exchange combined with other impacts such as mowing and trampling inhibit the expansion any saltmarsh present. Restoration activities at these sites consisted of excavation to re-grade the foreshore area to reclaim natural hydrological processes suitable for saltmarsh establishment. This was followed by a replanting program using tube-stock and transplantation of salvaged saltmarsh species. It was considered important to establish the success of the restoration activities through a scientifically rigorous monitoring program and an adaptive management approach to the staggered restoration timeframe. It was initially predicted that, with regular watering of newly established saltmarsh with saline/brackish water, recovery could be achieved within 12 to 24 months of planting. Monitoring results showed this was not achieved due to low survivorship of tubestock in the low shore and slow expansion of saltmarsh in the upper shore. This has been linked to lack of regular tidal influence and fluctuating lake levels limiting the rapid expansion of the newly established saltmarsh in the Tuggerah Lakes estuary. It is now evident that rehabilitation to a level of reference sites has been achieved in sites that have had three and a half years of recovery time. Monitoring data from sites rehabilitated first was used to tailor works at subsequent sites in order to establish the best methods for a non-tidal system. The rehabilitation sites completed last have shown greater capacity to recover given the combination of retaining functional elements of the environment, such as saltmarsh in the low zone, with construction works. These sites developed more rapidly to levels consistent with nearby natural saltmarsh areas.

Introduction

Saltmarsh is an important component of coastal estuaries in Australia and occurs along the extent of the coastline of NSW, although it is generally limited to small patches that have been highly modified (Laegdsgaard 2006). Saltmarshes occur in the near-shore between the high tide mark and the sub littoral zone. This unique position allows them to function in several ways, such as flood and erosion control, buffering of storm

surges, and improvement of water quality by filtering pollutants and excess nutrients (Burchmore 1991; Morrisey 1995). Despite their recognised value, the loss and degradation of saltmarsh habitats in some areas has been severe. NSW in particular has suffered a distinct decline in the abundance and distribution of saltmarsh habitat and it has therefore been afforded protection as an Endangered Ecological Community (EEC) under the NSW *Threatened Species Conservation Act 1995* (TSC Act). A significant consequence of this listing is the increase in the need to understand these ecosystems and manage them for recovery and expansion.

The need to rehabilitate wetland/saltmarsh habitat within the Tuggerah Lakes estuary was highlighted in the Tuggerah Lakes Estuary Process Study (Roberts 2001) as an important and high priority management issue. As part of the Tuggerah Lakes Estuary Management Plan implementation, Wyong Shire Council has identified specific areas for rehabilitation to re-establish saltmarsh to the shores of the Tuggerah Lakes estuary (Dickinson *et al.* 2006). Sites were located on the foreshores of Lake Munmorah and Tuggerah Lake (**Figure 1**).

The dominant shoreline vegetation of the Tuggerah Lakes estuary has traditionally been saltmarsh because there are few mangroves within this estuary. Some areas of good quality saltmarsh persist and a total of 30 native saltmarsh species have been recorded during surveys conducted for a Passive Saltmarsh Rehabilitation Plan (AECOM 2009). Wyong Shire Council's rehabilitation initiatives hope to expand the occurrence and distribution of these species.

The main impediment to saltmarsh expansion at sites chosen for rehabilitation was elevation. The shorelines of these locations were elevated above the water level of the lake and therefore lacked adequate saltwater inundation for the establishment of saltmarsh beyond a very narrow band on the foreshore. In Tuggerah Lakes there is minimal tidal exchange with gravitational and wind circulation being the dominant drivers of shoreline inundation. Other impacts such as mowing and trampling also inhibit the expansion of the saltmarsh. Broadly, the key actions undertaken at the active saltmarsh rehabilitation sites were the excavation and re-grading of the foreshore area to reclaim natural hydrological processes suitable for saltmarsh establishment. Following this a replanting program was initiated using tube-stock grown from cuttings and seed collected from local saltmarsh plants within the Tuggerah Lakes estuary to maintain provenance. Transplantation of the existing saltmarsh species (found on-site previous to the rehabilitation) was also undertaken to re-establish saltmarsh species. Additionally, hard infrastructure such as fencing and information signage were installed to alert the public to the works undertaken and to ensure no trampling of tube-stock.

Often many rehabilitation efforts go unmonitored and so their success cannot be gauged and results cannot be used to improve rehabilitation methods. For this program, however, a staged approach was applied to the rehabilitation of sites around Tuggerah lakes and the success of each new site was documented by a scientifically rigorous monitoring program (Umwelt 2011, 2013) to detect significant changes at the rehabilitated sites that could guide subsequent rehabilitation efforts.

Figure 1. Location of rehabilitation (Long Jetty (LJ), Berkeley Vale (BV), Tuggerah Lake (TL5, 7, 8, 19, 20), Lake Munmorah (LM 7, 8), reference (RE1, RE2, RW1, RW2, LMR2) and control sites (CE1, CE2, CW1, CW2, LMC1, LMC2) in Tuggerah Lake and Lake Munmorah NSW.

Methodology

Monitoring followed the 'Beyond BACI' (Before, After, Control, Impact) approach as modified by Underwood (1991, 1992). This incorporates samples taken before the rehabilitation is commenced (baseline) as well as in other areas that are considered controls and references. Control sites are chosen to represent the 'before' condition of the potential restoration site in order to track the changes occurring at the restoration site with some degree of confidence. The reference site should be chosen to approximate the condition that will be reached by the restoration site once fully restored.

At each rehabilitation, control and reference site the survey area was divided into four sites (10 metres apart and approximately 15 metres wide) and two zones (upper and

lower) for floristic assessments. The upper zone comprised the high marsh zone merging into terrestrial vegetation while the low zone comprised the area immediately adjacent to the average lake inundation area.

In each zone at each site a total of five 1 x 1 metre quadrats were placed haphazardly to measure the percentage cover of groundcover (including plant species, bare ground, seagrass wrack and algae). Therefore, a total of 10 quadrats were sampled at each site (5 upper and 5 lower) giving a total of 40 quadrats at each location (4 sites per location).

Quadrats were divided with string into 100 squares and the groundcover beneath each intersection was counted and recorded as a measure of percentage cover. Only intersections on two outer edges of the quadrats were counted to ensure only 100 intersections were included in final estimates.

Saltmarsh cover was analysed at each site with a combination of graphical interpretation and univariate Analysis of Variance (ANOVA). To simplify the interpretation of the results it was considered appropriate to only analyse the final set of data collected for a difference among the locations sampled. This would give a measure of the significance of the differences among rehabilitation, control and reference sites and a reliable indication on the success of rehabilitation to date. Interpretation of the graph allows for discussion of site development over time.

Therefore, the analysis used was a three-factor mixed model ANOVA to compare the saltmarsh cover across all locations, sites and zones. The first factor in this ANOVA was location (orthogonal and fixed factor); the second factor was site (nested within location and random); the third factor was zone (orthogonal and fixed).

Results

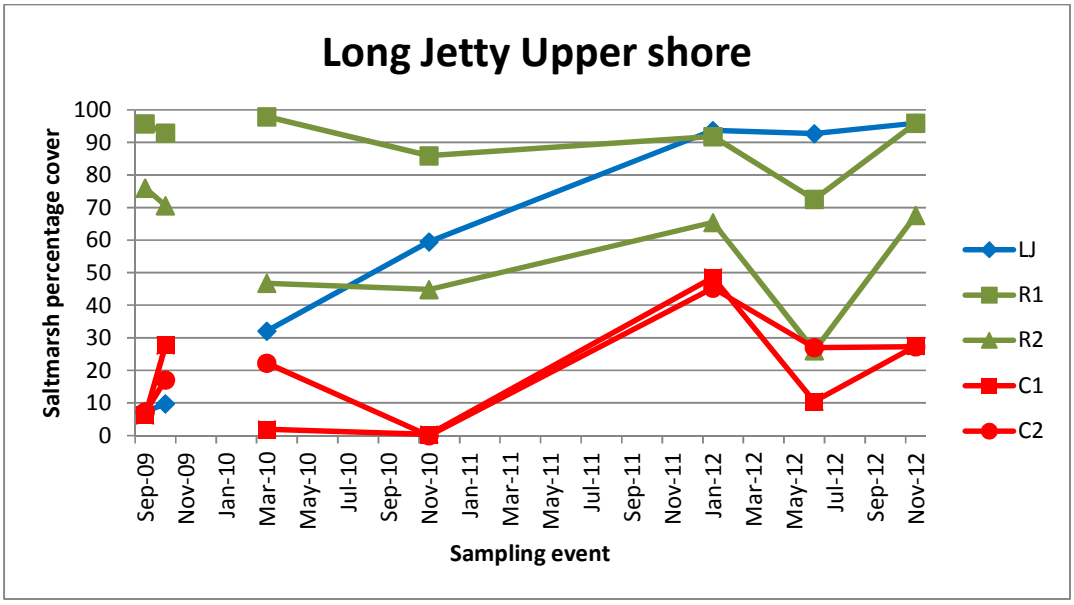
Long Jetty

Four species dominated the low shore of the Long Jetty rehabilitation site (*Paspalum vaginatum*, *Sarcocornia quinqueflora*, *Sesuvium portulacastrum*, *Sporobolus virginicus*) with an extra two species (*Apium prostratum*, *Atriplex* spp.) being recorded during the last sampling event. In comparison a total of ten saltmarsh species make up the community in the high zone (*Paspalum vaginatum*, *Sarcocornia quinqueflora*, *Sesuvium portulacastrum*, *Sporobolus virginicus, Apium prostratum*, *Atriplex* spp., *Juncus krausii, Selliera radicans, Triglochin striata, Lobelia anceps*).

The saltmarsh cover at the Long Jetty rehabilitation site showed a different pattern in the high shore compared to the low shore (**Figures 2** and **3**). The ANOVA results show a significant interaction among locations within sites and zones ($F=3.04$; $P=0.0002$) which highlights the differences particularly within zone (high and low). On the low shore saltmarsh cover at the rehabilitation site has not progressed and remains patchy and bare. SNK tests to assess the nature of significances within the ANOVA reveal that the density of saltmarsh is significantly below that of reference sites and even the controls (**Figure 3**).

The upper shore showed successful growth of the tube-stock species such as *Sesuvium portulacastrum, Sporobolus virginicus* and *Paspalum vaginatum* and had a similar cover of saltmarsh to reference locations (**Figure 2**). Saltmarsh cover showed a steady increase in the upper shore over the initial recovery period after rehabilitation to a level >90 per cent and has retained this level of cover (**Figure 2**).

The lower shore of the Long Jetty rehabilitation site is supporting clumps of *Sarcocornia quinqueflora* that are in poor condition and not spreading. A slight increase in cover was recorded in March 2013 (A5) which may signify the start of an incline and the appearance of some additional species (**Figure 3**).



Note: Standard Error bars are not shown on any Saltmarsh Cover graphs to allow for easier reading of the data.

Figure 2. The average cover of saltmarsh species in the upper shore at Long Jetty rehabilitation (LJ), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 09) and after (Mar 10 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

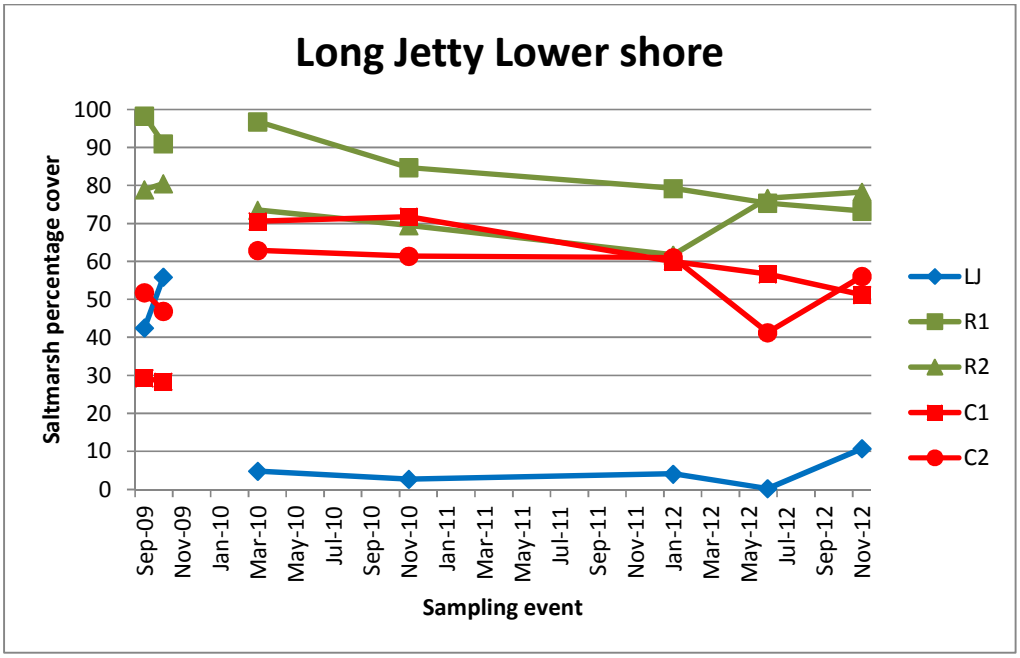


Figure 3. The average cover of saltmarsh species in the lower shore at Long Jetty rehabilitation (LJ), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 09) and after (Mar 10 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

Berkeley Vale

A total of 11 species make up the community of saltmarsh at Berkeley Vale (*Paspalum vaginatum*, *Sarcocornia quinqueflora, Sesuvium portulacastrum, Sporobolus virginicus, Apium prostratum, Atriplex* spp*., Juncus krausii, Selliera radicans, Triglochin striata, Lobelia anceps, Cotula coronipifolia*) for the low and the high shore. Some species (*Triglochin striata* and *Lobelia anceps*) have only been present in the later sampling times giving an indication of site maturity and increasing species diversity.

Saltmarsh cover at Berkeley Vale is showing some variation over time (**Figures 4** and **5**) which is particularly evident within the lower shore. ANOVA results highlight a significant interaction between location and zone ($F=27.70$; $P<0.0001$) meaning that saltmarsh cover is not following the same pattern within the upper and lower shores. It is clear from the graphs that saltmarsh cover on the upper shore has steadily increased over time to resemble the reference locations (**Figure 4**).

The differences on the lower shore are more complex and likely to be more greatly driven by fluctuating lake levels during the monitoring period. There was not a lot of distinction among the reference, control and rehabilitation sites from time A3 onwards (**Figure 5**). Saltmarsh cover at Berkeley Vale increased rapidly on-site after the A2 sampling time (90 to 100 per cent cover) then showed a slight decrease which was also reflected at the reference sites.

It is clear that saltmarsh has developed across the whole site at Berkeley Vale over time. The lower shore has advanced from a level of approximately 40 per cent cover

before rehabilitation to a cover of 70 to 80 per cent cover after 2.5 years while the upper shore has increased from <10 per cent cover to 80 to 90 per cent cover .

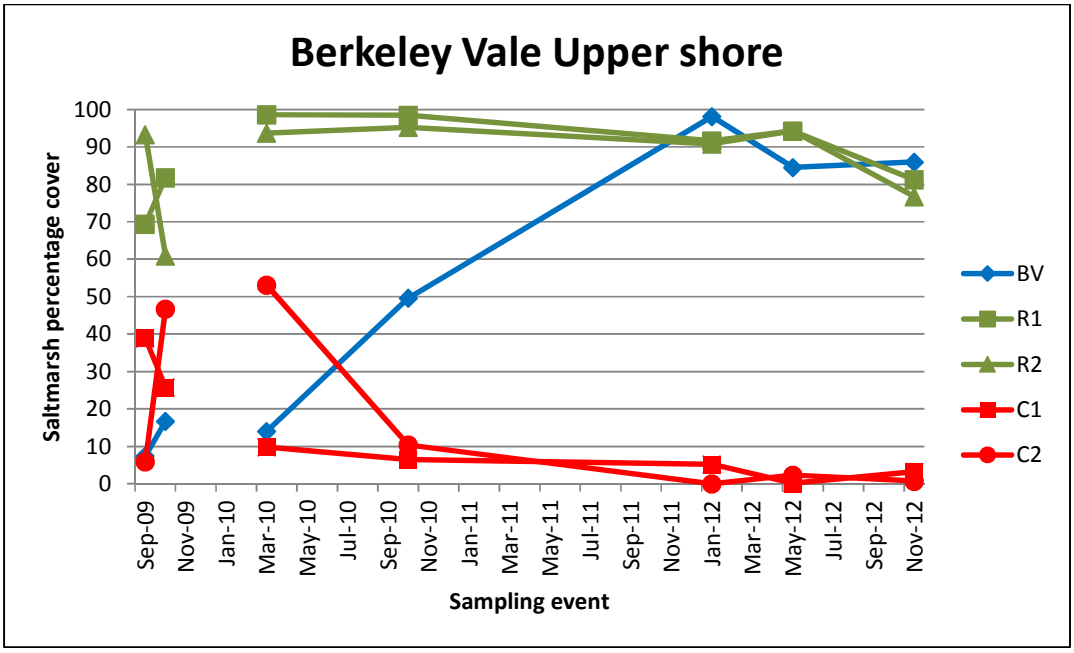


Figure 4. The average cover of saltmarsh species in the upper shore at Berkeley Vale rehabilitation (BV), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 09) and after (Mar 10 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

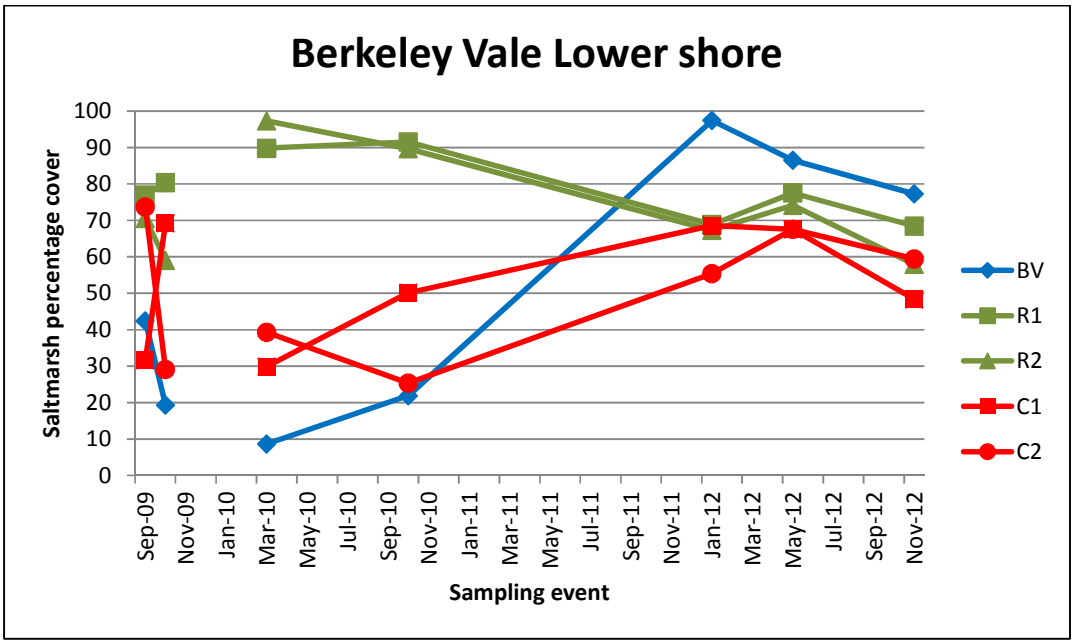


Figure 5. The average cover of saltmarsh species in the lower shore at Berkeley Vale rehabilitation (BV), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 09) and after (Mar 10 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

Lake Munmorah

A total of 12 saltmarsh plant species occurred at the two adjacent rehabilitation sites (LM7 and LM8) at Lake Munmorah (*Paspalum vaginatum*, *Sarcocornia quinqueflora, Sesuvium portulacastrum, Sporobolus virginicus, Apium prostratum, Atriplex* spp*., Juncus krausii, Selliera radicans, Triglochin striata, Cotula coronipifolia, Chenopodium glauca, Bacopa moniera)*. Species composition is similar at the two sites with only an additional two species being recorded in the high zone of LM8 (*Chenopodium glauca and Bacopa moniera*). Several species were only recorded in the later stages of the monitoring process when the sites were more mature (*Triglochin striata* and *Cotula corononipifolia*).

The saltmarsh cover at the Lake Munmorah rehabilitation sites is showing a different pattern in the high shore compared to the low shore (**Figure 6** and **7**). The ANOVA results show a significant interaction among locations within sites and zones ($F=6.04$; $P<0.0001$) which highlights that the differences within zone (high and low) are not consistent among the locations (rehabilitation, reference and control).

After rehabilitation where all the saltmarsh was removed from the site there was slow growth, for several months, of the tube stock planted at both sites (**Figure 6** and **7**). Once tube stock had established there was a rapid increase in the cover of saltmarsh at both sites in the upper and lower shores to levels within the reference range. On the low shore there has been a corresponding increase in saltmarsh at the control sites so that at time A5 there is no significant difference in the cover of saltmarsh plants at reference, controls or rehabilitation sites. All sites and locations exhibit a slight decrease in saltmarsh cover within the last monitoring occasion (**Figure 6** and **7**).

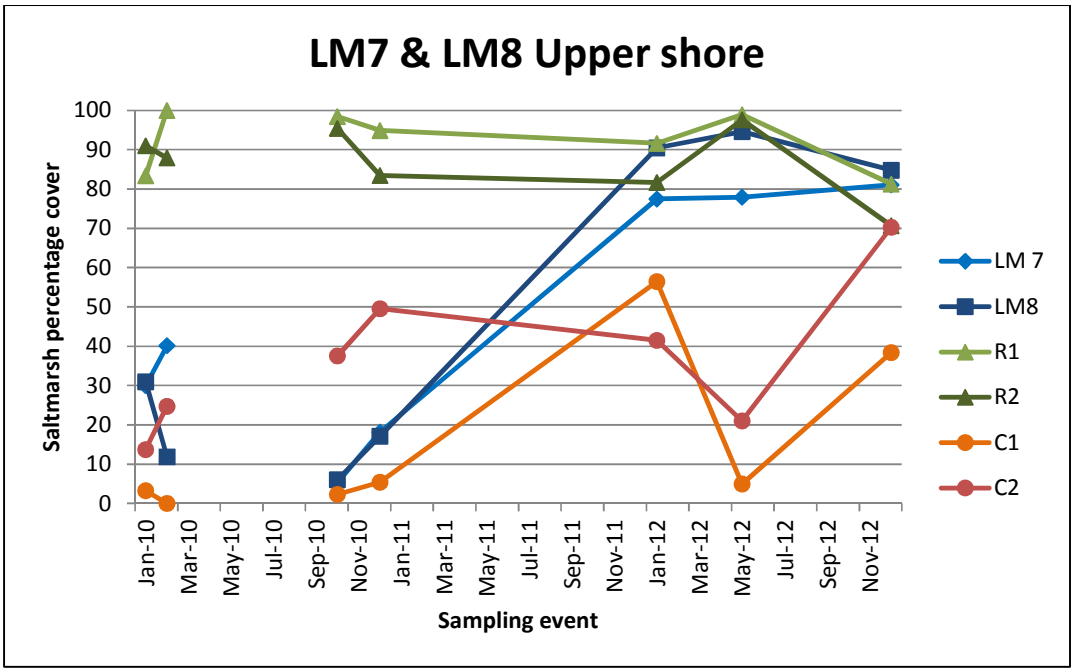


Figure 6.The average cover of saltmarsh species in the upper shore at Lake Munmorah rehabilitation (LM7 & LM8), control (C1 & C2) and reference (R1 & R2) locations before (Jan/Feb 10) and after (Oct 10 to Dec 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

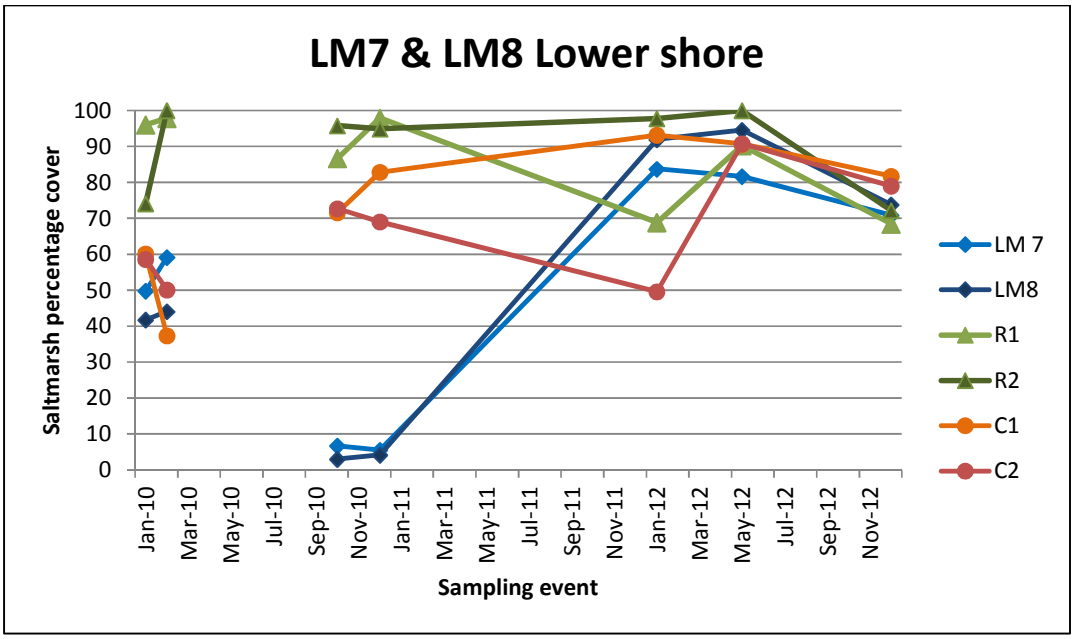


Figure 7. The average cover of saltmarsh species in the lower shore at Lake Munmorah rehabilitation (LM7 & LM8), control (C1 & C2) and reference (R1 & R2) locations before (Jan/Feb 10) and after (Oct 10 to Dec 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

Tuggerah Lake (West)

The low shore at both sites is dominated by very few species (TL19 (*Paspalum vaginatum*, *Sarcocornia quinqueflora*, *Juncus krausii;* TL20 *Paspalum vaginatum*, *Sarcocornia quinqueflora*, *Sesuvium portulacastrum, Juncus krausii, Selliera radicans*). The upper shore contains a mosaic of up to ten species dominated by species more tolerant of drier conditions. A number of species were only recorded during the last monitoring event (*Cotula coronipifolia, Samolus repens, Spergularia marina, Leptinella longipes*) in the upper shore which would have contributed to the increased cover values shown in **Figure 8** for the upper shore.

The saltmarsh cover at the Tuggerah Lake (west) rehabilitation sites (TL19 and TL20) are showing different patterns in the high shore compared to the low shore (**Figures 8** and **9)** that are not consistent among the locations (rehabilitation, reference and control)(ANOVA (F= 3.07; P=0.0002) .

On the upper shore there is a significant increase in saltmarsh cover in the last monitoring event (A3) compared to previous events (**Figure 8**). In addition there is a significant departure of the cover of saltmarsh at the rehabilitation sites (40 to 60 per cent cover) compared to the control sites (<5 per cent cover) at A3 which was not evident in previous monitoring events (**Figure 8**). The rehabilitation sites have significantly less saltmarsh (40 to 60 per cent) than the reference sites (around 80 per cent).

The lower shore of the rehabilitation sites was dominated by a band of *Paspalum vaginatum* with small amounts of *Chenopodium glauca* prior to rehabilitation which

accounts for similarities between rehabilitation sites and reference sites in the low zone before works commenced (**Figure 9**). This saltmarsh band was removed as part of rehabilitation works whereby saltmarsh cover dropped in the low zone to levels below that of reference sites and controls (**Figure 9**). The low zone saltmarsh cover has not increased and remains significantly lower (<5 per cent cover) than controls (50 to 60 per cent cover) or reference sites (60 to 70 per cent cover).

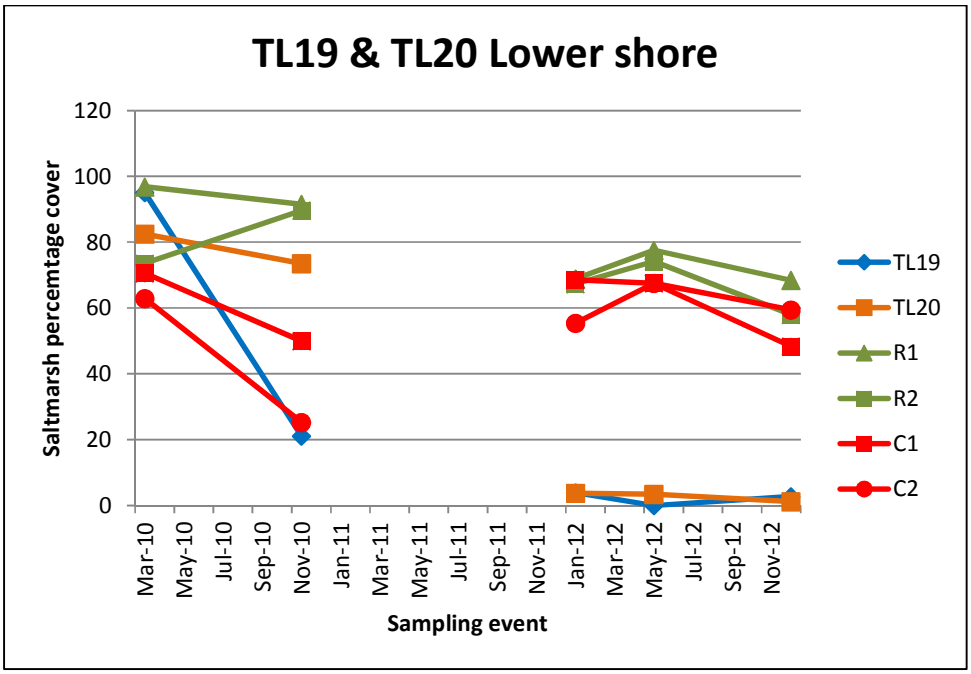


Figure 8. The average cover of saltmarsh species in the upper shore at Tuggerah rehabilitation sites (TL19 & TL20), control (C1 & C2) and reference (R1 & R2) locations before (Mar/Nov 10) and after (Jan 12 to Dec 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

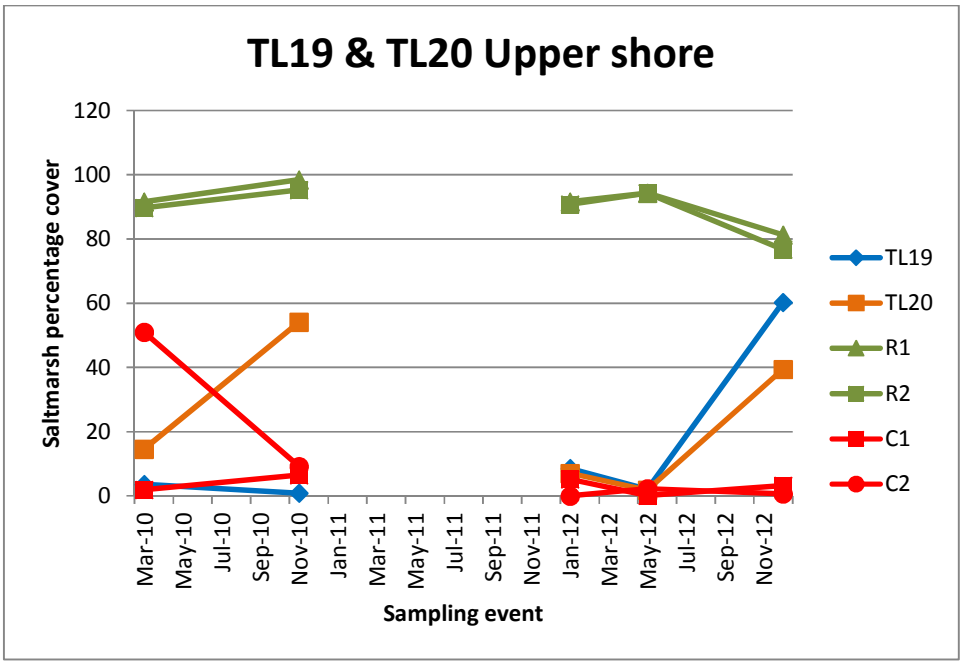


Figure 9. The average cover of saltmarsh species in the lower shore at Tuggerah rehabilitation sites (TL19 & TL20), control (C1 & C2) and reference (R1 & R2) locations before (Mar/Nov 10) and after (Jan 12 to Dec 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

Tuggerah Lake (East)

The three sites located in Tuggerah Lake East (TL5,7 and 8) only had a brief period of recovery post rehabilitation (approximately 6 months) at the time of survey but the sites contained a relatively good level of saltmarsh prior to rehabilitation that was retained as part of the rehabilitation process.

The species diversity is greater in the upper shore (12 species; *Paspalum vaginatum* , *Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Apium prostratum, Atriplex* spp*., Juncus krausii, Selliera radicans, Lobelia anceps, Cotula coronipifolia, Bacopa moniera, Spergularia marina, Leptinella longipes)* compared to the low shore (8 species; *Paspalum vaginatum* , *Sarcocornia quinqueflora*, *Sesuvium portulacastrum*, *Sporobolus virginicus* , *Apium prostratum, Atriplex* spp*., Juncus krausii, Selliera radicans*) at all sites which reflects the planting regime. The low zone is dominated by species that were left intact during the rehabilitation process while the upper zone has a mixture of species that were planted to increase biodiversity and presently these seem to be surviving and persisting in the environment.

The ANOVA results show a significant interaction among locations within sites and zones (TL5 F=3.11; P=0.0002; TL7 F=3.25; P=0.0001; TL8 F=4.86; P<0.0001) which highlights that the differences within zone (high and low) are not consistent among the locations (rehabilitation, reference and control).

On the upper shore all the rehabilitation sites (TL5, 7 and 8) there is no difference between rehabilitation sites and the control sites in terms of saltmarsh cover and they

have significantly less saltmarsh than the reference sites (**Figure 10**). The cover of saltmarsh plants at the rehabilitation sites has shown only a slight increase in cover over time since rehabilitation works were undertaken.

On the low shore all the locations are statistically similar in saltmarsh cover which has not increased since rehabilitation (**Figure 11**) reflecting rehabilitation method of retaining the narrow strip of saltmarsh on the lower shore.

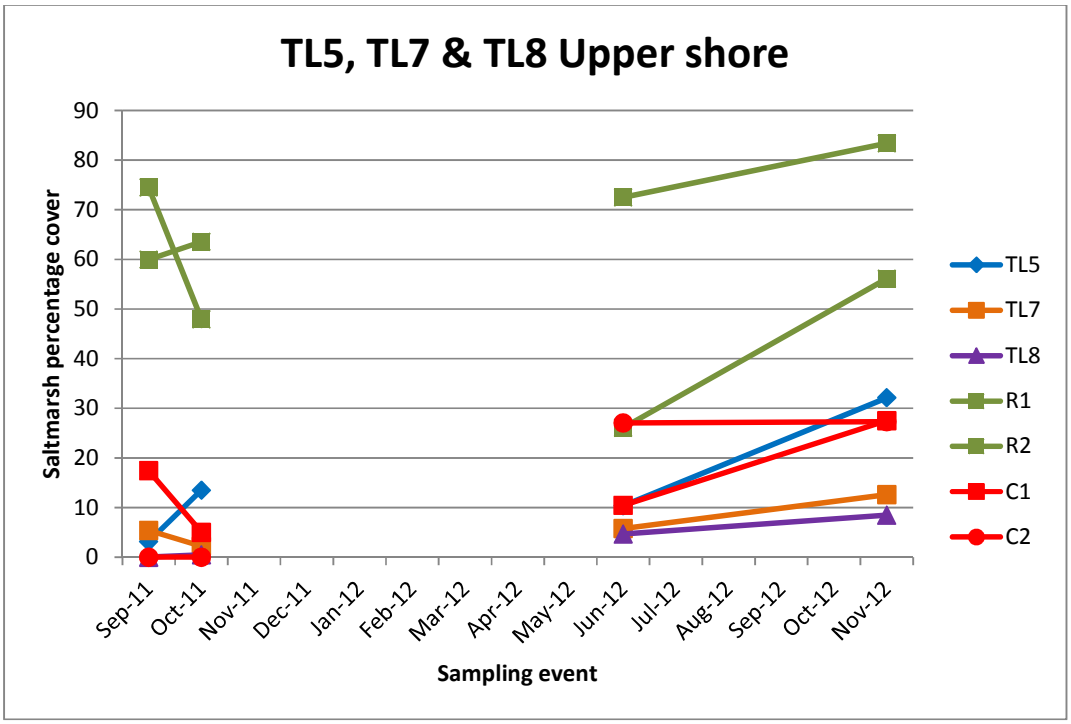


Figure 10. The average cover of saltmarsh species in the upper shore at Tuggerah rehabilitation sites (TL5, TL7 & TL8), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 11) and after (Jun 12 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

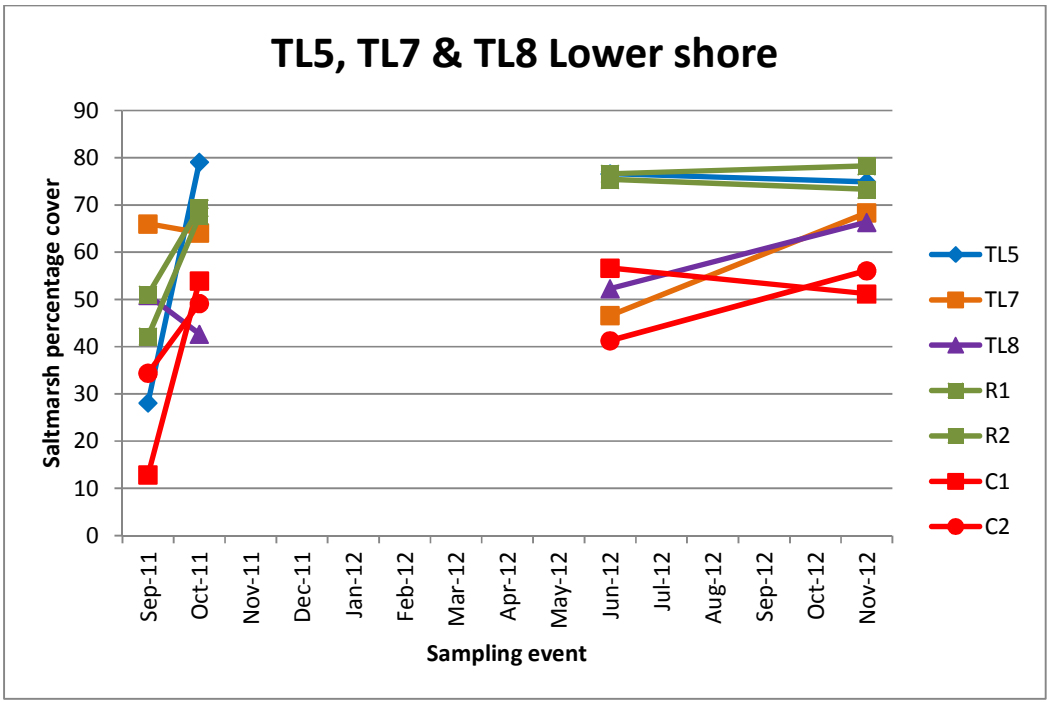


Figure 11. The average cover of saltmarsh species in the lower shore at Tuggerah rehabilitation sites (TL5, TL7 & TL8), control (C1 & C2) and reference (R1 & R2) locations before (Sep/Oct 11) and after (Jun 12 to Nov 12) the rehabilitation. The gap indicates time when rehabilitation works were conducted.

Discussion

Wyong Shire Council has undertaken active rehabilitation works at nine sites around the Tuggerah Lakes estuary (seven in Tuggerah Lake and two in Lake Munmorah) to allow periodic inundation with lake water and restore saltmarsh communities. The aim of the rehabilitation works was to establish or improve saltmarsh communities around the lake edge where saltmarshes have been lost through historical changes to the lakes foreshores. Tuggerah Lakes are essentially non-tidal and establishing saltmarsh in these environments had not been tested previously. As a result, methods have been refined and altered using an adaptive management approach to achieve the best results in terms of rehabilitating saltmarsh on the shores of Tuggerah Lakes. A detailed monitoring program was designed to assess the progress of rehabilitation along with its success when compared to appropriate reference and control sites. Over the time span of the project, a number of sites have been progressively rehabilitated and monitored (Umwelt 2011, 2013).

The Long Jetty site was the first to be rehabilitated and has had over three years for planted saltmarsh to establish and grow. Given this was the initial test site for rehabilitation of saltmarsh in a non-tidal lake environment it is not surprising that success was not immediate and changes to designs and approaches were necessary. At Long Jetty, saltmarsh grew more successfully in the upper zone than the lower zone and in the first 12 months the lower shore only achieved an average of 2.7 per cent cover compared to 60 per cent in the upper zone. The random planting regime used at

this site and the fact that the lower shore was constantly inundated probably contributed to the low survivorship within this zone.

In addition, tube-stock utilised at these sites was initially not adequately hardened to saltwater before being planted into the environment. Placing plants that are used to only freshwater within a saline environment reduces their capacity to thrive.

During late 2012 the lake went through a period of very low water levels that completely drained water from the low zone at Long Jetty. This period of dryness may have aided the saltmarsh persisting in this zone and contributed to the slight increase in cover that was recorded in March 2013 from lows of around two per cent cover to over ten per cent. This may signify the start of an incline and a build-up of resistance of the saltmarsh to periodic long submersion times. Older mature plants can tolerate prolonged submergence as long as stems of the plant remain alive to regenerate once water levels drop (Adams & Bate 1994).

In contrast to the lower shore, the upper zone of the site has shown a steady increase in cover of saltmarsh over time. There is a good mix of species within the upper zone that is similar to the reference sites with over 90 per cent cover of plants.

In an attempt to increase survivorship of the plants, planting at the following sites was adapted to reflect the mosaic nature of species in a more natural saltmarsh. Plants were clustered into monospecific patches to facilitate spread and reduce competition among species.

It was apparent after 11 months at Berkeley Vale that the low shore was functioning more successfully with around 22 per cent cover. The upper shore still progressed faster than the lower shore. Similarly, the two sites at Lake Munmorah were progressing rapidly within the first few months of rehabilitation. These sites have now been established for 2.5 to 3 years and have a well-developed saltmarsh community in the majority of the lower (70 to 80 per cent cover) and upper (80 to 90 per cent cover) zones of the sites. Although the cover of saltmarsh plants is within the range of nearby reference saltmarshes the groundcover structure is still unique at the rehabilitation sites compared to naturally occurring saltmarshes. This reflects the maturity of the plants, the biodiversity and the patchiness of the rehabilitated sites. It is likely that over time more species will recruit and there will be less wrack and bare ground contributing to the differences in groundcover being recorded presently.

Two sites on Tuggerah Lake (TL19 and TL20) were rehabilitated in late 2011 with similar methods used at Berkeley Vale and Lake Munmorah. Prior to rehabilitation these sites were able to maintain a very narrow band of saltmarsh on the low shore in front of the stepped foreshore. All of this saltmarsh was however removed in the low zone as part of the rehabilitation process and cover has remained extremely low in this area since rehabilitation. Cover has been reduced from >80 per cent cover to <5 per cent cover in the low zone. To date this has not increased on this site. It is likely that growth is extremely slow in this zone due to levels of submergence of plants experienced after planting. The lake was observed to be at higher than normal levels keeping plants in the low zone inundated for long periods thereby minimising their chance of survival and growth. The tube stock planted in these areas being immature plants have not had suitable conditions or sufficient time to become firmly established

and may take several years to reach the density of the saltmarsh that was present in this zone prior to rehabilitation.

In contrast the upper zone before rehabilitation was completely dominated by up to 94 per cent with buffalo grass and weeds. After the rehabilitation process whereby all these were removed and replaced with saltmarsh species there has been an increase in the cover of these saltmarsh species to 60 per cent at TL19 and 40 per cent at TL20. Although this is not at a level of the reference sites as yet the site has only been recovering for just over a year and is progressing well within this zone.

It was determined that the levels to which the previous sites had been excavated were too low and allowed water to remain in the low zone for too long when prevailing rain conditions raised the lake levels. Saltmarsh plants prefer infrequent or occasional inundation and can be destroyed by long periods of submergence, especially succulent species such as *Sarcocornia quinqueflora* (Adams & Bate 1994).

The following three sites in Tuggerah Lake (TL5, TL7 and TL8) that were identified for rehabilitation exhibited a more developed band of saltmarsh within the low zone prior to rehabilitation. Given the slow recovery being recorded at other sites within this zone it was considered appropriate to retain the low saltmarsh at these sites and just re-shape the mid and upper zones of the site to provide a gentler gradient and remove exotic species.

Consequently the lower shore of these sites shows little change or difference across the monitoring period. This would be expected if the saltmarsh was retained and unaffected by the rehabilitation of the remainder of the site. There was no difference in the low zone among the sites (rehabilitation, reference or control) before or after the rehabilitation at these sites.

The upper zone has only had a period of around 8 months to re-establish and is showing only a slight increase in saltmarsh cover at two sites (TL7 and TL8) and more substantial growth at the third site (TL5). The tube stock planted at this site has not had sufficient time to attain great coverage but the community structure of the groundcover is showing distinct differences before and after rehabilitation as well as a unique community compared to control and reference sites. This indicates that while cover is still low the community has transformed and consists of more saltmarsh species, bare ground and seagrass wrack than exotic species and weeds.

The low shore appears to be functioning as it was prior to rehabilitation and the upper shore is progressing towards a more natural saltmarsh community. It is predicted that the communities will form a complementary mosaic across the whole of these sites with more recovery time.

It is clear from these results that the rehabilitated areas, especially at Berkeley Vale and Lake Munmorah have departed in appearance from controls, which reflect their previous condition, and resemble the naturally occurring saltmarshes within the region. Rate of saltmarsh expansion is dependent on the zone and is slower within the low zone compared to the high zone at these sites and is likely to be dependent on the species planted and the ambient receiving environment for tube stock. Species selected for planting in the upper zones are species that are more tolerant of drier less saline conditions (e.g. *Juncus kraussii*, *Paspalum vaginatum, Sesuvium portulacastrum, Selliera radicans*) and more likely to thrive and spread within these

zones. The low zones of the sites experience different extremes of salinity, inundation, water-logging and temperature which may influence the way the saltmarsh expands and grows within this area. The immature plants used in the planting of this zone would also be more susceptible to these influences and show slower response times.

Through a process of adaptive management the methods utilised for rehabilitating the sites has evolved and improved over time to achieve the best results within the environment based on monitoring data and observations. All the actively rehabilitated sites have been converted from habitats dominated by exotic species and weeds to areas dominated by native saltmarsh species. The speed and extent of the recovery has been variable according to methods used and prevailing environmental conditions.

The adaptive approach to rehabilitation has highlighted the importance of monitoring and tailoring rehabilitation methods to suit the receiving environment. The rehabilitation sites completed last have shown greater capacity to recover more rapidly given the combination of retaining functional elements of the environment with removal of incompatible elements (weeds and exotic species). This has been the most successful because the low zone was retained and this has been the area where recovery has been most problematic with establishing communities from tube-stock. Continued monitoring at these sites would confirm this pattern.

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