EXPERIMENTAL AND FIELD REGENERATION OF COASTAL SALTMARSH WITHIN SYDNEY OLYMPIC PARK

Swapan Paul and Mark Farran

Sydney Olympic Park Authority
E-mail: Swapan.Paul@sopa.nsw.gov.au

ABSTRACT

During realignment of the former stormwater drain in late 1999, coastal saltmarsh beds were constructed along the upper portion of Haslams Creek (the Haslams Creek Flats precinct) within Sydney Olympic Park. While the northern flats of the Creek have had reasonable regeneration of coastal saltmarsh, regeneration on the southern flats was not as successful.

Several trials had been undertaken to regenerate coastal saltmarsh on the southern flats. The attempt that yielded the best outcome was through replacement of topsoil followed by vegetation planting. This was considered an expensive approach. Prior to employing this approach in the remaining areas, an alternative approach was trialled in 2006-07. These trials yielded even better outcomes, and did not involve replacing the topsoil, but rather amelioration of the existing topsoil/sediment through incorporation of mangrove mulch.

Saltmarsh plants naturally seeded on the flats and significantly higher numbers of seedlings self-germinated and continued to grow in mangrove-mulch incorporated treatments. To validate this approach a field regeneration attempt was made in 2007 in one section of the flats and successful results have been achieved. The results were so encouraging that the same approach was applied in 2008 to allow self regeneration in the remaining parts of the flats and the results are equally promising. The experimental trial provided valuable additional information. Based on the findings some useful management recommendations are suggested.

INTRODUCTION

McLoughlin (1987) claimed that although the remnant coastal saltmarsh in Homebush Bay was very small compared to what was there previously, it was the second most extensive (about 32.0ha) in the Sydney region and the largest in the Sydney Harbour system (Parramatta River system). The coastal saltmarshes in Homebush Bay, the bulk of which has been under the management of Sydney Olympic Park Authority, are regarded by Adam (1996) as important in the Sydney region, because of their size and species composition. Burchett *et al*. (1998) claimed over 68% loss and Saintilan & Williams (1999) claimed over 70% loss of saltmarsh in the area in last 200 years or so.

To protect from further loss and degradation and to enhance and conserve coastal saltmarsh in New South Wales, the Scientific Committee established by the *Threatened Species Conservation Act* listed coastal saltmarsh as an Endangered Ecological Community. Not too long before this listing and ever since, the Sydney Olympic Park Authority has been attempting to regenerate coastal saltmarsh, with mixed results. Recently, there has been an increasing trend in

creation, rehabilitation, and repair of saltmarsh, however, not many of these projects have been described in published or unpublished forms, except Burchett *et al.* (1999) in NSW.

Site Background

Haslams Creek Flats at Sydney Olympic Park are elevated estuarine beds that were created to allow saltmarsh regeneration (SOP, 2002). The flats were created during the realignment of the former channelized Haslams Creek to a naturalistic estuarine feature during late 1999, in the period leading up to the Sydney 2000 Olympics (Figure 1). Gabion walls were constructed to create the elevated intertidal beds and saltmarsh plants were transplanted onto the imported topsoil. The species were *Sarcocornia quinqueflora, Suaeda australis, Sporobolus virginicus*, and *Halosarcia pergranulata*. Although the elevation was appropriate for saltmarsh, poor topsoil that contained mainly rubble and sand prevented the species growing well (Chalmers, 2002), particularly on the southern flats. Kelleway *et al.* (2007) also classed the patch of saltmarsh in this area as 'poor'.

The total area of this precinct (Haslams Creek Flats) is about 16.0ha. It includes the 13.8ha Creek area and 2.2ha of the saltmarsh flats, with a linear length along the Creek of approximately 2km. Out of the 2.2ha, the Upper Zone (>1.85m tidal elevation) contained mainly *Sporobolus virginicus* with scattered *Halosarcia pergranulata*; the Middle Zone (roughly 1.60-1.85m tidal elevation) remained almost bare; and the Lower Zone (roughly 1.45-1.60m tidal elevation) just above the gabion contained some *Sarcocornia quinqueflora.*

To promote saltmarsh regeneration on the southern flats, trial plantings were performed in 2004-06, which involved replacement of the existing topsoil with garden soil and then transplanting saltmarsh plants. Initial results indicated that by transplanting saltmarsh species it might be possible to regenerate saltmarsh on these flats. However, given the size of the area it was estimated that approximately 4,400m^2 of the area may need topsoil replacement; the quantity of topsoil that will have to be replaced would be about 440m^3, which would be expensive to implement.

Study Aims

As an alternative to replacing topsoil, ameliorating the topsoil was tested. The main aim was to confirm if self-germination of naturally occurring seeds and their subsequent survival was possible, with suitably ameliorated existing topsoil. Then, should the trial regeneration be considered successful, field regeneration attempts would be undertaken.

METHODS

Pre-treatment Observations

Prior to the present experimental trial, two trials and one set of field observations had been made. The outcomes of these are briefly discussed below:

Trial-1: According to Kay (2004) the trial involved 6 treatments in 4m x 2m quadrats with or without topsoil replacement, addition or not of fertiliser and planting or not planting with *Sarcocornia quinqueflora* plants. After one year no definitive conclusions could be drawn, however, there were no significant differences between the treatments in survival and cover of *Sarcocornia quinqueflora*. It was also suggested that a prolonged drought in 2004 was probably responsible for the poor result.

Trial-2: A second trial was conducted in 2005 in 10m x 4m quadrats involving replacement of topsoil of better quality than the previous trial and transplantation of five species of saltmarsh plants, *Wilsonia backhousei, Suaeda australis, Sarcocornia quinqueflora, Sporobolus virginicus and Juncus kraussii*. This transplant trial yielded promising results in quadrats with topsoil replacement.

In addition to the above-mentioned trials several field observations were made. These include:

Sporadic saltmarsh vegetation that existed in the area was the remnant of that which had been planted in late-1999, with almost no new recruits.

Most parts of the area, specifically the Middle Zone, remained almost bare.

Several months before the trial was implemented it was noticed that the leaf litter that had been washed in by stormwater, supported new germination of *Sarcocornia* and *Suaeda*. Nevertheless, these seedlings did not survive the following summer. Possible reasons could be (i) the leaf litter present in the area acted as top mulch, thus provided physical support for holding the seeds as well as containing the much needed moisture for germination; and (ii) as leaf litter was not incorporated into the topsoil, the topsoil did not contain the required moisture to sustain the germinated seedlings.

Design of Experiment

The present trial was particularly designed to check whether by augmenting the capacity of topsoil to hold moisture, and at the same time supplying organic compounds by incorporating mulch with the topsoil, self regeneration as well as sustained growth of the regenerated seedlings was possible.

There were six treatments (Treatment 1-6) with 3 replicate quadrats (A, B & C) in each treatment. Each replicate quadrat was 2m x 2m in size and was randomly distributed in 3 pre-decided locations along Haslams Creek Flats. These three locations were selected because a pre-existing irrigation facility was available in these locations where trials were conducted in the past. At each location, on either side of these previous saltmarsh trial areas, 3 quadrats were randomly positioned, at about the same tidal elevation (approximately at the upper end of the Middle Zone). Tidal elevation was determined after Paul (2001).

Treatment Details

All treatments involved 2m x 2m quadrats marked with wooden pegs.

Treatment 1

Quadrats were left bare with no other augmentation.

Treatment 2

Mangrove mulch incorporated 10cm into the top soil by ploughing the ground and mixing the mulch. Mangrove mulch was used because it was available. Any other mulch could be used for this purpose.

Treatment 3

25 *Sarcocornia* plugs were transplanted from nearby areas into 20cm x 20cm x 10cm holes and 10cm thick mangrove mulch spread on the top soil, without ploughing the ground.

Treatment 4

10cm thick mangrove mulch spread on the top soil without ploughing the ground; Jute mat laid over the quadrats to hold the mulch and moisture; 25 *Sarcocornia* plugs transplanted from nearby areas into 20cm x 20cm x 10cm holes.

Treatment 5

Jute mat laid over the quadrats to hold moisture; 25 *Sarcocornia* plugs transplanted from nearby areas into 20cm x 20cm x 10cm holes; no mangrove mulch was provided.

Treatment 6

Jute mat laid over the quadrats to hold moisture; no *Sarcocornia* plants were transplanted and no mangrove mulch was provided.

The field preparation for the treatments started in late June 2006 and was completed by the third week of August 2006. It was assumed that there would be no substantial differences in the sediment quality among the treatment quadrats.

Following successful trials and the confirmation that by incorporating mulch into the existing top soil self-regeneration of saltmarsh vegetation was possible in this area, two field regeneration attempts were made. In 2007 approximately 1,300m^2 area was regenerated and in 2008 approximately 3,100m^2 was regenerated. In mid-September 2007 the area was tilled using a Rotary-hoe Tractor. Prior to tilling, a silt fence was erected on a temporary basis to avoid unintended washing of sediment into the waterway. Up to 10cm of the top soil was tilled and any large rocks over the size of a tennis ball were removed. Soon after, mangrove mulch, to a thickness of approximately 10cm, was evenly spread over the tilled area. The mulch was mixed with the tilled top soil by further tilling with the back-hoe. Meanwhile saltmarsh vegetation seeds were collected from the Badu Saltmarsh area and let dry in paper bags. Collected seeds of *Suaeda australis* and *Sarcocornia quinqueflora* were sowed by a hand spreader after mixing with sand, and by September 2007 the first attempt on field regeneration was completed. The second regeneration attempt in the following year commenced in mid-July and was completed by early August 2008.

Data Collection

The first set of trial regeneration data was collected on 30 October 2006, the second set on 23 January 2007 and the final set on 25 May 2007. Data were gathered on a number of variables. These are discussed below.

Self-germination of saltmarsh vegetation, especially *Sarcocornia* and *Suaeda*, was recorded by simply counting the total number of seedlings present in each quadrat. A 0.5m x 0.5m quadrat (with 16 sub-quadrats) was used to aid in the counts. When required, a plant identification guide was used.

Height of seedlings was measured by using a ruler. Up to 20 seedlings of each species were measured haphazardly and the heights were recorded.

Additional height readings of up to 20 seedlings from nearby quadrats under previous trials were also taken. In addition, qualitative observations were made on the general health and condition of the seedlings and transplanted vegetation.

In case of field regeneration attempts in 2007 and 2008, no systematic data were collected; nevertheless, field observations were made on the regeneration success, considering seedling counts and survival.

Data Analysis

Data were analysed using a suitable statistical package, GMVA5 for two-factor ANOVA (Underwood & Chapman 1998). SNK Multiple Range tests were also performed in the same package to determine significant differences between treatments.

RESULTS

Self-germination of *Sarcocornia quinqueflora*

Sarcocornia self-germinated in 15 out of total 18 treatment quadrats. There were large variations in total germination between treatments. Overall, Treatment 2 contained very high number of seedlings whereas Treatments 1 & 3 had very low seedlings population at the times of data gathering. Treatments 4, 5 & 6 showed slightly better germination than Treatments 1 & 3 (Figure 2; Appendix I).

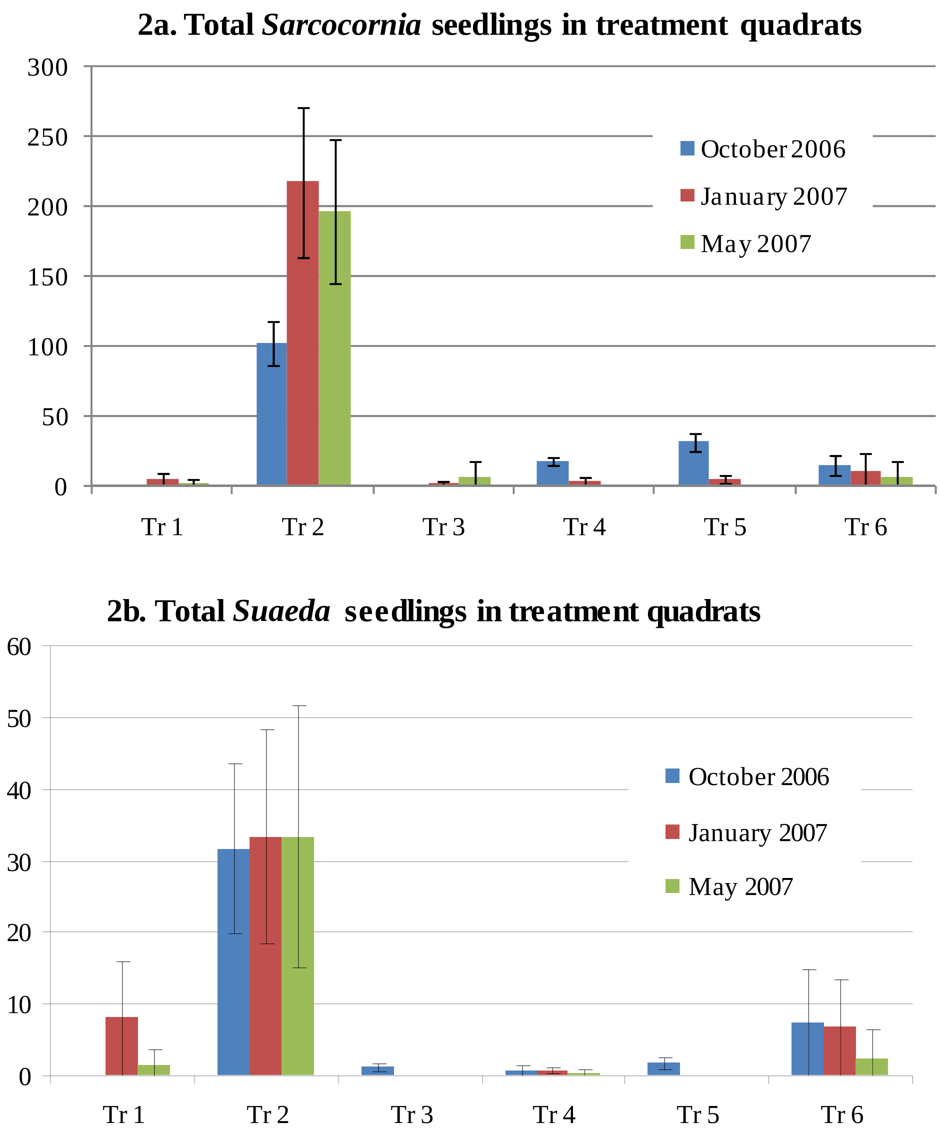


Figure 2. Total seedlings numbers (mean ± SE) of *Sarcocornia* and *Suaeda* in treatment quadrats. (Tr1-Tr6 indicate Treatment 1 through Treatment 6).

Transformation of data was required before carrying out ANOVA, as Cochran's C was significant in most cases. The main reason of C being significant was the large variation between replicate readings, particularly due to zero values in some quadrats. After square-root transformation of data statistically significant differences between the means of treatments could be identified. It was found that the mean total number of *Sarcocornia* seedlings was significantly higher in Treatment 2 than all other treatments (F=96.17, P<0.001; Table 1). SNK also confirmed that the numbers of *Sarcocornia* seedlings in Treatment 1 and Treatment 3 through Treatment 6 were not significantly different (Table 2).

Table 1. ANOVA and Cochran's Test results for variations between treatments.

Test Statistic	***Sarcocornia* germination**	***Suaeda* germination**	***Sarcocornia* height**	***Suaeda* height**
Cochran's Test (C)	0.2615	0.2764	0.1816	0.2956
Cochran's P	NS	NS	NS	NS
Transformation	Squrt (X + 1)	None	None	Squrt (X + 1)
Treatment F	96.17	21.56	3.82	6.07
Treatment P	0.0000	0.0000	0.0071	0.0004
Treatment d.f.	5	5	5	5
Treatment MS	170.24	1456.99	5077.87	62.46
Period F	0.78	0.24	3.18	0.56
Period P	0.4663	0.7889	0.0534	0.5596
Period d.f.	2	2	2	2
Period MS	1.38	16.13	4231.25	6.07
Treatment x Period F	5.66	0.20	2.28	0.92
Treatment x Period P	0.0000	0.9949	0.0347	0.5276
Treatment x Period d.f.	10	10	10	10
Treatment x Period MS	10.01	13.55	3027.75	9.45

Table 2: SNK multiple range test results for *Sarcocornia* and *Suaeda*.

a. Comparisons between treatments for self regeneration.

	Self Regeneration of *Sarcocornia*						**Self Regeneration of *Suaeda***					
Treatment	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1		**	ns	ns	ns	ns		**	ns	ns	ns	ns
T2	**		**	**	**	**	**		**	**	**	**
T3	ns	**		ns	ns	ns	Ns	**		ns	ns	ns
T4	ns	**	ns		ns	ns	Ns	**	ns		ns	ns
T5	ns	**	ns	ns		ns	Ns	**	ns	ns		ns
T6	ns	**	ns	ns	ns		Ns	**	ns	ns	ns	

ns - non significant; ** indicates significance at levels at P<0.01.

b. Comparisons Between Treatments for Period of Study.

	Sarcocornia						***Suaeda***					
Period	P1	P2	P3					P1	P2	P3		
P1		ns	ns				P1		ns	ns		
P2	ns		ns				P2	ns		ns		
P3	ns	ns					P3	ns	ns			

ns - non significant; ** indicates significance at levels at P<0.01.

Table 3: SNK multiple range test results for *Sarcocornia* and *Suaeda.*

a. Comparisons between treatments for seedling height (mm).

	Height of *Sarcocornia*						Height of *Suaeda*					
Treatment	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1		**	ns	ns	ns	ns		**	**	**	**	**
T2	**		ns	ns	*	*	**		**	ns	**	**
T3	ns	ns		ns	ns	ns	**	**		**	**	**
T4	ns	ns	ns		ns	ns	**	ns	**		**	**
T5	ns	*	ns	ns		ns	**	**	**	**		**
T6	ns	*	ns	ns	ns		**	**	**	**	**	

ns - non significant; ** indicates significance at levels at P<0.01; * indicates significant at P<0.05.

b. Comparisons between treatments for period of study.

	Sarcocornia						*Suaeda*					
Period	P1	P2	P3					P1	P2	P3		
P1		ns	ns				P1		ns	ns		
P2	ns		ns				P2	ns		ns		
P3	ns	ns					P3	ns	ns			

ns - non significant; ** indicates significance at levels at P<0.01; * indicates significant at P<0.05.

Self-Germination of *Suaeda australis*

Suaeda self-germinated in all but 5 (of 18) treatment quadrats. There were large variations in total germination between treatments.

Overall, Treatment 2 contained very high number of seedlings whereas treatments 3, 4 and 5 had very low seedling populations. Treatments 1 and 6 contained a small number of seedlings.

After transformation of data it was found that the mean total number of *Suaeda* seedlings was significantly higher in Treatment 2 than all other treatments ($F=21.56$, $P<0.001$; Table 1).

Height in *Sarcocornia quinqueflora*

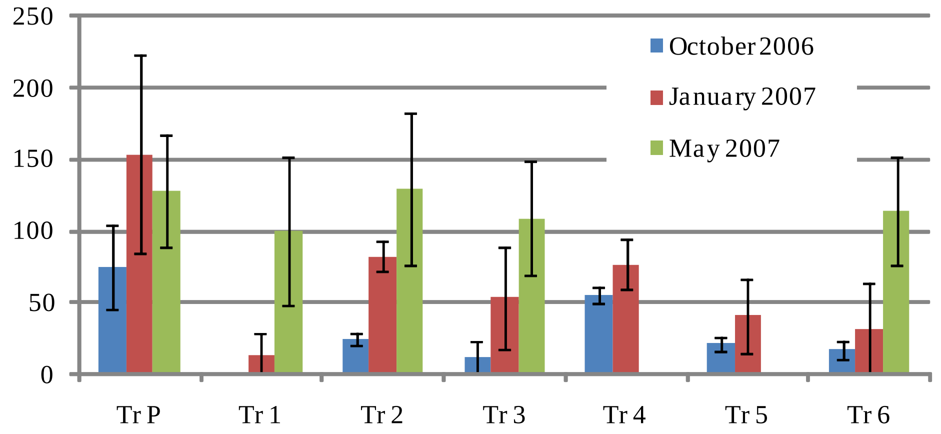
Sarcocornia showed height increases in 11 (out of 18) quadrats; with highest increase of 86.25mm in Treatment 1 (in quadrat B) between January 2007 and May 2007 and the lowest of 21.70mm in Treatment 4 between October 2006 and January 2007 (Appendix I). All 3 quadrats of Treatment 2 increased in height. On the other hand 4 quadrats from all treatments showed no mean increase in height during the October 2006 and January 2007 period (Figure 3; Appendix I).

Comparisons of height differences were made between the experimental quadrats and the existing larger (3) quadrats (Figure 3). In case of *Sarcocornia*; the existing quadrats appeared to have shown greater height during all the data-gathering periods.

Height in *Suaeda australis*

During the trial period *Suaeda* demonstrated an increase in mean height in all the treatments except Treatment 3 and Treatment 5. The ANOVA of transformed (Square Root + 1) data suggests that significantly higher mean height was achieved between the remaining treatments ($F=6.07$, $p<0.0004$; Figure 3; Appendix I).

3a. Average height (mm) of *Sarcocornia* in treatment quadrats



3b. Average height (mm) of *Suaeda* in treatment quadrats

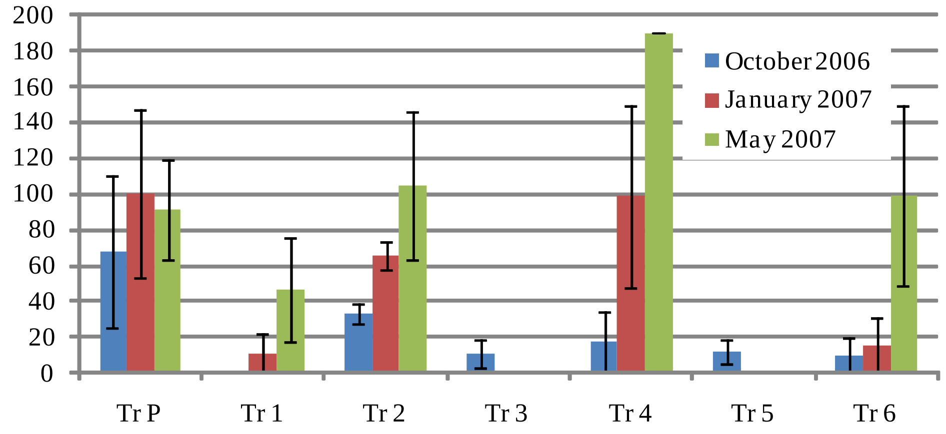


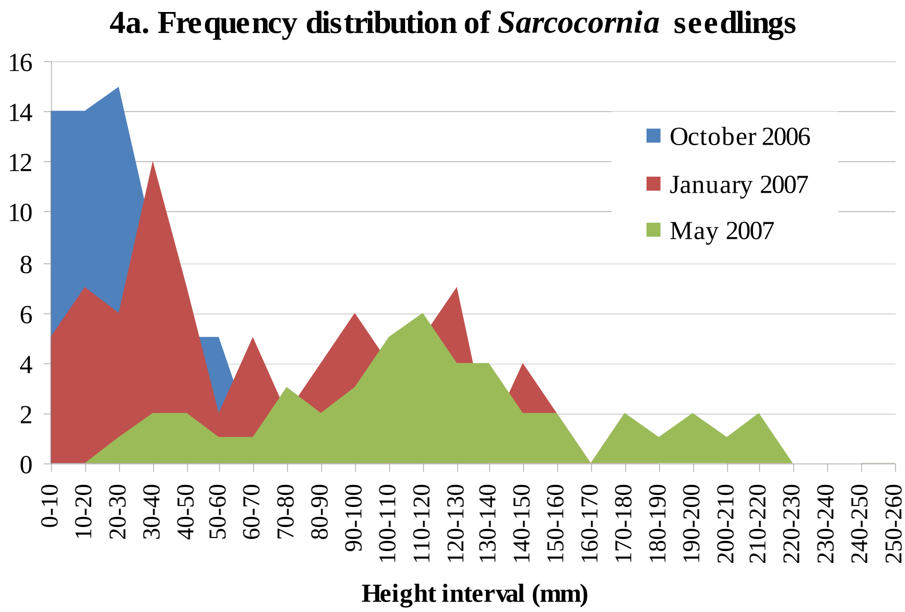
Figure 3: Total seedlings height (mean ± SE) of *Sarcocornia* and *Suaeda* in treatment quadrats. (Tr1-Tr6 indicate Treatment 1 through Treatment 6; TrP indicates Past Quadrat).

SNK confirmed that compared with all other treatments Treatment 2 and Treatment 4 had significantly taller seedlings (Table 2).

Comparisons of height differences were made between the experimental quadrats and the existing larger (3) quadrats (Figure 3). *Suaeda* generally showed greater height in the existing quadrats. The findings corroborate those from the *Juncus acutus* removal and subsequent vegetation regrowth experiment conducted within SOP (Paul *et al.* 2007).

Germination Period

To find out the length of germination, length-frequency distribution graphs were drawn after pooling all the data from all the treatments (Figures 4 & 5).



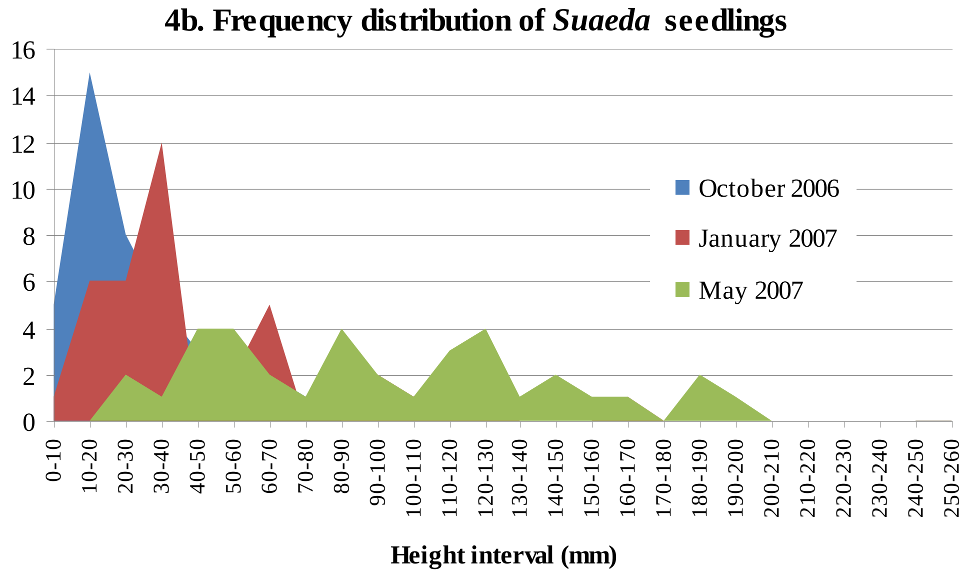


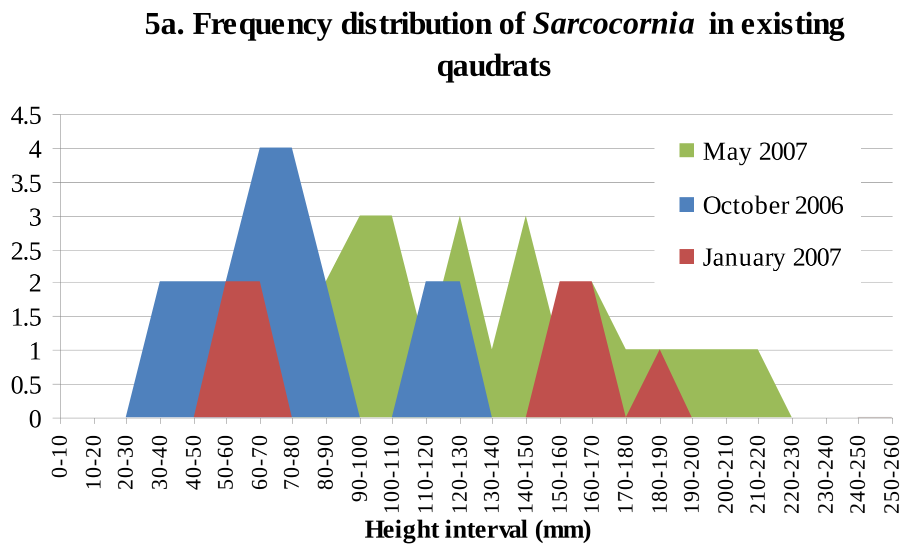
Figure 4: Frequency distribution of seedlings of *Sarcocornia* and *Suaeda* in treatment quadrats.

Field Regeneration in 2007

Germination was noticed approximately eight weeks after sowing the seeds. Both *Suaeda* and *Sarcocornia* emerged about the same time, with a tendency for *Suaeda* to germinate slightly earlier. The bulk of the germination was completed before December 2007, with very little germination in December 2007.

Field Regeneration in 2008

The germination was observed approximately seven weeks after sowing the seeds. *Suaeda* seeds germinated slightly before *Sarcocornia*, with very little new germination beyond November 2008.



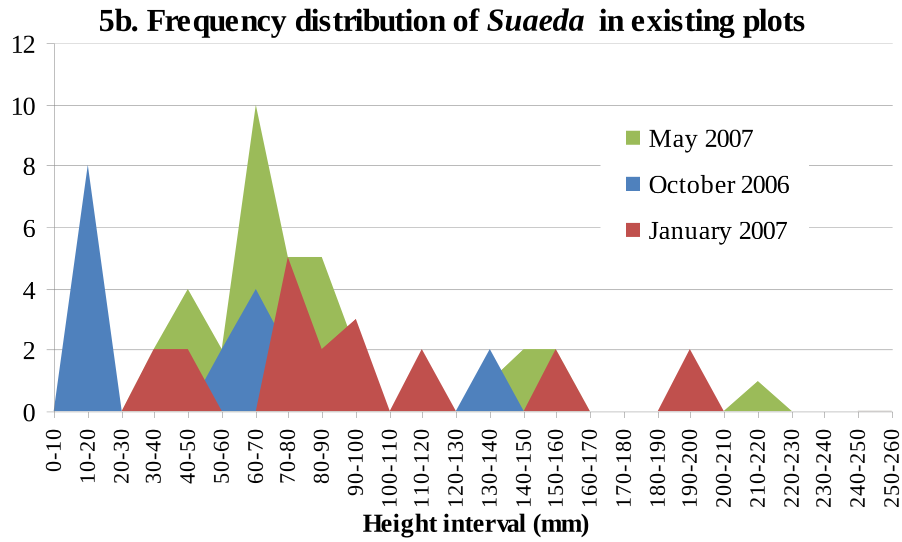


Figure 5: Frequency distribution of seedlings of *Sarcocornia* and *Suaeda* in existing quadrats.

DISCUSSION

Trial Regeneration

The results of the trial (experimental) regeneration conducted during 2006-07 are discussed below, in light of the main objectives of the experimental trial. These are expressed in the form of questions and answers.

Did the presence of a Jute mat help in self-germination and/or height increase?

Three sets of comparisons are made. Firstly, Treatment 4 (mangrove mulch with Jute mat) & Treatment 3 (mangrove mulch without Jute mat) were compared. Overall, there were no significant differences between these two treatments, thus suggesting that the Jute mat did not contribute to significantly higher self-germination or height increase in *Sarcocornia*. Rather, in Treatment 4 the limited number of

Sarcocornia seen in January 2007 died before the May 2007 sampling. This was possibly due to a lack of moisture in the ground.

Suaeda was very poorly represented in the three sampling periods for both Treatment 3 & 4. However, the few solitary plants that were present in Treatment 4, showed very sharp increases in height. This height was, however, remarkably higher than all other treatments except Treatment 2. This indicates that although the Jute mat did not provide any advantages to *Sarcocornia*, it may have given some advantage to *Suaeda* in the height gains.

Secondly, when Treatment 3 and Treatment 5 (Jute, no mulch) were compared it was found that overall these two treatments were not significantly different in self germination or height changes in *Sarcocornia* or *Suaeda*. Rather, there was a total mortality in Sarcocornia seedlings in Treatment 5 between January 2007 and May 2007. This gives an indication of a better performance by mangrove mulch over Jute mat.

Thirdly, when Treatment 1 (control) was compared with Treatment 6 (Jute mat only) it was found that overall, these were not significantly different.

It seems that although apparently Jute mat provided some moisture and assisted in harbouring of naturally occurring seeds, it was not significantly advantageous over mangrove mulch or any other treatment.

Did transplanting *Sarcocornia* help self-germination of seedlings?

To answer this question, two comparisons were made. Firstly, Treatment 3 (with saltmarsh transplanting) and Treatment 2 (without saltmarsh transplanting) were compared. Treatment 2 showed significantly higher self-germination in both *Sarcocornia* and *Suaeda* than Treatment 3, indicating that transplanting did not provide any additional help in self-germination of the seedlings. It was, nevertheless, noticeable that there was no significant difference in the mean heights in *Sarcocornia* or *Suaeda* between these two treatments. *Suaeda*, however, experienced a total mortality in Treatment 3 from the second sampling period. It is worth mentioning here that Treatment 2 was set up a few weeks earlier than Treatment 3. It is not clear whether this time gap played any critical role in the differences in the results.

Secondly, comparison was made between Treatment 5 (with saltmarsh transplanting) and Treatment 6 (without saltmarsh transplanting). Here also, germination of both *Sarcocornia* and *Suaeda* was slightly greater in Treatment 5. This time also, transplantation occurred a few weeks after the other treatments had been set-up.

It is plausible that due to the delays in the setting up of the treatments that involved transplantation of saltmarsh vegetation, the peak period of seedlings germination was already over. It is also plausible that any seed sources that were present in the quadrats that involved transplantation were highly disturbed during the transplantation exercise, perhaps at the early stage of seedling germination. However, this is not clearly attributable from the self germination data in other treatments.

It seems that in this instance vegetation transplanting did not provide any added advantage over self germination.

Did mangrove mulch prove to be any better?

In answering this, two scenarios were taken into account: firstly, spreading of mangrove mulch on the top soil without incorporating it with the soil; and secondly, incorporation of the mangrove mulch into the top soil.

To assess the first situation, comparisons were made between Treatment 4 and Treatment 5. It is clear from the results that these two treatments were not significantly different. This confirms that spreading of mangrove mulch over the top soil was not effective in encouraging new germination of saltmarsh species. On the contrary, the second scenario is very clear. Since Treatment 2 had the highest results it is clear that incorporation of mangrove mulch was effective in promoting self-germination.

The significantly higher outcomes in Treatment 2 in terms of numbers of germination and survival could be due to incorporation of mangrove mulch into the sand-enriched-and-nutrient-improved soil. It is plausible that the incorporated mulch assisted in the maintenance of aerobic conditions. Any anaerobic conditions in saltmarsh soils will tend to promote denitrification (Adam, 1990). The mangrove mulch might have also provided organic nutrients. The decomposition process results in the release of nutrients and other elements which may be recycled within the system and, of these, two of the most important are nitrogen and phosphorus because of their role in primary production (Wilson, 1988). In addition, mangrove mulch has probably assisted in the enhanced ability for the soil to hold moisture, which must have played a critical role in the germination, survival, and growth.

However, high degrees of variations between treatments and within the treatment replicates are interesting. The reasons for the high variations are not clear, nevertheless, either or both of the following reasons may apply.

By far the greatest degree of variations between the replicate quadrats were in Treatment 2. Among the three replicate quadrats in Treatment 2, quadrat 2B had the greatest number of seedlings. One reason could be that early setting-up of quadrat B in Treatment 2 a few weeks before the two other replicate quadrats A & C were prepared. It may also be that during this late preparation of these two quadrats any germinated *Sarcocornia* seedlings that already had existed might have been damaged.

Did germination take place over a long period?

To answer this question length-frequency distribution graphs were drawn after pooling all the data from all the treatments.

Since there were no seedlings of 10mm or greater length in the January 2007 samples, it indicates that *Sarcocornia* germination period did not continue beyond December 2006. Similarly, *Suaeda* of less than 10mm height were not represented in the samples of January 2007. To check if the height was influenced by the treatments, height readings were also taken from the nearby previously established quadrats. When the length-frequency data between the treatment and earlier quadrats were compared, it became clear that the nearby earlier quadrats followed a similar pattern (Figures 4 & 5). This confirms that on this occasion these two species showed December as the end of germination period.

Regrowth of Transplanted *Sarcocornia*

In Treatment 2, only 11 of the 75 transplanted *Sarcocornia* plugs did not survive. In those which survived, the regrowth of the 64 transplanted plants was satisfactory. Each of the transplanted plants that succeeded in regrowth showed new growth around the transplanted mother *Sarcocornia* plugs.

The satisfactory results were perhaps due the presence of mangrove mulch and/or Jute mat in these treatments involving *Sarcocornia* plugs transplantation.

Condition and Health

The condition and health of the transplanted plants only were assessed individually and an estimate was given for that assessed quadrat. Observations were recorded as poor, good or excellent. The colour and density of regrowth was used to assess the health of plants. It was observed that transplanted *Sarcocornia* that survived, almost always showed good-to-excellent health.

Field regeneration in 2007

It appeared that the germination was dependent on rainfall, sufficient to saturate the ground. It is believed that the rain events in October 2007 triggered germination.

The germination was thin, patchy and variable between pockets. It was perhaps due to the delays in sowing the seeds. After conducting the experiment and this field regeneration study it is suggested that saltmarsh seeds might better germinate in August-September. Nevertheless, the germinated seedlings grew well and, until November 2008 the germinated plants kept growing. Some of the seedlings that had already matured, seeded in the 2008 season.

Field regeneration in 2008

Like the previous season, it appeared that the germination was dependent on rainfall sufficient to saturate the ground. It is believed that the rain events in October 2008 triggered germination. The germination was patchy, however, variable between pockets of hand-sowed and non-sowed areas; with more dense seedlings in the hand-sowed areas. The germinated seedlings continued to grow beyond November 2008, when the last observations were taken.

CONCLUSIONS

Based on the past trials, experimental regeneration and field regeneration attempts it is concluded that on the flats of Haslams Creek within Sydney Olympic Park, coastal saltmarsh can be successfully regenerated by simply incorporating mangrove mulch into the existing, nutrient depauperate topsoil/sediment, without requiring sowing seeds or transplanting.

Management recommendations

It is recommended that:

- Before regenerating or newly creating any saltmarsh bed it is crucial that the quality of the existing soil/sediment is known in details and, if required, suitable topsoil/sediment is provided.
- Should suitable topsoil/sediment not be present, it may be possible to ameliorate the existing topsoil/sediment by carefully incorporating mangrove mulch or maybe other garden mulch.
- Should tidal waters have seed sources, it is possible that there would not be any need to sow seeds in the proposed regeneration areas.

- Should the above be seen as a possibility, the beds should be prepared before July.
- Should seeds be collected, it is advisable to collect seeds during June-July or earlier.
- Should seed sowing be chosen, it is suggested that this is performed during July-August.
- Transplanting of mother-plants may be chosen as a last option only if faster colonisation or introduction of a new species is required. In those instances 4-5 plugs per square metres of the area seems adequate.

ACKNOWLEDGEMENTS

The help and assistance from Andrew Jack in field regeneration study is greatly appreciated.

REFERENCES

Adam, P. (1990). Saltmarsh Ecology, Cambridge University Press, Cambridge.

Adam, P. (1996). *Saltmarsh vegetation study*. In: Homebush Bay Ecological Studies 1993 – 1995. Vol. 2. Olympic Coordination Authority and CSIRO, Collingwood, pp. 113 – 127.

Burchett, M. D., Pulkownik, A. and McFarlane, G. (1998). *Rehabilitation of saline wetlands. Olympics 2000 Site, Sydney (Australia) – II: Saltmarsh transplantation trials and application.* Marine Pollution Bulletin, **37**:526 – 34.

Chalmers, H. (2002). *Factors Affecting Saltmarsh Regeneration at Sydney Olympic Park.* Thesis, University of Technology Sydney.

Kay, S. (2004). *Experimental Re-establishment of Sarcocornia quinqueflora in Haslams Creek. Final Report.* Sydney Olympic Park Authority.

Kelleway, J., Williams, R. J. and Allen, C.B. (2007). An Assessment of the Saltmarsh of the Parramatta River and Sydney Harbour. NSW DPI Fisheries Final Report Series No. 90., p.92.

McLoughlin, L. (1987). *Mangroves and grass swamps: changes in the shoreline vegetation of the Middle Lane Cove River, 1780's to 1880's*. Wetlands (Australia) **7**:13 – 24.

Paul, S. (2001). *A Simple and Accurate Method of Tidal Mapping in Mangrove Wetlands.* Paper was presented at the Second Asian Wetlands Symposium 2001 held on 27-30 August 2001 in Penang, Malaysia.

Paul S, Young R, MacKay A. (2007). *Experimental control of exotic Spiny Rush, Juncus acutus from Sydney Olympic Park: II. Effects of treatments on other vegetation.* Wetlands (Australia) **24**:1-13.

Saintilan, N. and Williams, R. J. (1999). *Mangrove transgression into saltmarsh environments in south-east Australia.* Global Ecology and Biography, **8**:117 – 24.

Sydney Olympic Park (SOP). (2002). *Parklands Plan of Management (PoM),* Sydney Olympic Park Authority.

NSW Threatened Species Conservation Act (1995). Retrieved from: http://www.legislation.nsw.gov.au/viewtop/inforce/act.

Underwood, A. J. and Chapman, M. G. (1998). Design of Biological Experiments – Training Manual, University of Sydney.

Wilson, J. G. (1988). The biology of estuarine management. Chapman and Hall, New York.

APPENDIX I. GERMINATION (NUMBER) AND HEIGHT (MM) OF *SARCOCORNIA* AND *SUAEDA* DURING THE EXPERIMENTAL PERIOD.

Treatments	Plots	*Sarcocornia* Total Germination			*Suaeda* Total Germination		
		Oct-06	Jan-07	May-07	Oct-06	Jan-07	May-07
Treatment 1	1A	0	0	0	0	0	0
	1B	0	15	6	0	24	4
	1C	0	0	0	0	0	0
Treatment 2	2A	88	177	150	28	29	27
	2B	120	279	252	45	50	54
	2C	99	197	189	22	21	19
Treatment 3	3A	1	4	0	1	0	0
	3B	0	0	19	2	0	0
	3C	0	3	3	0	0	0
Treatment 4	4A	13	9	0	0	0	0
	4B	24	0	0	2	1	1
	4C	18	3	0	0	1	0
Treatment 5	5A	21	4	0	3	0	0
	5B	43	10	0	2	0	0
	5C	32	0	0	0	0	0
Treatment 6	6A	4	0	0	0	0	0
	6B	27	35	20	22	20	7
	6C	15	0	0	0	0	0

Treatments	Plots	*Sarcocornia* Height			*Suaeda* Height		
		Oct-06	Jan-07	May-07	Oct-06	Jan-07	May-07
Treatment 1	1A	0	0	0	0	0	0
	1B	0	42.4	100.5	0	32.5	46.7
	1C	0	0	0	0	0	0
Treatment 2	2A	28	79	146.6	45	79	140
	2B	29.2	102.4	105.5	29.3	66	103.6
	2C	17	66.6	157	26	52.7	98.2
Treatment 3	3A	36	122.25	0	6	0	0
	3B	0	0	110.3	25.5	0	0
	3C	0	38	106.6	0	0	0
Treatment 4	4A	46.4	76.2	0	0	0	0
	4B	65.1	108	0	51	126	190
	4C	55.7	46.2	0	0	170	0
Treatment 5	5A	30.3	87.5	0	23.6	0	0
	5B	12.7	35.2	0	12.5	0	0
	5C	21.5	0	0	0	0	0
Treatment 6	6A	6.75	0	0	0	0	0
	6B	28.6	95.8	114.2	29.1	46	98.7
	6C	17.6	0	0	0	0	0

Appendix II. Height (mm)-Frequency Distribution of *Sarcocornia* and *Suaeda* in Treatment and Existing Quadrates.

	Sarcoconia						***Suaeda***					
	Treatment Quadrats			Existing Quadrats			Treatment Quadrats			Existing Quadrats		
Height (mm)	Oct. 2006	Jan. 2007	May. 2007	Oct. 2006	Jan. 2007	May. 2007	Oct. 2006	Jan. 2007	May. 2007	Oct. 2006	Jan. 2007	May. 2007
0-10	5	1	0	0	0	0	14	5	0	0	0	0
10-20	15	6	0	8	0	0	14	7	0	0	0	0
20-30	8	6	2	0	0	0	15	6	1	0	0	0
30-40	5	12	1	0	2	2	9	12	2	2	0	0
40-50	3	0	4	0	2	4	5	7	2	2	0	0
50-60	1	2	4	2	0	2	5	2	1	2	2	0
60-70	2	5	2	4	0	10	1	5	1	4	2	0
70-80	1	0	1	2	5	5	3	2	3	4	0	0
80-90	0	2	4	0	2	5	0	4	2	2	0	2
90-100	0	2	2	0	3	2	1	6	3	0	0	3
100-110	0	1	1	0	0	0	0	4	5	0	0	3
110-120	0	2	3	0	2	1	1	5	6	2	0	1
120-130	0	3	4	0	0	0	1	7	4	2	0	3
130-140	0	0	1	2	0	1	0	1	4		0	1
140-150	0	0	2		0	2	0	4	2		0	3
150-160	0	0	1		2	2	0	2	2		2	1
160-170	0	1	1		0	0	0	0	0		2	2
170-180	0	0	0		0	0	0	2	2		0	1
180-190	0	0	2		0	0	0	0	1		1	1
190-200	0	0	1		2	0	0	0	2		0	1
200-210	0	0	0			0	0	0	1		0	1
210-220	0	0	0			1	0	1	2		0	1
220-230	0	0	0				0	0	0		0	
230-240	0	0	0				0	0	0			
240-250	0	0	0				0	0	0			
250-260	0	0	0				0	0	0		0	