ESTABLISHMENT OF *SARCOCORNIA QUINQUEFLORA* AND *SPOROBOLUS VIRGINICUS* IN A CREATED SALTMARSH: SPECIES-SPECIFIC RESPONSES TO TOPSOIL ADDITION AND ASSISTED PLANTING

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ABSTRACT

Saltmarsh restoration projects often require the creation of saltmarsh habitat on previously non-tidal areas through excavation of overburden to provide a substrate at an appropriate level within the tidal plane. Such sites may then be covered with topsoil and/or planted with target saltmarsh plant species. However, few such projects in saltmarsh establishment are designed in a way and/or monitored in a manner that would allow for the collection of data that may assess efficacy to guide future restoration projects. A small saltmarsh restoration project in Lake Macquarie, New South Wales, incorporated an experimental design that sought to address the questions as to whether topsoil addition and planting are necessary for the effective establishment of saltmarsh vegetation. Two years post saltmarsh establishment, topsoil addition facilitated the growth (in terms of percentage cover) and recruitment of *Sarcocornia quinqueflora*, though topsoil provided no appreciable benefit for *Sporobolus virginicus*. It was further shown that while planting assisted growth for *Sarcocornia quinqueflora*, it was a necessity for the establishment of *Sporobolus virginicus* within such time frames. Importantly, this study demonstrated the value of incorporating into a wetland restoration projection an experimental design that tests specific hypotheses.

INTRODUCTION

Saltmarsh is listed as an endangered ecological community under New South Wales threatened species legislation (Department of Environment and Climate Change 2004). Thus the need to arrest and compensate for the loss of saltmarsh is well documented and a number of measures have been proposed and implemented, most targeting revegetation (Laegdsgaard, 2006; Department of Environment and Climate Change NSW, 2008; Laegdsgaard et al., 2009). In central coastal New South Wales, saltmarshes are dominated by three main plant species: *Sarcocornia quinqueflora* subsp. *quinqueflora* (Bunge ex Ung.-Sternb.) A.J.Scott (Chenopodiaceae) and *Sporobolus virginicus* var. *minor* F.M.Bailey (Poaceae) in the lower marsh, and *Juncus kraussii* subsp. *australiensis* (Buchenau) Snogerup (Juncaceae) in the higher marsh, although other species may be interspersed with these or may be locally dominant. There is considerable variation within *S. virginicus* in Australia with Smith-White (1988) describing four morphotypes (and several ploidy levels within these morphotypes) compared with the two varieties presented in floras (var. *minor* and var. *virginicus*) (Simon and Jacobs, 1999). The plants from saltmarshes of central coastal NSW are apparently consistently of the one ‘race’ (type 1 tetraploid), the morphotype of which matches the typical description of variety *minor* (Smith-White, 1988). However, finer scale phenotypic and genetic variations also occur within this ‘race’ (Smith-White, 1981).

One approach to compensation for loss of vegetation is the creation of saltmarsh in areas where it presently does not exist by excavating the land to a level that would be inundated by tides at heights and frequencies appropriate for the growth of saltmarsh vegetation. While such activities are often undertaken as compensatory measures for various developments or restoration projects, they are generally poorly documented and provide little useful information to clearly guide future projects. Ideally, any restoration project should be treated as an experiment and the knowledge gained used to improve future restoration projects (Grayson et al., 1999; Zedler and Callaway, 2000).

A small number of studies have been designed to experimentally address particular questions in relation to saltmarsh creation in New South Wales (NSW), although these have been strictly experiments rather than restoration projects incorporating experimental designs. Burchett *et al.* (1998) investigated approaches to propagating and transplanting six saltmarsh species, including *S. quinqueflora* and *S. virginicus*, as well as monitoring natural recruitment along Haslams Creek at Homebush Bay in Sydney NSW. The creation area was on imported sandy fill although two strips of natural silty substrate were also included in the experiment. They found that all species could be effectively transplanted, and that some, including *S. quinqueflora*, readily recruit although other species, such as *S. virginicus*, do not. Establishment and survival of recruits was better on the natural silty substrate than the imported sandy fill, this possibly being due to plants more readily desiccating on the better drained sandy substrate. Nelson (2006) evaluated the effects of several treatments; topsoil, fertiliser, irrigation and planting, on the establishment of saltmarsh vegetation on a creation site at Kooragang Island in Newcastle NSW. He found that topsoil, which was described as loamy and was 30cm to 40cm deep, had a positive effect for both recruitment of *S. quinqueflora* and *S. virginicus* and growth of planted *S. quinqueflora* and *S. virginicus*, but irrigation and planting did not have significant effects. At a smaller scale, Laegdsgaard (2002) investigated the recovery of small patches of *S. quinqueflora* saltmarsh and *S. virginicus* saltmarsh from which vegetation had been removed. She observed rapid (21 months) revegetation of *S. quinqueflora* by vegetative means at lower elevations but slower revegetation at higher elevations where reduced tidal flushing would be likely to lead to higher salinity stress. Little volunteer seed recruitment by *S. quinqueflora* was observed. Recovery of *S. virginicus* was also slow and was mainly by vegetative means, although some volunteer seed recruitment was observed in larger bare patches (Laegdsgaard, 2002). Paul and Farran (2009) trialled various combinations of mangrove mulch, jute matting and planting of *S. quinqueflora* along Haslams Creek at Homebush Bay in Sydney NSW. They found that incorporation of organic material (mangrove mulch) into the sediment was effective in promoting colonisation by *S. quinqueflora* and *Suaeda australis*, but planting of *S. quinqueflora* gave no advantage over natural recruitment over the two years of the study (Paul and Farran, 2009) .

A number of northern hemisphere studies, mainly in North America, have also investigated saltmarsh revegetation strategies. Although they obviously relate to different plant species than those found in NSW, some of the results may have relevance for NSW conditions. Success of transplants tends to be site-specific, with abiotic factors such as soil hypersalinity, excessive sedimentation, lack of topographic heterogeneity, and drought weather conditions being identified as factors contributing to failure of transplants (Handa and Jefferies, 2000; Zedler et al., 2003; Larkin et al., 2006; O'Brien and Zedler, 2006). Factors favouring survival of transplants included cluster planting, fertiliser application and mulching (Handa and Jefferies, 2000; Zedler et al., 2003; O'Brien and Zedler, 2006). Establishment and success of volunteer seed recruits, on the other hand, was essentially species-specific, with chenopods being common recruits, and species that rely on vegetative spread being poor recruits (Handa and Jefferies, 2000; Lindig-Cisneros and Zedler, 2002; Zedler et al., 2003; O'Brien and Zedler, 2006).

The results of these studies, while informative, leave issues requiring further research to clarify in relation to the establishment of vegetation in central coastal NSW saltmarshes. Of particular note are the conflicting results in NSW saltmarshes on the benefits of placing topsoil for both recruitment and the growth of plantings. Burchett *et al.* (1998) found that plants grew and recruited better on the natural subsoil than placed topsoil at their site, whereas Nelson (2006) found that placed topsoil had positive benefits for both growth and recruitment of saltmarsh plants. Given the extra cost involved for saltmarsh creation projects in placement of topsoil, this is an issue that warrants further investigation. Also needing clarification is to what extent is it necessary to plant some community dominants, such as *S. virginicus*, which evidently establish largely via vegetative spread. Both Burchett *et al.* (1998) and Nelson (2006) showed that a range of saltmarsh plants, including *S. virginicus* could be transplanted and will establish from transplants, and several studies have shown that *S. virginicus* will spread vegetatively (Burchett et al., 1998; Laegdsgaard, 2002; Nelson, 2006). However, it remains unclear to what extent *S. virginicus* will recruit naturally and therefore whether it is necessary to plant this species. Both Laegdsgaard (2002) over 21 months and Nelson (2006) over 4 years found recruitment of *S. virginicus* from seed, whereas Burchett *et al.* (1998) over 3 years found no recruitment of *S. virginicus*.

The major factors influencing seed recruitment in saltmarshes are seed availability and the biotic and abiotic conditions at the recruitment site, coupled with the biological characteristics of the seeds (Shumway and Bertness, 1992; Mackenzie, 2006). Seed availability is, in turn, dependent on seed production, and dispersal, including the seeds' ability to float and/or survive immersion in saline water (Huiskes et al., 1995; Rand, 2000; Elsey-Quirk et al., 2009). Water-borne dispersal of seeds of saltmarsh plants by tides is generally localised, with few seeds being transported into the marsh from elsewhere (Huiskes et al., 1995; Rand, 2000).

Sarcocornia quinqueflora is reported to flower in spring and summer (Carolin and Tindale, 1994), although flowering continues into autumn in the Hunter estuary and flowering time may depend on environmental conditions (Nelson, 1994). It is recorded to produce copious fertile seeds (Nelson, 1994) which are buoyant for more than 3 months in seawater and dispersal relies on water (Clarke and Hannon, 1970; Benson and McDougall, 1995; Mackenzie, 2006). Seeds germinate best in freshwater but optimal growth occurs in slightly saline water (7 ppt) (Clarke and Hannon, 1970). Field observations indicate that growth from seeds is most likely to occur in late winter and spring after rain (Clarke and Hannon, 1970; Winning, 2006), suggesting that seeds persist in the seed bank for at least several months, although there are no experimental data on this.

Sporobolus virginicus is reported to flower in summer (Carolin and Tindale, 1994) but also flowers into autumn and flowering time may depend on local environmental conditions (Nelson, 1994). As with most grasses, it is wind pollinated, but despite prolific flowering it produces few seeds (Clarke and Hannon, 1970; Nelson, 1994; Burchett et al., 1998). Smith-White (1988) suggested that a degree of sterility exhibited in the 'type 1 tetraploid' *S. virginicus* could be attributed to poor homology and meiotic irregularities. Seed dispersal is mostly by wind, although there is some evidence that seeds may also be water dispersed given their ability to survive immersion (Breen et al., 1977; Mackenzie, 2006). Seeds germinate best in freshwater on a damp substrate but can survive prolonged periods of immersion in salt water (Breen et al., 1977). Seeds have been collected from soil seed banks (Riddin and Adams, 2009) but there are no data on how long they may persist in the seed bank.

As part of the recent upgrade of Five Islands Road on the north-western shore of Lake Macquarie NSW, a small area of land which was unvegetated due to the influence of acid sulphate soil, was rehabilitated to saltmarsh in 2007. The opportunity was taken to design the rehabilitation in a manner that would allow testing of hypotheses about saltmarsh rehabilitation techniques to aid future restoration projects. The Five Islands project sought to establish lower marsh vegetation of *S. quinqueflora* and *S. virginicus* as mitigation for loss of some of this saltmarsh type. The aims of the experiment were to assess whether (1) placement of topsoil and (2) planting of seedlings on both topsoil and subsoil substrate facilitated establishment and growth of *S. quinqueflora* and *S. virginicus*. The experimental design was limited to these questions and did not address the broader issue of saltmarsh ecosystem restoration. Also, the site-specific nature of the study meant that there was no opportunity for replication.

METHODS

Study area

Five Islands is a cluster of deltaic islands at the mouth of Cockle Creek where it flows into Lake Macquarie NSW (Figure 1). While there were originally five discrete islands, this has changed as a result of past landfill activities in the area including the construction of Five Islands Road across the islands in the 1970s. The area now essentially comprises one main island in the middle of the creek and a number of previous islands on the southern bank of the creek that have been more or less joined by filling and siltation. The study site was a small area of bare land (approximately 600 m^2) on the south western edge of the new carriageway and adjacent to existing estuarine wetlands (Figure 2). The existing wetlands comprised mainly areas of mangrove dominated by *Avicennia marina* var. *australasica* and saltmarsh dominated by *S. quinqueflora* and *S. virginicus*, as well as two shallow ponds.

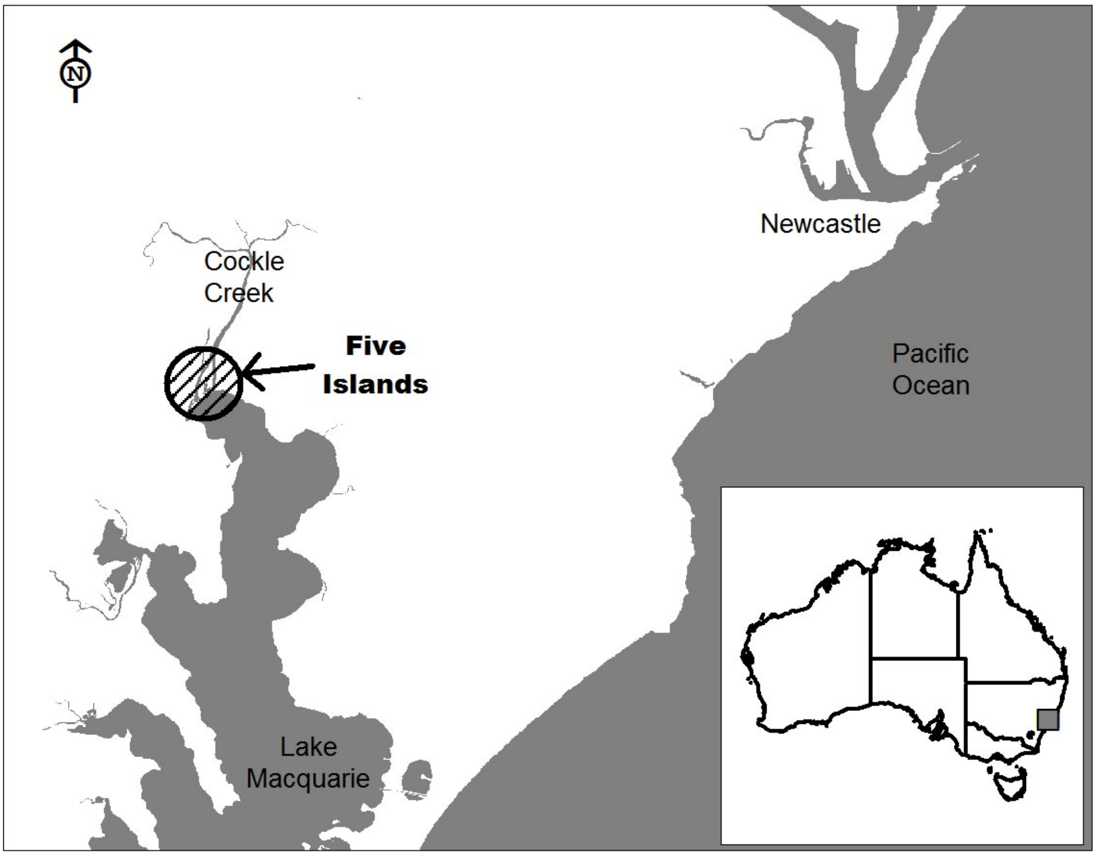

Figure 1. Location of the Five Islands area on the north western edge of Lake Macquarie, south of Newcastle on central coastal New South Wales, Australia. Approximate scale 1:175,000.

The elevation of the substrate in the study site was lowered by approximately 0.2 m to a level that was similar to adjacent saltmarsh (0.25 m AHD) using an excavator guided by a laser level. The levelled substrate had a medium clay field texture grade (McDonald and Isbell, 2009). All plantings were from cell-grown plants from a commercial nursery, grown from material collected at Five Islands. Once planted, they were watered with mains water by hose once a week for the first month, after which any water was from rainfall and tidal inundation.

Lake Macquarie has a very restricted astronomical tidal range of about 0.2m away from its entrance channel, although meteorological factors may add another approximately 0.2m to the range (Lake Macquarie Estuary Processes Study, 2005). As a consequence, saltmarsh areas may remain dry for extended periods. An analysis of tide levels for the Five Islands wetlands indicated that approximately 5% of high tides inundated the saltmarsh in the wetlands to some extent during 2007 and 2008 (G. Winning, unpublished data). At other times the site was either dry or inundated by rainfall runoff. Sporadic measurements between October 2007 and April 2008 revealed that the site was inundated by tidal water and/or rainfall for 69% of that time (though sometimes only partially inundated), and was dry 31% of that time (over 188 days). During that time water salinity, measured with a conductivity meter (Sper model 850038), ranged between 0.6ppt and 40.0ppt with a mean of 19.2ppt (n=9). While these figures are clearly unlikely to be representative of long term averages, they give an indication of the conditions under which the plants were growing.

Figure 2. Location of Five Islands study site. At the time of this photograph (January 2007) the new (western) carriageway had been completed and the old (eastern) carriageway was being upgraded. Planting of the study site was undertaken in May 2007. Approximate scale 1:1,200. (Aerial photograph used with permission of NSW Roads and Traffic Authority)

Experimental design

The experiment used a two-factor, two-level design to investigate the effects of topsoil addition (present, absent) and planting of seedlings (planted, unplanted) on the establishment of two saltmarsh plants, *S. quinqueflora* and *S. virginicus* on a subsoil substrate. Elevation of the substrate was introduced as a covariate to address unevenness of the levelled substrate which could affect plant establishment and growth through variation in inundation.

The study area (Figure 2) was divided into 144 plots of 2m x 2m. Bands of these plots were covered with approximately 20mm of sandy loam topsoil (approximately 80% sand, 10% silt and 10% clay fractions) such that two bands without topsoil (33 and 39 plots respectively) alternated with two bands with topsoil (each of 36 plots). While a random allocation of topsoil to plots would have been preferred, this was not really feasible without causing substantial damage to the substrate from the movement of wheelbarrows and people. As topsoil was placed on top of the levelled substrate, topsoil areas were nominally higher than non-topsoil areas although the overall unevenness of the substrate effectively countered this as discussed below. The relative elevation of the centre of each quadrat was recorded to the nearest centimetre using a laser level (ProShot L4+).

Planting treatments were randomly allocated to the plots such that half (72) of the plots were unplanted and half (72) were planted (half of these with *S. quinqueflora* and half with *S. virginicus*). Planting was at a nominal density of 10 plants/m^2 and was completed in May 2007. Due to edge effects, including physical damage by bicycles, along the eastern edge of the site during 2008, the row of plots along this edge were removed from analyses (Table 1). Plant cover in each plot was measured 6-monthly until November 2008 using a 1m x 1m quadrat, placed at the centre of each 2m x 2m plot to minimise edge effects. The quadrat was divided into 100 squares (0.1m x 0.1m) to assist in estimation of cover (% cover).

Table 1. Number of plots per treatment. Physical disturbance along the eastern edge of the study site in early 2008 necessitated removal of the row of plots along that edge from subsequent analyses.

	Initial (May 2007)			After Edge Disturbance (Nov 2008)		
	Topsoil	No Topsoil	TOTAL	Topsoil	No Topsoil	TOTAL
Sarcocornia quinqueflora	18	18	36	14	13	27
Sporobolus virginicus	18	18	36	13	16	29
Unplanted	36	36	72	28	25	53
TOTAL	72	72	144	55	54	109

Table 2. Results of ANCOVA for *Sarcocornia quinqueflora* cover in May 2009. Significant results are highlighted bold. Included in the right-most column are the results of the effects analysis, eta-squared (η^2), which is analogous to the coefficient of determination (r^2) in regression analysis and gives the percentage effect of each factor. The overall result (model) shows that the null hypothesis of no effect of the two explanatory variables (soil and plating) can be confidently rejected (i.e. the variables do bring a significant amount of information to explaining plant cover). Elevation had a significant effect on the cover of *Sarcocornia quinqueflora* and this effect was controlled for by the ANCOVA in determining the contributions of soil and planting to the observed variation in cover. Both of the main factors (soil and planting) had a significant effect on the cover of *Sarcocornia quinqueflora* but planting contributed far more (27.4%) to the cover than soil (7.4%). The large effect (56.4%) unexplained by the model (error) was due to the recruitment of *Sarcocornia quinqueflora* across plots of all treatment combinations (Figure 3).

Source	DF	Type III Sum of squares	Mean squares	F	Pr > F	η^2
Model	4	77198.9	19299.7	30.3	**< 0.0001**	
Elevation	1	10344.4	10344.4	16.2	**0.0001**	0.088
Soil	1	8658.3	8658.3	13.6	**0.0004**	0.074
Planting	1	32157.1	32157.1	50.5	**< 0.0001**	0.274
Soil*Planting	1	62.2	62.2	0.1	0.755	0.001
Error	104	66265.8	637.2			0.564

Statistical analyses

The contribution of topsoil presence and planting to percentage plant cover after 24 months was assessed using analysis of covariance (ANCOVA), which was used to control for the potential confounding influence of variation in elevation, with a type III sum of squares analysis in the SPSS 17 statistical package. The cover of the two plant species, *S. quinqueflora* and *S. virginicus*, were analysed separately. As differences in cover in relation to treatment were only assessed at 2 years post establishment, time was not included as a variable and thus the model did not require a repeated measures approach. The data were examined for violations of assumptions to ensure validity of the ANCOVA analysis. While ANCOVA is generally robust to violations of assumptions (Olejnik and Alinga, 1985), this robustness is reduced where more than one assumption is violated and/or in the case of unbalanced designs (Underwood, 1997; Gamst et al., 2008). Multiple violations were only evident for the *S. virginicus* datasets which were not improved by transformation of the data, so following the advice of Underwood (1997) the analyses were undertaken regardless of violations with the caveat that any marginal p-values needed to be examined for biological importance

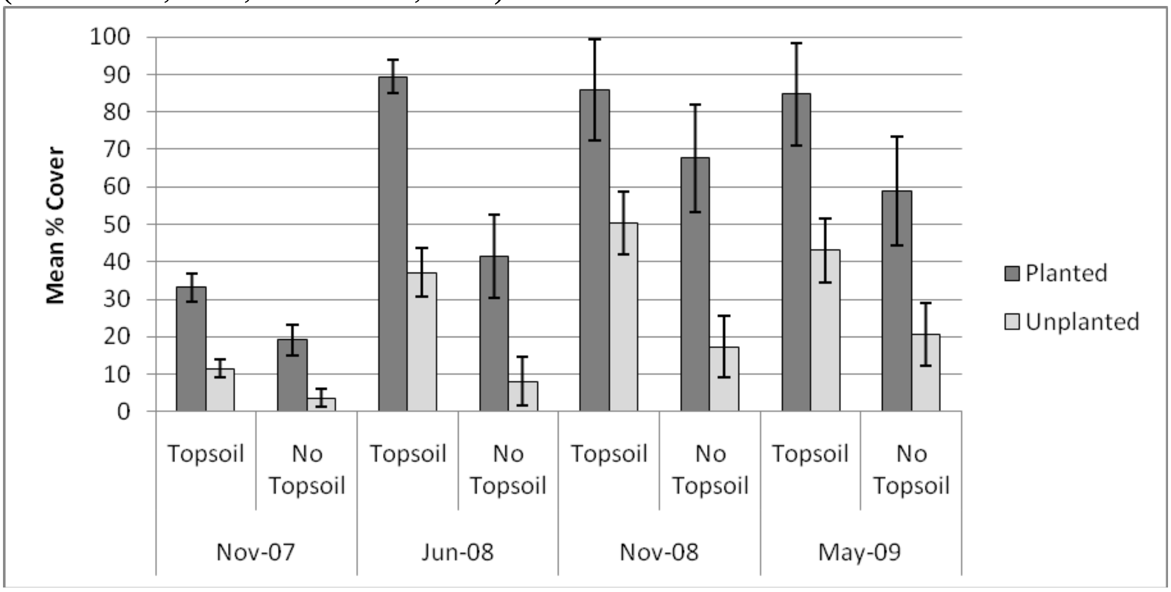

Figure 3. Mean percentage cover of *Sarcocornia quinqueflora* using estimated marginal means (i.e. means corrected for the covariate 'elevation'). Error bars are 95% confidence intervals. Planted plots achieved greater percentage covers than unplanted plots. Recruitment of plants is evident as increased cover over time in unplanted plots (lighter columns), especially on topsoil plots. Recruitment on no-topsoil plots was lower. Growth of both planted (darker columns) and unplanted plots was better with topsoil present.

RESULTS

The analysis of percentage cover of *S. quinqueflora* after two years (in May 2009) confirmed that the unevenness of the levelled substrate was a confounding factor for percentage cover of *S. quinqueflora* (df=1, F=16.2, p=0.0001) (Table 2). After controlling for the effect of elevation as a covariate, it was evident that both the presence of topsoil (df=1, F=13.6, p=0.0004) and planting (df=1, F=50.5, p<0.0001) enhanced the cover of *S. quinqueflora*, although planting contributed much more to cover (27.4%) than topsoil presence (7.4%) and elevation (8.8%) (Table 2). An examination of changes in cover of *S. quinqueflora* at 6-monthly intervals (Figure 3) revealed recruitment of plants into unplanted plots, initially presumably from seeds from outside of the study site (i.e. in the November 2007 sample) and then probably from seeds of initial plantings inside the study site as well (after the first flowering of plantings in early 2008).

For *S. virginicus* only the planting factor contributed significantly to increases in percentage cover after two years (df=1, F=470.3, p<0.0001), contributing almost all of the variation in cover for this species (81.1%) (Table 3). There was no difference in cover between topsoil and non-topsoil plots at any time during the experiment for planted plots, and the covariate 'elevation' had little effect on cover for this species (Table 3). A significant interaction between planting and soil in May 2009 suggests that the vegetative spread observed in unplanted plots may have been slightly improved by the presence of topsoil after two years, though this effect was considered negligible due to the marginal significance (df=1, F=5.1, p=0.026), violation of the homogeneity of variances assumption (Levene's test, p<0.0001) and, further, the low proportion of variance explained by this interaction (0.9%) (Table 3). Observations at 6-monthly intervals revealed there was no evident recruitment from seed, with the observed growth in unplanted plots being obvious vegetative spread from nearby planted plots (Figure 4).

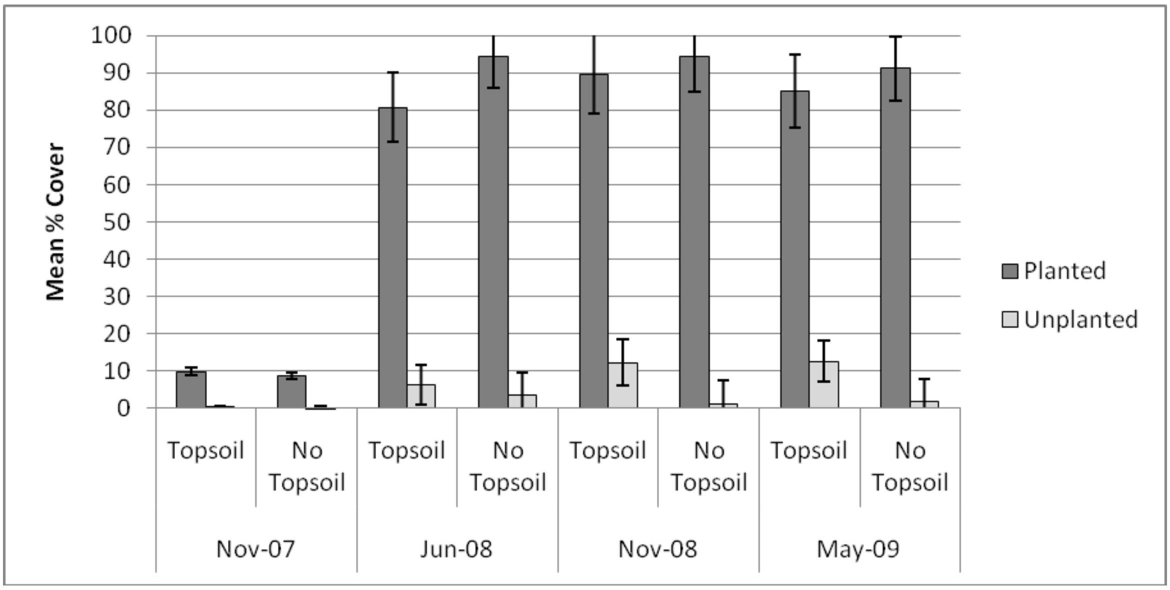

Figure 4. Mean percentage cover of *Sporobolus virginicus* using estimated marginal means (i.e. means corrected for the covariate 'elevation'). Error bars are 95% confidence intervals. After the first growing season (summer of 07/08) planted *Sporobolus virginicus* (darker columns) quickly covered both topsoil and no-topsoil plots but there was little recruitment to unplanted plots (lighter columns) during the study, and the recruitment that did occur was observed to be due to vegetative spread from adjoining planted plots.

Table 3.
Results of ANCOVA for *Sporobolus virginicus* cover in May 2009. Significant results are highlighted bold. Included in the right-most column are the results of the effects analysis, eta-squared (η^2), which is analogous to the coefficient of determination (r^2) in regression analysis and gives the percentage effect of each factor. The overall result (model) shows that the null hypothesis of no effect of the two explanatory variables (soil and plating) can be confidently rejected (i.e. the variables do bring a significant amount of information to explaining plant cover). Elevation had a negligible effect on the cover of *Sporobolus virginicus*. Of the main factors only planting had a significant effect on the cover of *Sporobolus virginicus* contributing almost all of the variation in cover (81.1%). The marginally significant effect of the interaction between soil and planting is considered to be unreliable due to the violation of the homogeneity of variances assumption; this conclusion is supported by the low η^2.

Source	DF	Type III Sum of squares	Mean squares	F	Pr > F	η^2
Model	4	140951.0	35237.7	121.0	< **0.0001**	
Elevation	1	166.1	166.1	0.6	0.452	0.001
Soil	1	84.7	84.7	0.3	0.591	0.001
Planting	1	136973.9	136973.9	470.3	< **0.0001**	0.811
Soil*Planting	1	1478.1	1478.1	5.1	**0.026**	0.009
Error	104	30287.3	291.2			0.179

DISCUSSION

Topsoil

This study showed a clear advantage in the placement of topsoil for the establishment of *S. quinqueflora* on subsoil substrate, both for plantings and recruitment by seed. Similar results were obtained for an earlier experiment on Kooragang Island in the Hunter River estuary, NSW (Nelson, 2006). However, *S. quinqueflora* has been also successfully established, both by planting and recruitment, at other saltmarsh creation sites without the application of topsoil, such as at Sydney Olympic Park, NSW (Burchett et al., 1998; Paul and Farran, 2009) and at a number of sites in the Hunter River estuary (Streever and Genders, 1997; MacDonald, 2001; Laegdsgaard, 2003; Nelson, 2006). Data from the present study suggest that recruitment of *S. quinqueflora* would be faster on sites treated with topsoil compared with those left untreated (Figure 3), although the study was not specifically set up to test this.

Topsoil addition was found to be largely unimportant for increasing *S. virginicus* percentage cover, with the exception of marginal increases of vegetative spread to unplanted topsoil plots after two years which, even if reliable, is perhaps insufficient benefit to warrant a recommendation of topsoil addition for this species. This contrasts with the results of Nelson (2006) who found the growth of *S. virginicus* in topsoil plots was triple that of subsoil plots in the first year of his experiment but slightly less important after 4 years. As both the Five Islands site and Nelson's (2006) Kooragang Island site had a clay subsoil substrate and used a loamy topsoil, the most likely explanation for the different results for this species was the depth of placed topsoil. The current study used a thin layer of top soil (approximately 2cm) whereas Nelson (2006) used a much deeper layer of topsoil (30-40cm). *S. quinqueflora* is a shallow-rooted, decumbent, spreading perennial (Nelson, 1994; Jacobs, 2000; Nelson, 2006) and would be well suited to growth in a shallow topsoil layer. *S. virginicus*, however, is a creeping rhizomatous and stoloniferous perennial with an aggressive, relatively deep root system (Jacobs and McClay, 1993; Nelson, 1994, 2006) and would be expected to grow better in deeper topsoil, although it is also known to grow in shallow soil situations.

Planting

The cover of plots planted with *S. quinqueflora* contributed significantly to the overall cover of this species in May 2009. However, there was also a substantial contribution from recruitment of *S. quinqueflora* into unplanted plots (Table 2, Figure 3). Observations during sampling suggested that little of this recruitment was due to vegetative spread from adjacent planted plots and the recruitment was due to germination of seed. It is important to note that by November 2008 the planted *S. quinqueflora* had flowered and set seed, thus recruitment by then was probably *in situ* as well as *ex situ*.

In contrast, all of the growth of *S. virginicus* was by vegetative means and there was no evident recruitment by seed of this species. Instead, it required active planting to establish in the rehabilitation area during the time frame of this study. In his study on Kooragang Island, even after four years Nelson (2006) found that the proximity of *S. virginicus* recruitment plots to *S. virginicus* planted plots was a significant predictor of recruitment, indicating that *S. virginicus* recruitment was largely, if not entirely, due to vegetative spread. Thus, recruitment and subsequent establishment of *S. virginicus* within a created saltmarsh in the absence of planting may take many years, even in proximity of nearby populations.

At the Five Islands site, both *S. quinqueflora* and *S. virginicus* occurred along the edge of the study site and elsewhere in the adjoining wetland. The ready recruitment of *S. quinqueflora* at the Five Islands site is likely to be a result of its recorded copious seed production and its recorded buoyancy (Clarke and Hannon, 1970; Nelson, 1994), which would have likely led to a substantial supply of seeds within the study site. The lack of recruitment of *S. virginicus*, on the other hand, is likely a reflection of its recorded poor seed production and germination characteristics (Clarke and Hannon, 1970; Nelson, 1994) but it is not known to what extent factors relating to seed dispersal may have contributed to the lack of recruitment. It is also possible that abiotic conditions at the study site inhibited germination of *S. virginicus*, though this is considered unlikely given the ready vegetative growth of *S. virginicus* at the site. To further understand differences in seed recruitment, research is required on the phenology of seed production and dispersal for both *S. virginicus* and *S. quinqueflora*, and indeed for most NSW saltmarsh species.

CONCLUSIONS

Few projects involving saltmarsh creation or rehabilitation are supported by adequately designed and implemented monitoring (Grayson et al., 1999; Chapman and Underwood, 2000; Department of Environment and Climate Change NSW, 2008; Kelleway et al., 2009), and even where some monitoring is undertaken, the results do not always find their way into the published literature. Accordingly, past projects are generally unable to provide the data to answer key questions that may aid future projects. This study sought to answer at least two questions: whether topsoil addition and assisted planting of seedlings assist establishment of two dominant saltmarsh species in NSW estuarine marshes. The results suggest that *S. quinqueflora* will readily colonise from proximate seed sources but that planting may provide a short term advantage for establishment. Placement of a layer of topsoil, at least where there is a clay substrate, will assist growth and recruitment of *S. quinqueflora*. For *S. virginicus* however, topsoil addition is of little benefit though active planting would greatly assist its establishment on a creation site, as reliance on recruitment from seed may mean that many years transpire before establishment is achieved. Burchett *et al.* (1998) also found species-specific results with several rare species surviving transplanting but not establishing by recruitment, and they recommended that these species may need to be planted at restoration sites even if more common species are allowed to establish by recruitment. Rather than a “one-size-fits-all” approach to saltmarsh restoration, a knowledge of target species autecology is essential in facilitating the development of a diverse marsh community.

This study demonstrates the value of incorporating into a wetland restoration projection an experimental design that tests specific hypotheses. Even though the study was limited by being restricted to a single site, and the small size of the site did not permit testing of more levels of the treatment factors, the results provide potentially useful information to guide future restoration projects. While designing a restoration project to experimentally test hypotheses may compromise the completeness or rate of establishment of vegetation on a restoration site, this can be greatly outweighed by the usefulness of the information derived from the project to aid future restoration initiatives.

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