

Seagrass Rehabilitation in Adelaide
Metropolitan Coastal Waters
V. Large Scale Recruitment Trial



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by
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TABLE OF CONTENTS

TABLE OF CONTENTS.....	1
ACKNOWLEDGEMENTS.....	2
EXECUTIVE SUMMARY	3
1 INTRODUCTION	5
1.1 Background.....	5
1.2 Objectives	7
2 METHODS	9
2.1 Site Description	9
Physical Conditions.....	9
Biotic Conditions.....	11
2.2 Experimental Design	11
2.3 Methods of Analysis.....	14
3 RESULTS	15
3.1 Effect of distance from seed source on recruitment levels.....	15
3.2 Plant length.....	17
4 DISCUSSION.....	21
4.1 Effect of distance from seed source on recruitment	22
4.2 Magnitude of recruitment and mortality.....	23
4.3 Recruitment unit success	25
4.4 Timing of recruitment event and interaction with mortality	25
5 CONCLUSIONS AND FUTURE DIRECTIONS.....	27
5 REFERENCES	29

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EXECUTIVE SUMMARY

A major factor impeding the rehabilitation of seagrass beds is the instability of the substrate to which juvenile seedlings must attach in order to recruit. The use of hessian sandbags to provide a stable substrate has been investigated and has shown promise in the case of at least one seagrass species (*Amphibolis antarctica*). However, whilst success has been achieved on recruitment units placed close to existing meadows, any attempt at broad-scale rehabilitation would involve a larger area and consequently bags being placed at varying distances from the seedling source. This experiment involved a large-scale (1 hectare) deployment of recruitment units and examined variability in recruitment success as a function of distance from the meadow.

We found that:

- Initial recruitment (after 4 months) varied substantially between bags, from 0 to 12 individuals per recruitment unit, averaging 1.35 individuals per bag.
- Only 65% of bags supported recruits after 4 months submersion.
- After 8 months, average recruitment success had changed little (an average of 1.4 individuals/bag)
- Recruitment success to 13 months appeared to increase to 3.7 individuals per bag. This was the result of an influx of new recruits, indicating that bags are useful for more than a single recruitment event.
- 30% of recruitment units actually increased the number of individuals on them between the 4 month (January) and 8 month (April) surveys, indicating the presence of potential recruits during this time, which has not previously been considered as a recruitment period.
- There was no significant effect of distance from the meadow on recruitment success after 4 months, 8 months or 13 months.

The very low initial recruitment rates may be an indicator that it was a meadow some distance away that acted as the donor bed rather than the adjacent bed. However, if the lack of effect of proximity of seedling source is a real effect, repeated in years of high recruitment, then this is encouraging as it indicates that broad scale rehabilitation

efforts will not require a high degree of precision in placement of recruitment units. This would make vessel deployment a viable proposition.

The consistency in population size between 4 and 8 months may reflect low mortality or, as is indicated from monitoring individual bags, be an indication of a dynamic situation whereby recruits are lost and replaced by others throughout this period. An initial flush of recruits is probably being thinned out by mortality, but a “trickle” rate of recruitment throughout the year is able to replenish these and cover the loss. Whilst this is a concerning scenario (because it implies that juveniles are not retained for long enough to establish a root system) there is no indication that recruitment outside of the major recruitment event is of great magnitude. Thus in previous years of higher initial recruitment, the great majority of surviving recruits are more likely to have persisted from the initial recruitment event.

There is clearly a need to conduct further investigation in a different year to confirm the findings under conditions of high initial recruitment. This would require a small scale experiment where a series of replicate bags could be placed at differing distances from the bed edge and surveyed over the ensuing period. There is also a need to identify the nature and cause of the population fluctuations, which have been apparent. This will require an intensive approach to be applied to a small number of bags and the individuals upon them.

1 INTRODUCTION

1.1 Background

The loss of seagrass meadows due to increased human influence in the coastal region has been recognised as a global issue for some time (Ehrenfield, 2002). Walker et al. (2006) estimated that 18% of the world's seagrasses have been lost as a result of human impacts. This phenomenon has been observed locally off the Adelaide coast, where over 5200 ha of seagrass meadows have been lost since the 1950s (Seddon, 2002). Various anthropogenic stressors have been suggested as causes for seagrass loss, with the most recent studies identifying excessive nutrient loads from effluent treatment plants and industry as the most likely causes (Bryars et al., 2006; Collings et al., 2006a & 2006b).

Substantial efforts have been made to improve the environmental situation and halt the loss of these important beds. However, the slow growth rates typical of the major meadow-forming taxa of Adelaide (*Posidonia* and *Amphibolis*; e.g. Shepherd et al., 1989; Marbà and Duarte, 1998, Marbà and Walker, 1999), and the alteration of the environment, from stabilised seagrass bed to unstable bare sand, make recolonisation a difficult process. Additionally, without existing seagrass meadows to ameliorate hydrodynamic energy (Fonseca and Calahan, 1992; Reusch and Chapman, 1995; Worm and Reusch, 2000), disturbance through storms is more likely. There is evidence that some seagrasses may react to increasing water velocity by increasing the growth rate of roots and strength of stems, (Peralta et al., 2006), but this finding was made using flume tanks (with relatively laminar flow) where the maximum velocity reached only 0.35 m s^{-1} . It is unlikely that such a finding is relevant to the Adelaide situation, where water movement is far more turbulent and severe. Arnaud-Haond et al. (2007) contend that the lack of success of *Posidonia oceanica* recruitment may be due to the fact that it is only those seeds trapped close to the parent plant that are successful. A key benefit of the region close to the parent plant is the reduced energy of an area already colonised by adult seagrass (Campbell, 2003).

Considerable effort has been expended on artificially recolonising denuded areas. Methods attempted included transplantation of adults and seedlings, germination and subsequent outplanting of seeds and, most recently, a suite of techniques designed to

facilitate natural recruitment of juveniles. Facilitation of natural recruitment, through the provision of an artificial hessian substratum, appears to provide the best chance of restoring Adelaide's seagrass beds (Wear et al., 2006). Hessian provides an anchoring point for the “grappling hook” apparatus (see Figure 1) of juvenile *Amphibolis* to attach to, allowing them to resist water movement until more substantial root systems are grown. Specifically, a 20kg hessian sandbag with a coarseweave hessian mesh sewn to it (see Figure 2) has been shown to be the most cost effective and efficient in terms of recruitment.

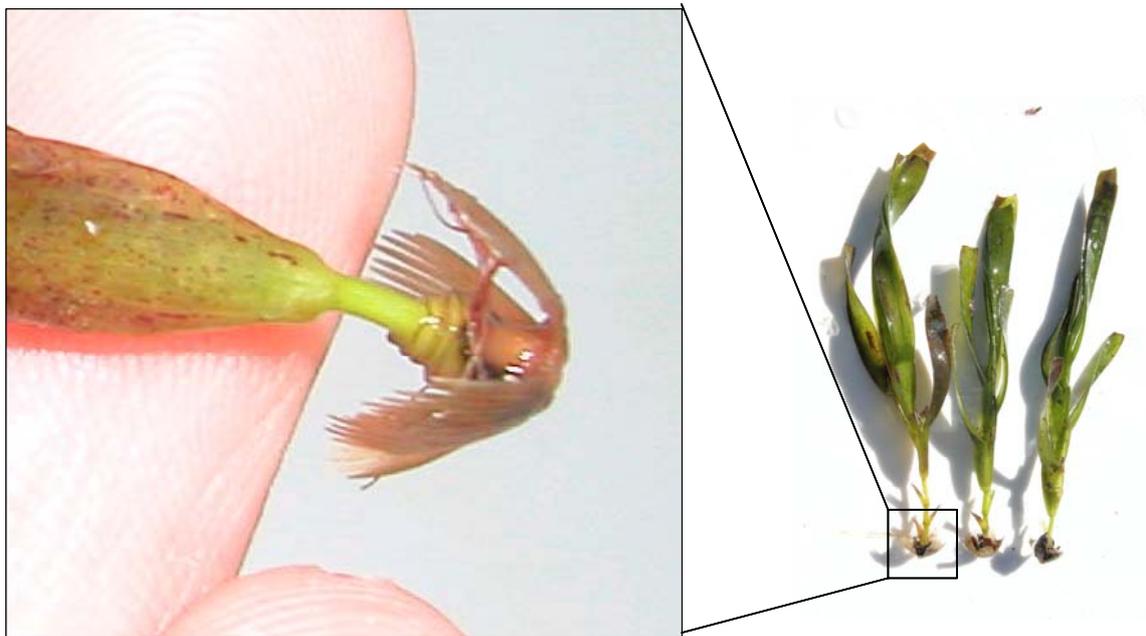


Figure 1. “Grappling hook” apparatus of *Amphibolis* juveniles which assists with anchoring the plant to the substratum before roots are able to do so. Photo: R Wear.

Previous work on the Adelaide coast is documented in a series of publicly available reports (Seddon et al., 2004 & 2005; Wear, 2006; Wear et al., 2006; Collings et al., 2007). These may form a useful background, but will not be reviewed in any depth here.

An important issue facing managers proposing large-scale rehabilitation through deployment of hessian recruitment units is the effect of proximity of the seedling source to the units themselves. To date, studies in the region have concentrated on large-scale geographic and temporal variability (Wear et al. 2006; Collings et al., 2007). In all cases, recruitment units have deliberately been placed in close proximity to the existing seagrass meadow. However, if the technique is to be used on a broad scale, it is economically unfeasible to locate units using divers to put them near

meadow edges. Rather, it will be necessary to deploy from a vessel, simply dropping the units in the area to be rehabilitated. An important question then is whether such haphazard placement will result in a reduced chance of successful recruitment as bags are, in many cases, likely to be some distance from the meadow edge and therefore seedling source.

Previous work (Collings et al., 2007) has indicated that distance from seed source may be an important factor determining the level of recruitment onto recruitment units, but experiments to date have not been designed specifically to test the hypothesis at a broad scale. A number of other issues may also alter the success of large scale deployment of recruitment units compared to smaller scale experimental studies. Deploying a large number of units may increase competition for seedlings, resulting in decreased success per bag. The physical environment may also be different in larger areas of bare sand, resulting in poorer conditions for recruitment and survival, for instance due to sand movement. All of these factors mean that a large scale trial (or series of trials) is needed before the method can be employed for broad scale seagrass rehabilitation.

Thus, this study represents a trial broad scale deployment of recruitment units over a 1 ha (100m x 100m) area of sand on the inshore margin of a seagrass meadow. This allows an assessment to be made of the effect of distance from the meadow across that area. By assessing a series of marked units at three points in time, it is also possible to draw inferences about the dynamics of the recruit populations.

1.2 Objectives

Specifically, this study aimed to:

- 1) To test the effect of distance from donor bed on recruitment unit success.
- 2) Quantify the recruitment success of the 2006 recruit population in the context of previous years.
- 3) Make an evaluation of the timing of the recruitment window for *Amphibolis antarctica* in this region.



Figure 2. Deployment of recruitment units from the deck of the R.V. Ngerin. Close-up of individual unit, showing coarsweave hessian wrapped around and sewn to a 20kg sandbag.

2 METHODS

2.1 Site Description

Physical Conditions

This study was conducted on the inshore edge of the *Amphibolis* meadow off Grange at a depth of approximately 8 m (S 34 54.249' E 138 28.248'; Figure 3). This is adjacent to the “Site 1” studied by Wear et al., (2006), and the “Grange 8 m” site of Collings et al., (2007). Recruitment facilitation units were placed at these sites in September 2004 and 2005 respectively. The current study was initiated in September 2006.

Surface water temperature within the area varies seasonally between 11.0 °C and 26.6 °C, while total dissolved solids generally varies between 33.0 and 38.8 µgL⁻¹. Other water quality parameters are provided in Table 1. Values are relatively typical for the Adelaide metropolitan region.

Table 1. Surface water quality of the Grange region. These data were collected from Grange jetty between 1996 and 2003 by the Environment Protection Authority, South Australia.

Temperature (°C)	11.0 - 26.6
TDS (g L ⁻¹)	33.0 –38.2
pH	7.46 – 8.35
Turbidity (NTU)	0.337 - 24
Ammonia (mg L ⁻¹)	0.005 – 0.19
Nitrate (mg L ⁻¹)	0 - 0.178
Nitrite (mg L ⁻¹)	0.005 - 0.02
Phosphorus (mg L ⁻¹)	0.018 – 0.68

The light climate of the Adelaide metropolitan coast is typified by relatively turbid water, particularly during storm periods when surface runoff contributes to a nearshore plume of turbidity. Photosynthetically active radiation (PAR) is generally highest around solar noon, and demonstrates seasonal variability, with higher irradiance in summer than winter (Figure 4).

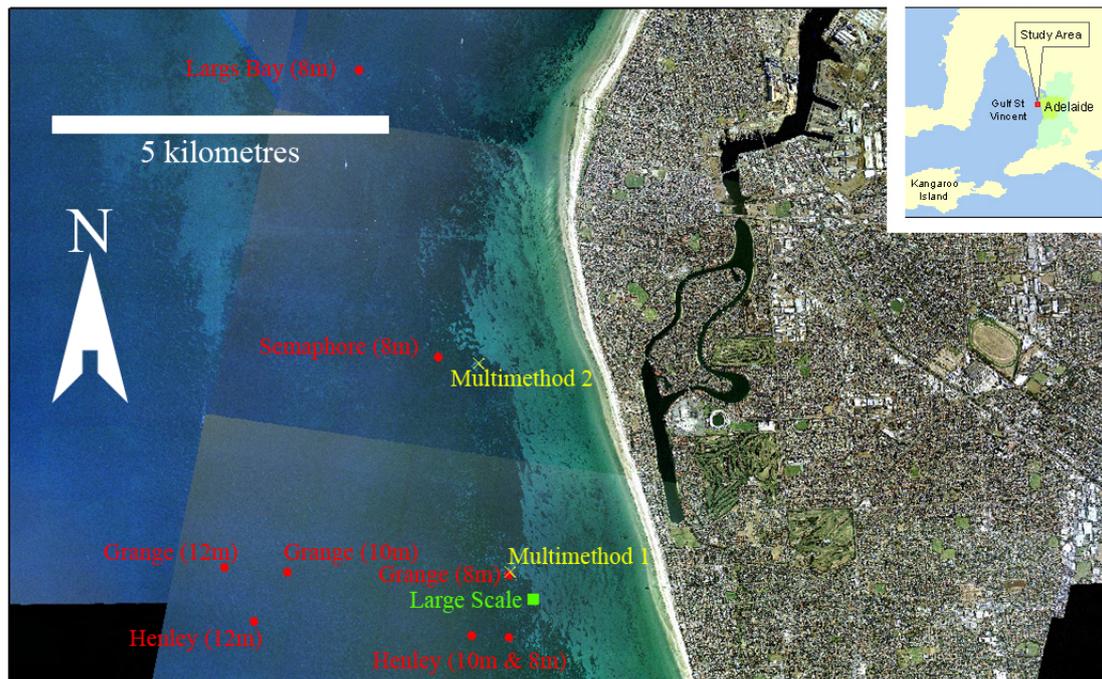


Figure 3. The large scale site of the current study is shown in green. It is located on the edge of the seagrass bed at Grange. Sites used in previous studies are shown for geographic reference. Note that immediately adjacent to the current site are “Site 1” of Wear et al., (2006) (in yellow) and the “Grange 8m” site of Collings et al., (2007) (in red). Aerial photograph from S.A. Department for Environment and Heritage.

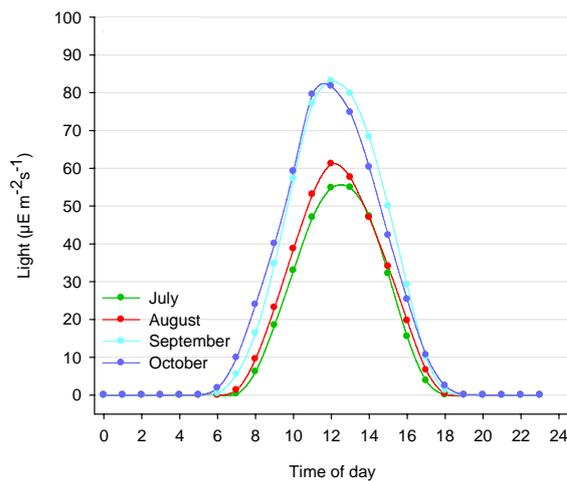


Figure 4. Average light availability at the seafloor (7 m) of two nearby (Henley and Grange) sites, during July, August, September and October 2005 (from Wear et al., 2006).

Biotic Conditions

The site consists of a one hectare square area (100 m x 100 m), sited on the edge of a meadow of relatively dense *Amphibolis antarctica*. The square is set into the meadow by 10 m and extends out of the meadow by 90 m across largely bare sand (Figure 4). Biotic assessment of the area was carried out by video survey, using an underwater video camera attached to a GPS recording device. This was subsequently converted to a GIS map using Habitat Mapper (an in-house SARDI program) and ArcGIS (ver 9.2, ESRI). Transects for assessing recruitment (see following section) were situated on the southern portion of this square, leaving the northern half undisturbed, for later analysis.

2.2 Experimental Design

Recruitment facilitation units were constructed in a similar manner to previous years. They consisted of 75 x 45 cm hessian bags, with a coarse jute weave (“Soil Saver” – JA Grigson Trading Pty. Ltd.) wrapped around and sewn to the bag. Sewing of jute to the hessian bag was carried out by Bradey Canvas Company. These were filled with 20 kg of playpit sand and sewn shut by Lonsdale Sand and Metal supplies.

1000 of these recruitment units were dropped from the RV Ngerin on August 29th 2006 over a 100 m x 100 m area. The area was chosen for a relatively straight and easily defined meadow edge, with no significant pockets existing in the bare sandy region toward the shore. The 100 m width of the recruitment area began 10m inside the meadow and continued to a point 90 m outside of the inshore margin (Figure 5). A relatively even spread of bags was achieved by dropping at a controlled rate, but some minor variability is inevitable as bags will fall through the water on different trajectories. This provided an average “sowing” density of 1 bag per 10 m² on the seafloor.

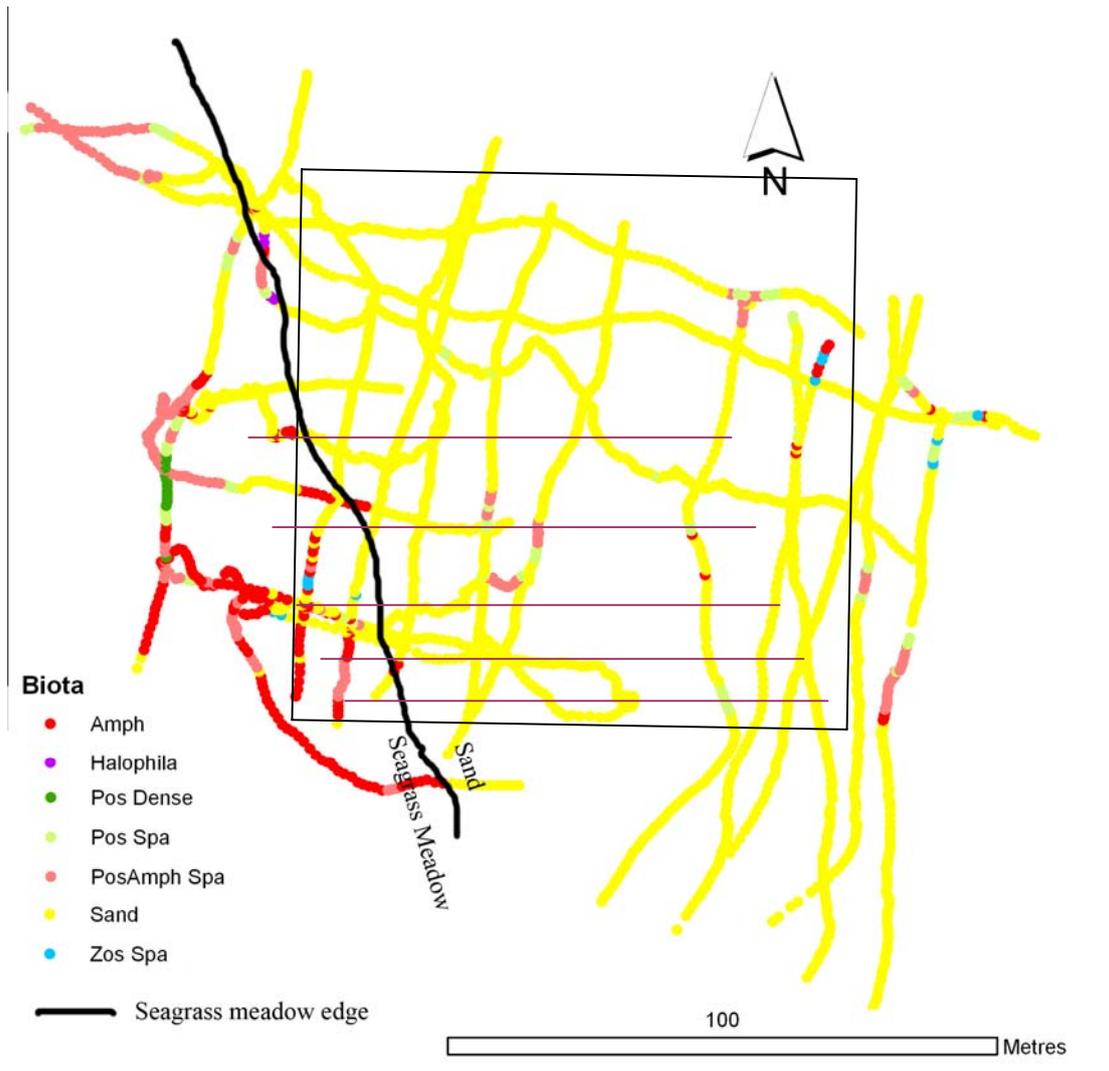


Figure 5. Video analysis of the area sewn with bags. With rare exceptions, the sandy area to the east of the seagrass meadow contains no *Amphibolis*. This line defining the edge of the bed and estimates of position are placed on subjectively. All other points are mapped from GPS on a boat trailing a video camera. This trailing introduces variability into the estimates of position. The actual line of the edge of the seagrass meadow was well defined – see Figure 6. Transects (marked in purple) began 10 m into the bed and extended 70 m beyond the edge of the bed. “Amph” = *Amphibolis*, “Pos” = “*Posidonia*”, “Zos” = *Heterozostera*, “Spa” = Sparse.

Subsequent to deployment from the surface, on September 4th 2006, a series of bags were moved slightly so that they were aligned along 5 transects within the 100m x 100m area. On each of these transects, a recruitment unit was placed at the following points

- | | |
|------------------------------|------------------------------|
| a) 10m inside the meadow | e) 20 m away from the meadow |
| b) on the meadow edge | f) 40 m away from the meadow |
| c) 5 m away from the meadow | g) 60 m away from the meadow |
| d) 10 m away from the meadow | h) 90 m away from the meadow |

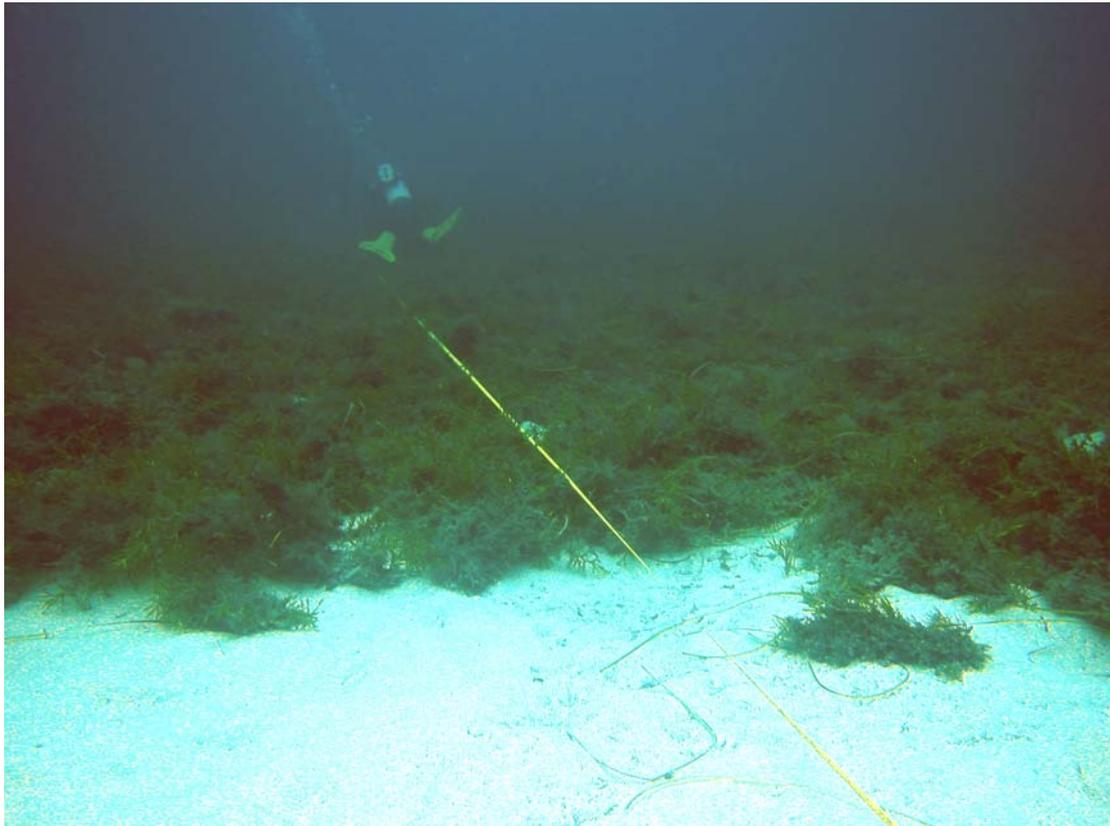


Figure 6. The seagrass meadow showing a well defined edge.

Each bag was marked with a stake 1 m away so that it could be readily identified on subsequent surveys. Any other bag that had fallen close to this point was moved away so as to remove the possibility of confusion. Whilst some of the deployed bags did have recruits on them at this stage, none of those used on the transects had recruits attached.

The bags were resurveyed on January 16th 2007 (after approximately 4 months), April 23rd (after 8 months), and finally (after 13 months) on October 9th. On the final occasion, a single bag (inside the meadow) could not be relocated, and had to be treated as missing data.

On each occasion, the length of every *Amphibolis* stem was measured and recorded. In the initial survey, each stem represented a single recruit. In later surveys, it was possible that a single recruit possessed two or more stems. It was considered important not to disturb the plant and substrate, so no attempt was made to dig the plant out and clarify this situation. However, the majority of stems were well spaced,

indicating separate plants, and the small average size of plants also makes it likely that each plant was represented by a single stem.

Although a comparison of average height of seedlings might be misleading as an influx of juveniles would mask any growth of the original recruits, a brief model was prepared to examine the maximum possible growth. Almost always there were more recruits on a given bag after 13 months than after 4 months. It was assumed that the larger number represented the original surviving recruits plus the new recruits from the next year. It was further assumed that if the originals survived, then they should be represented by the largest individuals after 13 months (and the remaining individuals are the new recruits). Thus it was possible to estimate the maximum possible growth rate by pairing up the size of the original recruits after 4 months with the largest recruits after 13 months and calculating the difference in size. Note that if the assumptions are invalid, this can only result in overestimation of growth rates.

2.3 Methods of Analysis

The number of individuals, average length of individuals and the total length of all individuals on a recruitment unit were measured. Changes across time and the effect of distance from the *Amphibolis* meadow edge were analysed using two way mixed model ANOVAs, with time treated as a repeated measure (as the same bags were measured in each instance) and distance from seedling source as a between-group factor. Where necessary, the dependent variables were $\ln(x+1)$ transformed to improve homogeneity of variance conditions. This transformation was used as it provided the most homogeneous variance between groups (as defined by Levene's test). In addition to simple column graphs of these factors, histograms were constructed to visualise the size structure of the recruit populations. SPSS version 14 (SPSS, 2005) was utilised for statistical analysis.

3 RESULTS

3.1 Effect of distance from seed source on recruitment levels

Whilst there was a significant effect of time, with overall higher densities after 13 months (3.7 individuals per recruitment unit c.f. 1.4 after 4 and 8 months; Figure 7, Table 2), a significant interaction effect indicated that this effect of time did not occur at all distances from the meadow edge. Indeed, in the meadow and on the edge of the meadow, there was no difference in recruit density between the different times. However, the difference was clear on those recruitment bags located 5 or more metres from the meadow edge. In these instances, there were more recruits after 13 months than after 4 or 8 months. There was no significant mortality evident (as indicated by decreasing recruit density) between the 4 and 8 month surveys. Importantly, there was no effect of distance on overall recruitment success ($P=0.895$; Table 2). There was no significant effect of distance from meadow edge on recruitment density at any point in time (Figure 7, Table 3).

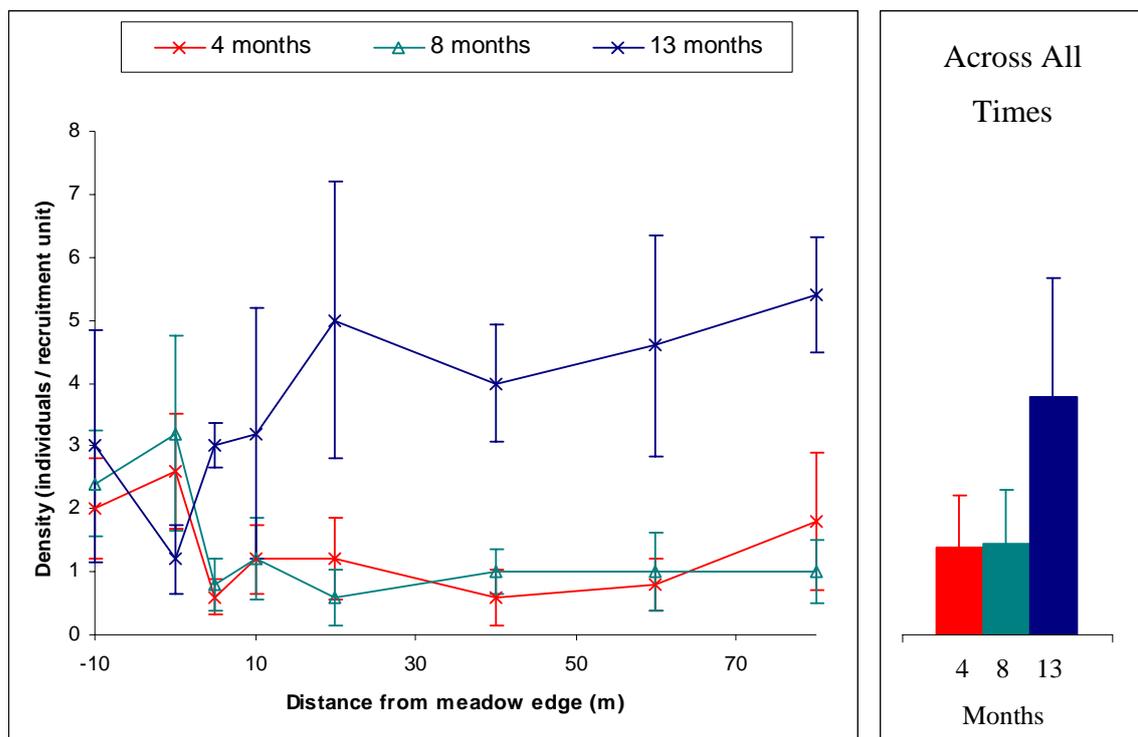


Figure 7. Density of recruits per recruitment unit as a function of distance from seed source (edge of meadow) and of time since placement of recruitment units. Error bars are standard error with 5 replicates.

Table 2. Results of mixed model ANOVA assessing the effect of time (as a repeated measure) and distance (as a between-group factor) on density of *Amphibolis* recruits. Data were (ln+1) transformed to improve homogeneity of variances. The assumption of sphericity was not violated (Mauchly's W; P=0.216). Cox's test of covariance of matrices was non-significant. PET = partial Eta-square, a measure of effect size.

Within Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Time	11.918	2	5.959	19.536	<0.001	0.387	1.000
Time x Distance	7.917	14	0.566	1.854	0.050	0.295	0.877
Error	18.913	62	0.305				

Between Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Distance	1.422	7	0.203	0.369	0.913	0.077	0.143
Error	17.044	31	0.550				

Table 3. Individual one way ANOVA results demonstrating no significant effect of distance from bed on recruit density at any point in time. Data were (ln+1) transformed. The homoscedasticity assumption was not violated for 4 and 13 month datasets, but the 8 month dataset was significant at p=0.021 (Levene's test). This is probably due to the high variability associated with the bed edge (0 m) units and could not be remedied by transformation.

SOURCE	SS	df	MS	F	P	PET	Power
At 4 months							
Distance	2.710	7	0.387	1.141	0.363	0.200	0.409
Error	10.863	32	0.339				
At 8 months							
Distance	2.724	7	0.389	1.058	0.412	0.188	0.380
Error	11.768	32	0.368				
At 13 months							
Distance	4.353	7	0.622	1.422	0.232	0.243	0.504
Error	13.558	32	0.437				

3.2 Plant length

Average plant length was not significantly affected by the distance from the edge of the seagrass meadow (Figure 8; ANOVA $P=0.33$; Table 4). However, there was a significant difference overall (i.e. regardless of distance from seed source) between the average stem length at different times (Figure 8; ANOVA $P<0.001$, Table 4). The average length of stems was shorter after 13 months than after only 4. Furthermore, there was no significant interaction between time and distance (ANOVA $P = 0.349$; Table 4). Thus the influence of time on average stem length can be considered a consistent effect.

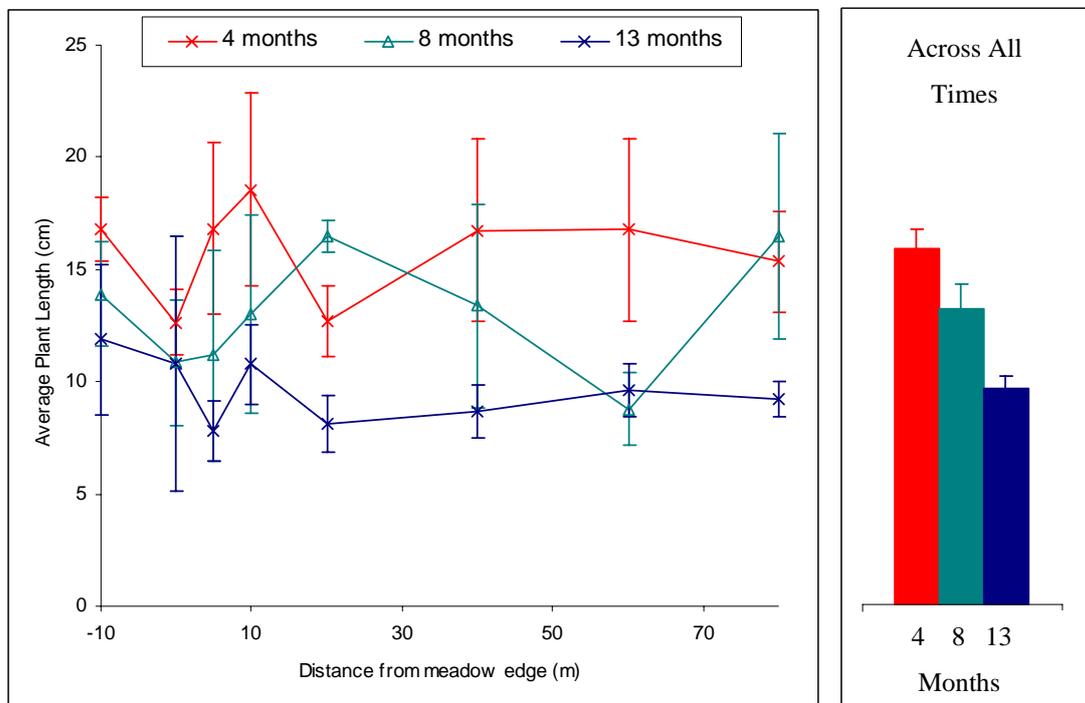


Figure 8. Average length of individual recruit stems as a function of time and distance from seed source. Error bars are standard error.

Table 4. Results of mixed model ANOVA assessing the effect of time (as a repeated measure) and distance (as a between-group factor) on the average length of *Amphibolis* recruit stems. Data were $(\ln+1)$ transformed to improve homogeneity of variance. Nevertheless Levene's test indicated significant heterogeneity of variance in the 8 month ($p=0.006$) and 13 month ($p<0.001$) datasets. The assumption of sphericity was not violated (Mauchly's W ; $P=0.442$). Cox's test of covariance of matrices was non-significant.

Within Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Time	1.704	2	0.852	16.036	<0.001	0.696	0.997
Time x Distance	0.919	14	0.066	1.235	0.349	0.553	0.430
Error	0.744	14	0.053				

Between Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Distance	.865	7	0.124	1.414	0.330	0.586	0.283
Error	0.612	7	.087				

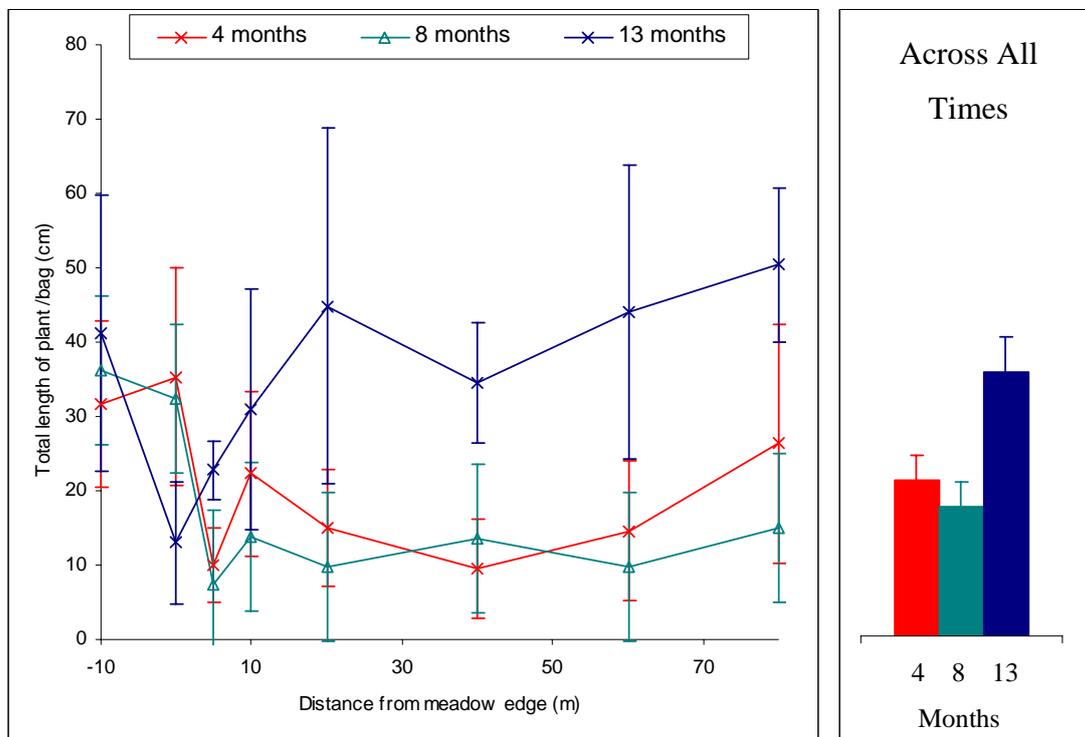


Figure 9. Total length of *Amphibolis* stems per recruitment unit as a function of time and distance from seed source. Error bars are standard error with 5 replicates.

Table 5. Results of mixed model ANOVA assessing the effect of time (as an repeated measure) and distance (as a between-group factor) on the total length of *Amphibolis* stems per recruitment unit. Data were (ln+1) transformed to improve homogeneity of variance. The assumption of sphericity was not violated (Mauchly's W; P=0.890). Levene's test indicated homogeneity of variance at all times except at 13 months (Levene's test P=0.038). Cox's test of covariance of matrices was non-significant.

Within Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Time	26.091	2	13.045	6.215	0.003	0.167	0.879
Time x Distance	30.883	14	2.206	1.051	0.418	0.192	0.582
Error	130.139	62	2.099				

Between Subjects Comparisons

SOURCE	SS	df	MS	F	P	PET	Power
Distance	8.245	7	1.178	0.356	0.920	0.074	0.139
Error	102.513	31	3.307				

The total length of stems per recruitment unit provides a surrogate for biomass. Again, there was no effect of distance from bed edge (ANOVA P=0.92; Table 5), but there was an effect of time (ANOVA P=0.003; Table 5). Greater total length of stems was evident in the later (13 month) surveys than in those conducted earlier (Figure 9). No interaction effect was evident (ANOVA P=0.418; Table 5), indicating that the effect of time was consistent, regardless of distance from the edge of the meadow. However, this is likely to be an effect of low power of the test, as it is clear from Figure 9 that the general tendency towards higher total stem length is not evident for those bags in, or on the edge of, the seagrass meadow.

Recruitment unit success (defined as the proportion of bags supporting one or more *Amphibolis* plants) across all bags was 65% after 4 and 8 months and increased to 87% after 13 months.

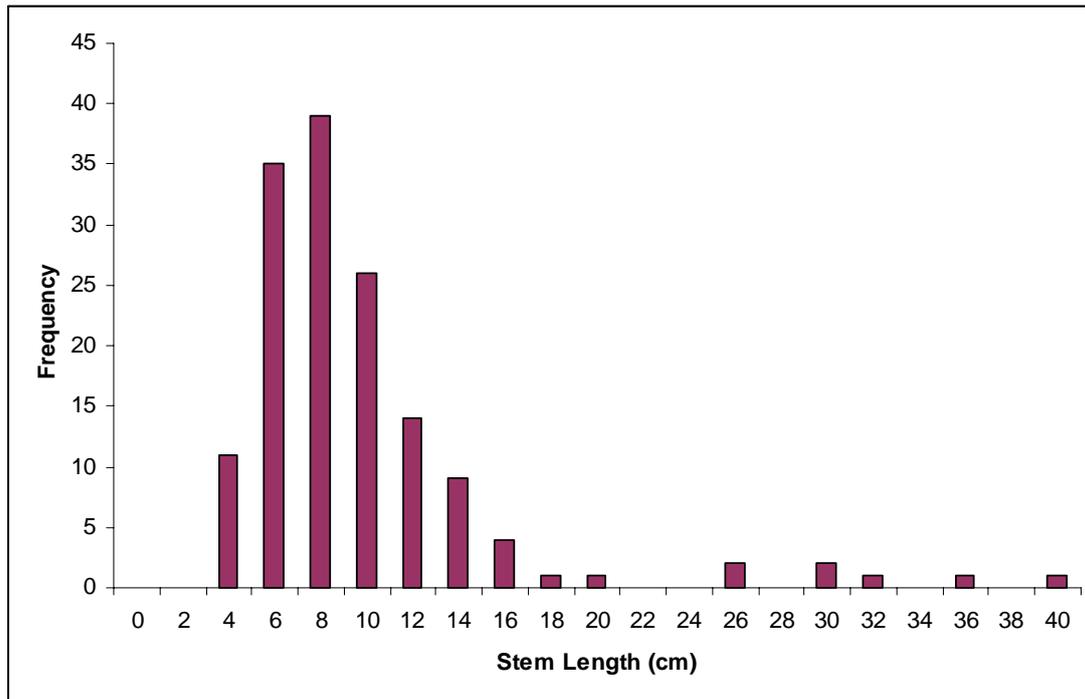


Figure 10. Histogram showing the size distribution of individuals after 13 months.

It is not possible, from the size distribution of the recruits (Figure 10), to estimate exactly how many individuals surveyed after 13 months were new recruits, as there were not two distinct cohorts. However, as the great bulk of recruits formed a relatively clear normal distribution, with a long right hand tail, it is probable that the majority were new recruits. Assuming the survival of the plants which were present in January and the fact that they would be the largest plants by October, it appeared that across the period January to October, the plants did not grow. In fact, 80% of them were smaller in October; 13% were larger; and 7% had not altered. Of those that were smaller, the average length had decreased from 15.2 cm to 9.6 cm, and of those that had apparently grown, the average length had increased from 13.3 cm to 22.2 cm.

4 DISCUSSION

Natural recolonization of denuded sand by seagrass is likely to be an extremely slow process, if it is successful at all. Marba and Walker (1999) concluded that recovery of disturbed *Posidonia sinuosa* and *Amphibolis antarctica* beds would likely involve timescales of centuries. Ultimately, the aim of seagrass rehabilitation is to increase the rate of this regeneration. The recruitment facilitation methods advanced in this project are designed to do this by providing scattered patches of substratum that are conducive to recruitment. Over time, vegetative growth of individuals should lead to these patches expanding and ultimately joining to form a continuous bed (Collings et al., 2007). In general, vegetative growth (as opposed to sexual reproduction) is considered to be the primary mechanism of natural regeneration for seagrasses (Vidondo et al., 1997; Rasheed, 1999 & 2004; Hemminga and Duarte, 2000; Campey et al. 2002; Sintes et al., 2005) as recruitment rates are low. However, for vegetative growth to occur either some adults must remain or new recruits must become established. We are trying to “fast-track” the initial recruitment, relying on natural processes to complete the process of rehabilitation.

One of the critical advantages of the use of recruitment units is that they do not need to be deployed by divers and can simply be pushed off a boat. This lends itself to the “sowing” of large areas in a relatively short time. However, numerous authors (e.g. Anderson and North, 1966; Deysner and Norton, 1982; Schiel, 1988; Kendrick and Walker, 1991; Arnaud-Haond et al., 2007) have demonstrated that the highest levels of recruitment occur in a relatively localised region around adult plants. Wear et al. (2006) intimated that this was likely in *Amphibolis*, and Collings et al. (2007) provided some data that supported this proposal on the Adelaide metropolitan coast. If such a phenomenon does occur, then rapid “sowing” of large areas with recruitment units may be ineffective anywhere except close to the existing meadow. The current project is the first to focus on this effect.

This study had two major findings. Firstly, it did not demonstrate a consistent effect of distance from seed source on the density of recruitment, the size of individual recruits or the size (as measured by total stem length) of the recruiting population to a

distance of 80 m from the meadow edge. Secondly, the number of recruits actually increased through time, rather than displaying the mortality that might be expected. However, the conclusions to be drawn from these results must be viewed in light of the extremely poor initial recruitment apparent in this year.

4.1 Effect of distance from seed source on recruitment

On initial appraisal the first finding, that distance from seed source (at least to 80 m) is irrelevant to the number of recruits captured, is particularly important for the method of rehabilitation ultimately used. It indicates that precise placement close to a seed source is not critical – anywhere within (at least) 80 m of the edge of the bed is adequate. Given that the preferred method, in terms of speed, efficiency and cost, is to simply motor a vessel over the sand in the general vicinity of a seagrass bed and dump recruitment units from the vessel, this is fortuitous. It means that this, somewhat inexact, method of placement is likely to be just as effective as the far more costly and time-consuming (see Wear et al. 2006) diver-deployed method. This might be considered a positive outcome for the prospects of large-scale rehabilitation efforts using the recruitment facilitation (i.e. sandbag) methodology.

The problem with this conclusion is that the levels of recruitment demonstrated in this study are very low. This is not unusual for seagrasses – recruitment as low as 0.07 seedlings m⁻² has been recorded for *Thalassia testudinum* (Whitfield et al., 2004), a late successional species. However, given that *Amphibolis antarctica* is considered to be a mid-successional species (Clarke and Kirkman, 1989), and we have deliberately intervened to improve colonization rates, less than 1.5 seedlings per bag cannot be considered particularly successful. Indeed previous studies in the same region (Wear et al., 2006; Collings et al., 2007) have demonstrated far higher initial recruitment with the same technique. Thus, it can only be concluded that 2006 – 2007 was a poor year for *Amphibolis* recruitment.

Fruiting can be highly variable in both time and space (Campey et al., 2002; Campbell et al., 2003; Collings et al., 2007) and it is possible that the bed immediately adjacent to the site had minimal or no fruiting and that the few recruits which were captured came from a bed some distance away, making the distance from

the adjacent bed less relevant. This could explain the inability to identify the effect of distance from nearest seed source – the adjacent bed was *not* acting as a source of seed, thereby invalidating the initial optimistic conclusion that distance from seed source (to a maximum of 80 m) was irrelevant to recruitment success.

Furthermore, the heterogeneity of recruitment has resulted in very low power in the tests of distance (Tables 2-4). In particular, simple observation of means in Figure 7 indicates the possibility that 4 and 8 months after initial recruitment, there is a tendency for the numbers of recruits on the bags in the area protected by the meadow (-10 m and 0 m) are higher than those anywhere outside the meadow (5 – 80 m). However, at a point in time just one month after a major recruitment event (i.e. the 13month survey) there are at least as many seedlings in the region outside of the meadow, if not more. Such a pattern would be consistent with initial recruitment being uniformly high across the whole area, but subsequent mortality being markedly higher outside the meadow where recruitment units are not afforded the protection of adult canopy. This possibility remains simply conjecture in light of the inability to detect statistically significant differences. However, in light of the low power of the test, it would be unwise to dismiss this possibility without further study.

4.2 Magnitude of recruitment and mortality

The second major finding is the lack of decline in recruit density on these recruitment units across 9 months (from 4 to 13 months). Indeed, recruit density has significantly increased. This can only mean that the recruitment units are effective long after the initial recruitment event. In fact, it appears that they still act as “catchers” of *Amphibolis* juveniles in the recruitment event commencing 12 months after they were initially deployed. While this is a significant and encouraging finding, it should be noted that it is contrary to previous studies within this project, which have not demonstrated this increase, and furthermore have shown substantial mortality, which was attributed to recruitment unit degradation (Collings et al., 2007).

The possibility that the apparent increase after 13 months simply reflected increased multistem growth, with no increase in the number of individuals *per se*, was

investigated by removing all individuals from a number of recruitment units which were not involved in the count. All individuals had a single stem, indicating that the increase in stem density was a result of an increase in the number of individual recruits.

Previous work (Collings et al., 2007) has identified high mortality rates as the cause of low recruitment success, rather than a lack of initial recruitment. As mentioned above, this study did not show the significant mortality of previous years. However, in the present instance, initial recruitment was poor. After 4 months, across all recruitment units, the average density of recruits was only 1.35 stems / bag. This contrasts with units deployed in previous years at the same site, which showed markedly higher initial recruitment. Collings et al. (2007) showed recruitment levels of nearly 90 stems per bag in the previous year after 3 months and 22 after 5 months, an order of magnitude higher than the present study. Wear et al. (2006), in work carried out at the same site, two years before the current study, demonstrated recruitment levels after 5 months of more than 70 seedlings per bag. The apparent lack of mortality probably reflects the fact that with only minimal recruitment, any mortality is covered by a “trickle” of recruits (possibly dislodged from elsewhere and transported into the system) throughout the year. If initial recruitment were higher, it is probable that the effect of mortality would be far more obvious.

The high mortality typical of previous years has previously been attributed to structural failure (i.e. fabric degradation) of the recruitment unit. If this is correct, then no such failure is evident this year. Why such a difference in recruitment unit stability should occur is open to conjecture. The hessian bags themselves were sourced from the same supplier (Colquhouns Bag Company), although the jute mesh which was attached to them came from a different source (J.A. Grigson as opposed to Treemax in previous studies). However, the company gave no indication that it was any different, and there was no obvious visible difference. The most probable conclusion is that, for various reasons, conditions in the year that this experiment ran were less likely to cause sandbag degradation. This may be a reflection of the tendency of the bags to be buried by mobile sand varying across years.

Continued monitoring of the populations on these bags is critical in the future to ascertain whether the populations on the recruitment units continue to grow over the succeeding year, or whether failure of the hessian material leads to catastrophic loss (i.e. all recruits are torn free as the bag disintegrates).

4.3 Recruitment unit success

Collings et al. (2007) raised the possibility that the important result is not *how many* seedlings exist per bag, but rather, what proportion of bags support some seedlings. In this instance, after 13 months, 87% of recruitment units supported *Amphibolis* seedlings, which is comparable to the 91% recruitment unit success rate at the same site in the previous year (Collings et al., 2007). However, in the present study far fewer individuals are present on each bag (3.4 /bag) compared with 9 in the previous year. This means that recruitment unit success is more easily affected, as it is necessary for fewer individuals to be removed before the unit is deemed a failure. Indeed almost a quarter of those bags which are currently deemed “successful” have 2 or fewer seedlings on them. These populations are clearly vulnerable to local (bag level) extinction.

4.4 Timing of recruitment event and interaction with mortality

Juveniles may develop on the adult plant for 12 months, and were believed to be released in the period July to December (Robertson, 1984), although Walker and Cambridge (1995) claim release occurs in June. Furthermore, juveniles have been observed that have recently snagged on seagrass root mat in the first week of June (Bryars, SARDI pers. obs), indicating release prior to this. Also, by monitoring individual bags, as has been done in the current study, it is possible to identify when increases have occurred, which must correspond to a time when seedlings were available. In this study, 30% of the bags had increased numbers of recruits on them across the period January to April. This is a conservative estimate of the number of bags that accumulated new juveniles across this period, as no account has been taken of mortality. Furthermore, the apparent size decrease across the year is more likely to be a reflection of the loss of larger plants and the arrival of new, smaller plants. (Grazing is a possibility, but has not been quantified and is considered unlikely.)

Thus, in contrast to accepted doctrine, it is evident that there is some form of seedling supply available at most times of the year.

Previously, in assessing the population dynamics of these recruitment units, it has been assumed that there is a major release of juveniles in the austral spring (September – November), which populate the bags, and thereafter there is little or no addition, and the dominant process is that of mortality, which acts to reduce each population over time. The implication of the seedling supply throughout the year, is that the processes of accumulation and loss from the bags could be highly dynamic – seedlings arrive, are retained for some time and lost, possibly being replaced by new seedlings which snag on the bag. This is a particularly concerning scenario as it implies that the juveniles are not being “hooked” for long enough to allow a good root system to form, and that the number present at any particular time of the year is merely a reflection of the relative magnitude of the effects of accumulation and loss in the immediate past. If this is the case, then it is clear that such a dynamic will not lead to long-term rehabilitation. It is important to reiterate that there has been no evidence of this in previous years – in these instances an initial recruitment pulse was followed by dwindling survival. In this instance, however, a “trickle” level of recruitment has become more apparent because of the failure of the initial recruitment pulse. These dynamics must be examined in more detail in future studies.

5 CONCLUSIONS AND FUTURE DIRECTIONS

This study demonstrated an effect of time but no effect of distance from seed source (out to a distance of 80 m). Whilst this could be encouraging for the prospect of large-scale rehabilitation, a generally low level of recruitment was found throughout, making it difficult to conclude confidently that distance to seed source has no effect on recruitment.

It is of interest that the recruitment units were still operating to catch seedlings released a year after originally submerged. While this is encouraging, it is critical to determine whether these individuals are retained. Indeed this experimental setup should yield interesting long term results – a series of bags have been permanently marked so they can be assessed through time, and relatively intense video analysis of the site will allow similar monitoring in future years across the broad area to determine whether patches of seagrass are, in fact, evolving.

It is possible that the capture of juvenile *Amphibolis* is a transitory event, the number of juveniles evident being a reflection of the short term balance between loss of individuals and capture of new seedlings, which are floating in the water column. If seedlings are not retained for any significant length of time, then any cover of seagrass on the bag will only consist of juveniles rather than growing adults, and eventually, as the bag degrades, or is covered in sand, even this will be lost. It is worth noting that this is the first time that such a scenario has been evident. In past years, there has been good evidence of an initial pulse of recruitment followed by mortality. Intensive studies are needed to identify the dynamics of these populations.

Several initiatives are already in place to cast light on some of the questions posed by this study. Monitoring of the large scale experimental units will be ongoing, and video analysis of the area should proceed at regular (although not necessarily short) intervals. This should provide information on longevity of bags, and the long term success of units over a broad area, including the ability to grow vegetatively from the bag and form expanding patches. This has not previously been studied in this environment.

In order to identify the timing of seedling release (and capture by recruitment units), a fresh set of recruitment units is being put in place every two months and the recruits on the previous set counted. In an effort to identify whether the population is a highly dynamic one, with a rapid turnover of individuals, long term video monitoring is to be used to follow the fate of individual plants on a recruitment unit. This may have the added benefit of helping to identify the cause of the loss of individuals.

Because of the possible influence of the low initial recruitment rates on the effect of proximity to seed source on recruitment success, it is recommended that a smaller scale, focussed study be initiated in the future with a set of bags placed at different distances from the meadow edge. This would involve the placement of a set of bags at distances of 0, 10m 100m and 200m from the meadow edge, and should be used to confirm the result obtained in the current study.

5 REFERENCES

- Anderson, E. K., North, W. J. (1966) In situ studies of spore production and dispersal in the giant kelp *Macrocystis*. In EG Young and JL McLachlan (eds), 5th *International Seaweed Symposium*. (pp. 73-86). Halifax: Pergamon Press.
- Arnaud-Haond, S., Migliaccio, M., Diaz-Almela, E., Teixeira, S., van de Vliet, M.S., Alberto, F., Procaccini, G., Duarte, C.M., Serrao, E.A. (2007) Vicariance patterns in the Mediterranean Sea: east-west cleavage and low dispersal in the endemic seagrass *Posidonia oceanica*. *Journal of Biogeography* **34**, 963-976.
- Bryars, S., Collings, G., Nayar, S., Westphalen, G., Miller, D., O'Loughlin, E., Fernandes, M., Mount, G., Tanner, J., Wear, R., Eglinton, Y., Cheshire, A. (2006) Assessment of the effects of inputs to the Adelaide coastal waters on the meadow forming seagrasses, *Amphibolis* and *Posidonia*. Task EP1 Final Technical Report. ACWS Technical Report No. 15 prepared for the Adelaide Coastal Waters Study Steering Committee. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD01/0208-19, Adelaide. 46 pp.
- Campbell, M.L. (2003). Recruitment and colonisation of vegetative fragments of *Posidonia australis* and *Posidonia coriacea*. *Aquatic Botany* **76**, 175-184.
- Campey, M.L., Kendrick, G.A., Walker, D.I. (2002) Interannual and small-scale spatial variability in sexual reproduction of the seagrasses *Posidonia coriacea* and *Heterozostera tasmanica*, southwestern Australia. *Aquatic Botany* **74**, 287-297.
- Clarke, S.M., Kirkman, H. (1989) Seagrass dynamics. In: Larkum, A.W.D., McComb, A.J. and Shepherd, S.A. Eds. *Biology of seagrasses*. Elsevier, Amsterdam, pp 304-345.
- Collings, G., Bryars, S., Nayar, S., Miller, D., Lill, J., O'Loughlin, E. (2006a) "Elevated nutrient responses of the meadow forming seagrasses, *Amphibolis* and *Posidonia*, from the Adelaide metropolitan coastline" ACWS Technical Report No. 11 prepared for the Adelaide Coastal Waters Study Steering Committee. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD01/0208-16, Adelaide.
- Collings, G., Miller, D., O'Loughlin, E., Bryars, S. (2006b) *Turbidity and reduced light responses of the meadow-forming seagrasses Amphibolis and Posidonia from the Adelaide metropolitan coast*. ACWS Technical Report No. 12 prepared for the Adelaide Coastal Waters Study Steering Committee. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD01/020817, Adelaide.
- Collings, G. J., Venema, S., Wear, R. J., Tanner, J.E. (2007) Seagrass rehabilitation in metropolitan Adelaide IV. Geographic and interannual variability of recruitment facilitation. Prepared for the Coastal Protection Branch, Department for Environment and Heritage. SARDI Aquatic Sciences Publication No. 2007/000268-1 SARDI Aquatic Sciences, Adelaide.

- Deysher, L., Norton, T. A. (1982) Dispersal and colonization in *Sargassum muticum* (Yendo) Fensholt. *Journal of Experimental Marine Biology and Ecology* **56**, 179-195.
- Ehrenfield, J.G. (2002) Evaluating wetlands within an urban context. *Ecological Engineering* **15**, 253-265.
- Fonseca, M.S., Calahan, J.A. (1992) A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine and Coastal Shelf Science* **35**, 565-576.
- Hemminga, M. A. and Duarte, C.M. (2000) *Seagrass Ecology*, Cambridge University Press, 298 pp.
- Kendrick, G. A., Walker, D. I. (1991) Dispersal distances for propagules of *Sargassum spinuligerum* (Sargassaceae, Phaeophyta) measured directly by vital staining and venturi suction sampling. *Marine Ecology Progress Series* **79**, 133-138.
- Marbà, N., Duarte, C.M., (1998) Rhizome elongation and seagrass clonal growth. *Marine Ecology Progress Series* **174**, 269-280.
- Marbà, N., Walker, D.I. (1999) Growth, flowering and population dynamics of temperate Western Australian seagrasses. *Marine Ecology Progress Series* **184**, 105-118.
- Peralta, G., Brun, F.G., Perez-Llorens, J.L., Bouma, T.J. (2006) Direct effects of current velocity on the growth, morphometry and architecture of seagrasses; a case study on *Zostera noltii*. *Marine Ecology Progress Series* **327**, 135-142.
- Rasheed, M. A. (1999) Recovery of experimentally created gaps within a tropical *Zostera capricorni* (Aschers.) seagrass meadow, Queensland Australia. *Journal of Experimental Marine Biology and Ecology*; **235(2)**, 183-200.
- Rasheed, M. A. (2004) Recovery and succession in a multi-speciestropical seagrass meadow following experimental disturbance: the role of sexual and asexual reproduction. *Journal of Experimental Marine Biology and Ecology* **310(1)**, 13-45.
- Reusch, T.B.H., Chapman, A.R.O. (1995) Storm effects on eelgrass (*Zostera marina* L.) and blue mussel (*Mytilus edulis* L.) beds. *Journal of Experimental Marine Biology and Ecology* **192**, 257-271.
- Roberston, E. (1984). Seagrasses. In: Womersley HBS. The marine benthic flora of southern Australia Part 1. Government Printer, South Australia. pp.100 - 106.
- Schiel, D. R. (1988). Algal interactions on shallow subtidal reefs in northern New Zealand: a review. *New Zealand Journal of Marine and Freshwater Research* **22**, 481-489.
- Seddon, S. (2002) Issues for seagrass rehabilitation along the Adelaide metropolitan coast; an overview. In: Seddon, S., Murray-Jones, S. (eds.) *Proceedings of the*

seagrass restoration workshop for Gulf St Vincent 15-16 May 2001. Department for Environment and Heritage and SARDI Aquatic Sciences, Adelaide. ISBN 0 7308 5272 5. pp. 1-8.

Seddon, S., Miller, D., Venema, S., Tanner, J. E. (2004). *Seagrass rehabilitation in metropolitan Adelaide I. Transplantation from donor beds*. Report to the Coast Protection Branch, Department for Environment and Heritage. SARDI Aquatic Sciences Publication No. RD04/0038. SARDI Aquatic Sciences, Adelaide.

Seddon, S., Wear, R. J., Venema, S., Miller, D. J., (2005). *Seagrass rehabilitation in Adelaide metropolitan coastal waters. II. Development of donor bed independent methods using Posidonia seedlings*. Prepared for the Coastal Protection Branch, Department for Environment and Heritage. SARDI Aquatic Sciences Publication No. RD004/0038-2. SARDI Aquatic Sciences, Adelaide.

Shepherd, S.A., McComb, A.J., Bulthuis, D.A., Neveraukas, V.P., Steffensen, D.A., West, R. (1989) Decline of seagrasses. In : Larkum, A.W.D., McComb, A.J. and Shepherd, S.A. (Eds), *Biology of seagrasses*, pp. 346-388. Elsevier, Amsterdam.

Sintes, T., Marba, N., Duarte, C.M., Kendrick, G.A. (2005). Nonlinear processes in seagrass colonisation explained by simple clonal growth rules. *Oikos* **108**, 165-175.

SPSS (2005) SPSS for Windows Release 14.0. SPSS Inc. Chicago.

Vidondo, B., Duarte, C.M., Middelboe, A.L., Stefansen, K., Nielsen, S.L. (1997) Dynamics of a landscape mosaic: size and age distributions, growth and demography of seagrass *Cymodocea nodosa* patches. *Marine Ecology Progress Series* **158**, 131-138.

Walker, D.I., Cambridge M.L. (1995) An experimental assessment of the temperature responses of two sympatric seagrasses, *Amphibolis antarctica* and *Amphibolis griffithii*, in relation to their biogeography. *Hydrobiologia* **302**, 63-70.

Walker, D. I., Kendrick, G. A., McComb, A. J. (2006) Decline and recovery of seagrass ecosystems – the dynamics of change. In Larkum, A. W. D., Orth, R. J., Duarte, C. M. (eds.) *Seagrasses: Biology, Ecology and Conservation*. Springer, The Netherlands. Pp 551-565.

Wear, R. J. (2006) *Recent advances in research into seagrass restoration*. Prepared for the Coastal Protection Branch, Department for Environment and Heritage. SARDI Aquatic Sciences Publication No. RD04/0038-4. SARDI Aquatic Sciences, Adelaide.

Wear, R. J., Tanner, J. T., Venema, S. (2006) *Seagrass rehabilitation in metropolitan Adelaide III: Development of recruitment facilitation methodologies*. Prepared for the Coastal Protection Branch, Department for Environment and Heritage. SARDI Aquatic Sciences Publication No.04/0038-3. SARDI Aquatic Sciences, Adelaide.

Whitfield, P.E., Kenworthy, J.W., Durako, M.J., Hammerstron, K.K., Merello, M.F. (2004) Recruitment of *Thalassia testudinum* seedlings into physically disturbed seagrass beds. *Marine Ecology Progress Series* **267**, 121-131.

Worm, B., Reusch, T.B.H. (2000) Do nutrient availability and plant density limit seagrass colonization in the Baltic Sea? *Marine Ecology Progress Series* **200**, 159-166.