

Seagrass Rehabilitation in Adelaide
Metropolitan Coastal Waters
IV. Geographic and Interannual Variability
of Recruitment Facilitation

Prepared for
Coastal Protection Branch,
Department for Environment and Heritage

by
Greg Collings, Sonja Venema, Rachel Wear, and Jason Tanner
SARDI Aquatic Sciences

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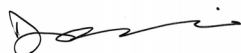
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TABLE OF CONTENTS

TABLE OF CONTENTS	1
ACKNOWLEDGEMENTS.....	2
EXECUTIVE SUMMARY	3
1. INTRODUCTION.....	5
1.1 Background	5
1.2 Objectives	9
2 METHODS	10
2.1 Site Characteristics	10
2.1.1. Physical Conditions of the Adelaide Metropolitan Waters	11
2.1.2. General Light Climate	13
2.1.3. Biotic Environment.....	13
2.2 Methods of Analysis	14
3 RESULTS.....	16
3.1 Proximity and density of donor <i>Amphibolis</i> plants to recruitment units	16
3.2 Recruitment success after 2 months.....	18
3.3 Recruitment success after 5 months.....	20
3.4 Recruitment success after 12 months.....	21
3.5 Trends across time.....	21
3.6 Effect of surrounding <i>Amphibolis</i> cover on initial recruitment success.....	22
3.7 Effect of surrounding <i>Amphibolis</i> cover on long term recruitment success.....	24
3.8 Mortality.....	26
3.9 Recruitment Unit Success.....	30
3.10 Temporal Variation in Recruitment Success.....	31
4 DISCUSSION.....	34
4.1 Geographic Variability	34
4.2 Temporal Variability	36
4.3 Trends and Predictions for Recruitment Success.....	37
5 CONCLUSIONS.....	41
6 REFERENCES.....	42

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EXECUTIVE SUMMARY

The provision of hessian bags to facilitate the recruitment of *Amphibolis antarctica* seedlings has previously been suggested as a fruitful approach to rehabilitating areas currently denuded of seagrass. To date, trials have been carried out in only a relatively restricted area and studied across a single year. In this study, we investigated the geographic consistency of recruitment and subsequent survival across a range of sites on the Adelaide metropolitan coast. Furthermore, this study allowed an assessment of the temporal variability in *Amphibolis* recruitment and survivorship across two years.

It was found that;

- Initial recruitment success varied substantially along the Adelaide coast (from an average of 3 to 122 seedlings per bag (0.3m²)), but not in a way that suggested a north-south gradient.
- Initial recruitment success (after 3 months) appeared strongly influenced by the density of nearby *Amphibolis* plants, although this is the subject of more detailed ongoing work.
- After twelve months, the relationship between recruitment and density of nearby *Amphibolis* no longer existed.
- Mortality was uniformly high (80-100% across 10 months), although slightly less so at deeper (12 m) sites, implicating water movement as a potential factor.
- Bag longevity appeared limited and this may result in loss of seedlings as the bag fails structurally.

These results are in contrast to a study conducted 12 months earlier at only two sites, which showed higher recruitment rates, lower mortality and greater stability of the hessian bags. Two sites in the current study were positioned immediately adjacent to those of the earlier study, and those of the original were resampled across the timecourse of the current study. Both of these provide evidence to suggest that there is a very strong element of temporal variability, and that some years are far more favourable than others in terms of the recruitment and survival of *Amphibolis*.

Despite the apparently low success of recruitment in this study, it is apparent that recruitment facilitation on hessian bags represents an improvement over the natural, unassisted situation, where virtually no seedlings are evident on bare sand. Given the evidence of other studies, which suggest that vegetative growth is far more important than recruitment of seedlings in many seagrass beds, it is evident that the initial goal of recruitment efforts should be to produce a successful recruitment unit (which may represent only a single successful plant), rather than to quickly recruit and maintain many individuals on each unit. Nevertheless, improving individual recruitment rates (i.e. the total number of recruits) will, to some degree,

impact on the success rate of the units, and for this reason further attempts should be made to improve these through modification of the unit design.

The high degree of geographic and interannual variability in success rates makes it clear that adequate estimation of the likelihood of success of these methods can only be made with an extension of the current program to quantify and incorporate information from more than the two years currently available. This information will also be invaluable in planning future large-scale rehabilitation efforts.

1. INTRODUCTION

1.1 Background

In addition to the economic benefits provided by a healthy ecosystem, seagrass meadows are globally recognized for their ecological importance. Seagrasses are known to be highly productive and play a crucial role in nutrient cycling, provision of substrate and stabilisation of sediments. Furthermore, they provide critical habitat for many species of vertebrates and invertebrates (e.g. Thayer et al. 1975, Ducker et al. 1977, West and Larkum 1982, Greenwood and Gum 1986, Howard et al. 1989, Short and Wyllie-Echeverria 1996). These benefits have been thoroughly described in previous reports in this series (Seddon et al. 2004, 2005; Wear 2006; Wear et al. 2006) and in the wider literature (see above references), and as such do not need to be dealt with further here.

Globally, increased urbanisation, particularly in the coastal region, has increased the anthropogenic pressure on nearshore coastal ecosystems (Ehrenfield 2002). The result has been widespread degradation of the biota in this region. In particular, seagrass meadows have shrunk in size throughout the world. Indeed, it is estimated that approximately 18% of the world's seagrasses have been lost as a result of human impacts (Walker et al. 2006). This has been reflected on a local scale off the Adelaide coast where over 5200 ha of seagrass meadows have been lost since the 1950s (Figure 1; Seddon 2002). Various anthropogenic stressors have been suggested as causes for seagrass loss, with the most recent studies identifying high turbidity and excessive nutrient loads from effluent treatment plants and industry as the most likely causes (Collings et al. 2006a & 2006b, Bryars et al. 2006).

As a result of our increasing knowledge of the consequences of seagrass loss, efforts have been made to improve the environmental situation to halt the loss of these important beds. However, the slow rates of growth typical of the major meadow-forming taxa (*Posidonia* and *Amphibolis*; e.g. Shepherd et al. 1989, Marbà and Duarte 1998, Marbà and Walker 1999), and the quantum shift in environment (from stabilised seagrass bed to unstable bare sand), make recolonisation of the degraded areas slow at best and unlikely at worst. For this reason, considerable effort has been expended on artificially recolonising these 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 appears to provide the best chance of restoring Adelaide's seagrass beds (Wear et al. 2006).

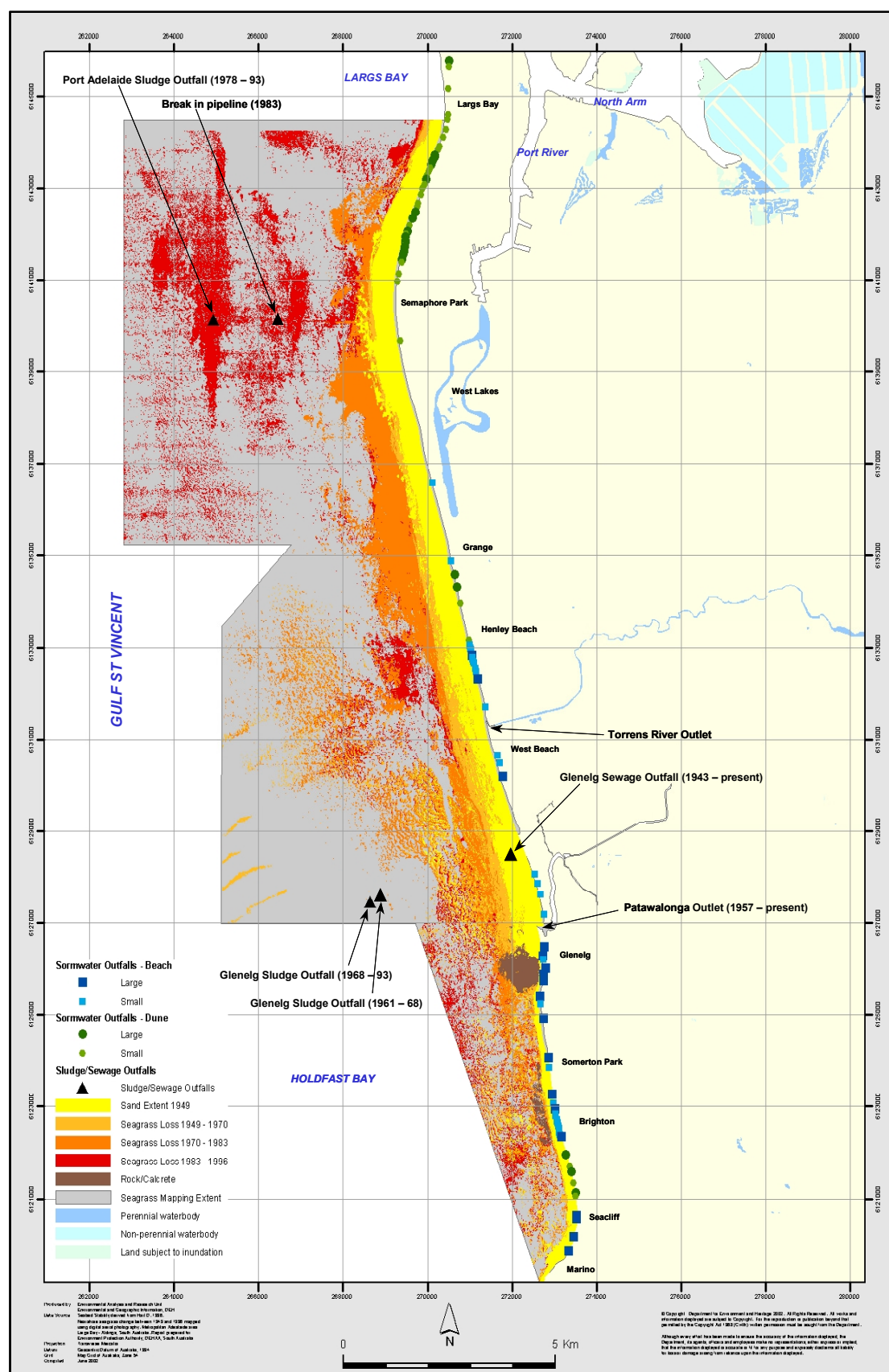


Figure 1. Map of the Adelaide metropolitan coast showing the extent of seagrass loss between Largs Bay and Marino between 1949 and 1996. Image from Seddon (2002) constructed by Tim Noyce, South Australian Department for Environment and Heritage.

Probably the single greatest hurdle faced by recruiting juveniles is the fact that the areas that need to be recolonised are currently bare sand. This environment poses two major problems. Firstly, whilst mature seagrass beds absorb considerable wave energy, providing a relatively protected environment, bare sand has no such protection and is subject to far greater water movement. Secondly, unlike the complex substrate provided in a seagrass bed, sand provides no anchoring points for the “grappling hook” apparatus (see Figure 2) of juvenile *Amphibolis* to attach to and resist water movement. Thus recruitment facilitation methods have focussed on providing a substrate onto which *Amphibolis* juveniles may attach, allowing them to resist water movement for a period sufficient to grow sufficiently deep roots to survive without assistance. As the anchoring materials are biodegradable, this growth must be rapid enough for the seedling to reach a self sustainable size before the material has degraded.

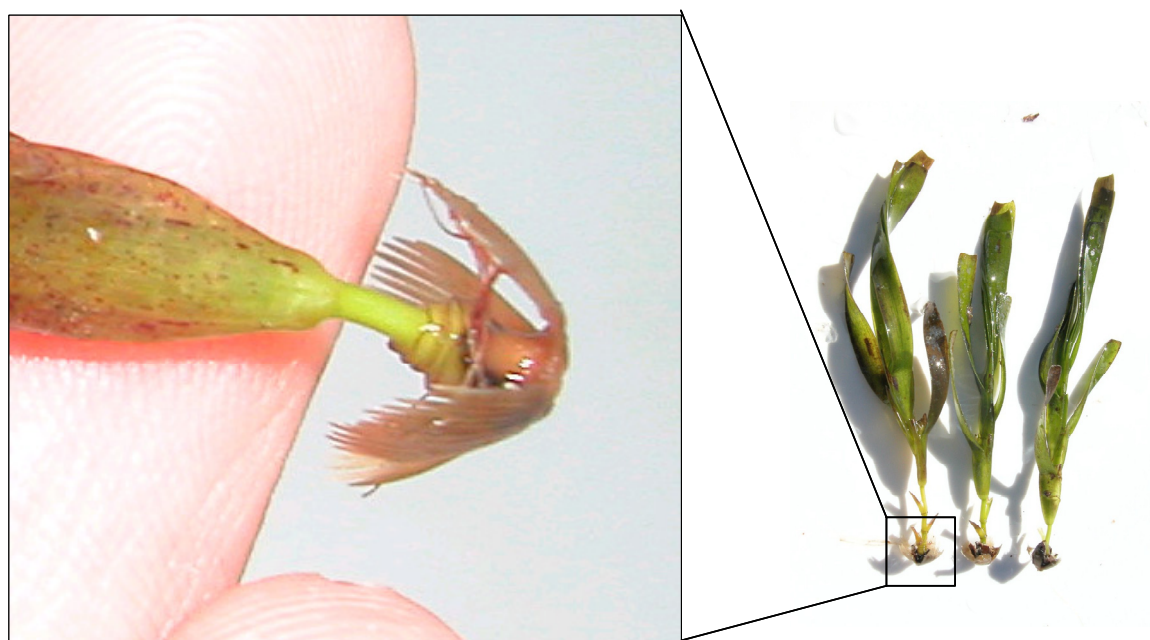


Figure 2. “Grappling hook” apparatus of *Amphibolis* juveniles which assists with anchoring the plant to the substrate before substantial roots are able to do so.

Previous work (Wear et al. 2006) on the Adelaide coast has indicated considerable potential for recruitment facilitation. This work identified the use of hessian sandbags, wrapped in a layer of coarse weave hessian, as the most environmentally acceptable and economic solution (see Figure 3). This conclusion was reached on the basis of the number of seedlings which recruited per dollar spent and involved testing ten different methods for a period of twelve months.

Encouraging recruitment figures, indicating the recruitment of 140 seedlings m^{-2} of hessian at one site and almost 100 seedlings m^{-2} at another were obtained after 12 months. However, both of these sites were in relatively close proximity, and the applicability of the results to the wider situation of the Adelaide metropolitan coast was unknown.



Figure 3. Hessian sandbag covered with coarse-weave hessian. This was the most economical method trialled for recruitment success. Views before deployment (above) and after a month of deployment (below).

Thus, this study represents a change in focus from the identification of an effective technique to identifying whether recruitment success is consistent across the Adelaide metropolitan coast. Additionally, reviewing the success of the sites set up by Wear et al. (2006) allows an important comparison to be drawn between recruitment success in consecutive years. This represents a further step in the identification of an appropriate method for the rehabilitation of Adelaide's degraded seagrass meadows.

1.2 Objectives

Specifically, this study aimed to

- 1) Identify the geographic consistency of recruitment success and identify what factors are likely to have caused it. As the factors are likely to change with the age of the recruits, analysis targeted different points in time.
- 2) Quantify both interannual and ontogenetic (age related) variability in recruitment and survival
 - a. by comparing the first year of recruitment in the study of Wear et al. (2006) with this study and
 - b. by resampling the units established previously by Wear et al. (2006) and comparing their success as two year old recruits with the success of the one year old recruits deployed 12 months later as part of the present study.
- 3) Predict the likelihood of success as the recruitment units (and their seagrass populations) age into the future.

2 METHODS

A series of 12 sites, at different locations and depths, were chosen to assess variability in recruitment success along the Adelaide coast. These sites were chosen on the basis of the presence of an appropriate sand patch with nearby donor *Amphibolis* plants. Sites ranged from Seacliff in the south to Largs Bay in the north (Figure 4, Table 1). Depths ranged from 8 to 12 m. At most sites 10 bags were arranged in two rows of 5, each placed approximately 50cm from the next. The exceptions to this were the Grange 8 m and Semaphore 8 m sites, where 30 bags were arranged in 6 rows of 5 bags, similarly spaced. Of these 30 bags, only 10 were of a type pertinent to this study.

Table 1. Locations of all sites in this study (WGS84 coordinate system).

Site	Latitude (degrees minutes S)	Longitude (degrees minutes E)
Seacliff 8 m	35 01.856	138 30.057
Brighton 12m	35 10.715	138 29.350
Brighton 10m	35 01.622	138 29.668
Brighton 8m	35 01.382	138 30.132
Henley 12m	34 54.432	138 25.987
Henley 10m	34 54.543	138 27.747
Henley 8m	34 54.560	138 28.043
Grange 12m	34 53.993	138 25.752
Grange 10m	34 54.025	138 26.257
Grange 8m	34 54.050	138 28.048
Semaphore 8m	34 52.277	138 27.475
Largs Bay 8m	34 49.945	138 26.834

All sites were set up with bags during the period from 7/9/05 to 13/9/05. They were then surveyed 2, 5 and 12 months later in late November 2005, February 2006 and September 2006. These surveys involved counting the number of individuals which were present on each bag.

2.1 Site Characteristics

Sites varied in terms of both their physical environment and the surrounding biota. Important physical characters that may vary included chemical water quality, light climate and temperature. The following data are provided simply to describe the general physicochemical context of the rehabilitation trials.

2.1.1. Physical Conditions of the Adelaide Metropolitan Waters

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 µg L⁻¹. Other water quality parameters are provided in Table 2.

Table 2. Surface water quality of the Adelaide metropolitan coast. These data were collected from jetties between 1996 and 2003 by the Environment Protection Authority, South Australia.

	Largs Bay	Semaphore	Grange	Henley Beach	Glenelg
Temperature (°C)	11.0 – 26.0	11.0 – 25.0	11.0 – 26.6	11.0 – 26.4	11.0 – 25.5
TDS (g L ⁻¹)	33.7 – 38.8	26.3 – 38.8	33.0 – 38.2	34.0 – 38.2	33.0 – 38.3
pH	7.88– 8.3	7.88– 8.3	7.46 – 8.35	7.76 – 8.33	7.79 – 8.38
Turbidity (NTU)	0.35 - 31	0.386 - 21.6	0.337 - 24	0.404 – 25.1	0.341 - 26
Ammonia (mg L ⁻¹)	0.005 – 0.2	0.005 - 0.164	0.005 – 0.19	0.005 – 0.216	0.007 – 0.19
Nitrate (mg L ⁻¹)	0 - 0.069	0 - 0.105	0 - 0.178	0 - 0.159	0 – 0.13
Nitrite (mg L ⁻¹)	0.005 - 0.01	0.005 - 0.01	0.005 - 0.02	0.005 - 0.014	0.005 - 0.018
Phosphorus (mg L ⁻¹)	0.013 – 0.32	0.011 – 0.14	0.018 – 0.68	0.014 – 0.091	0.013 – 0.165

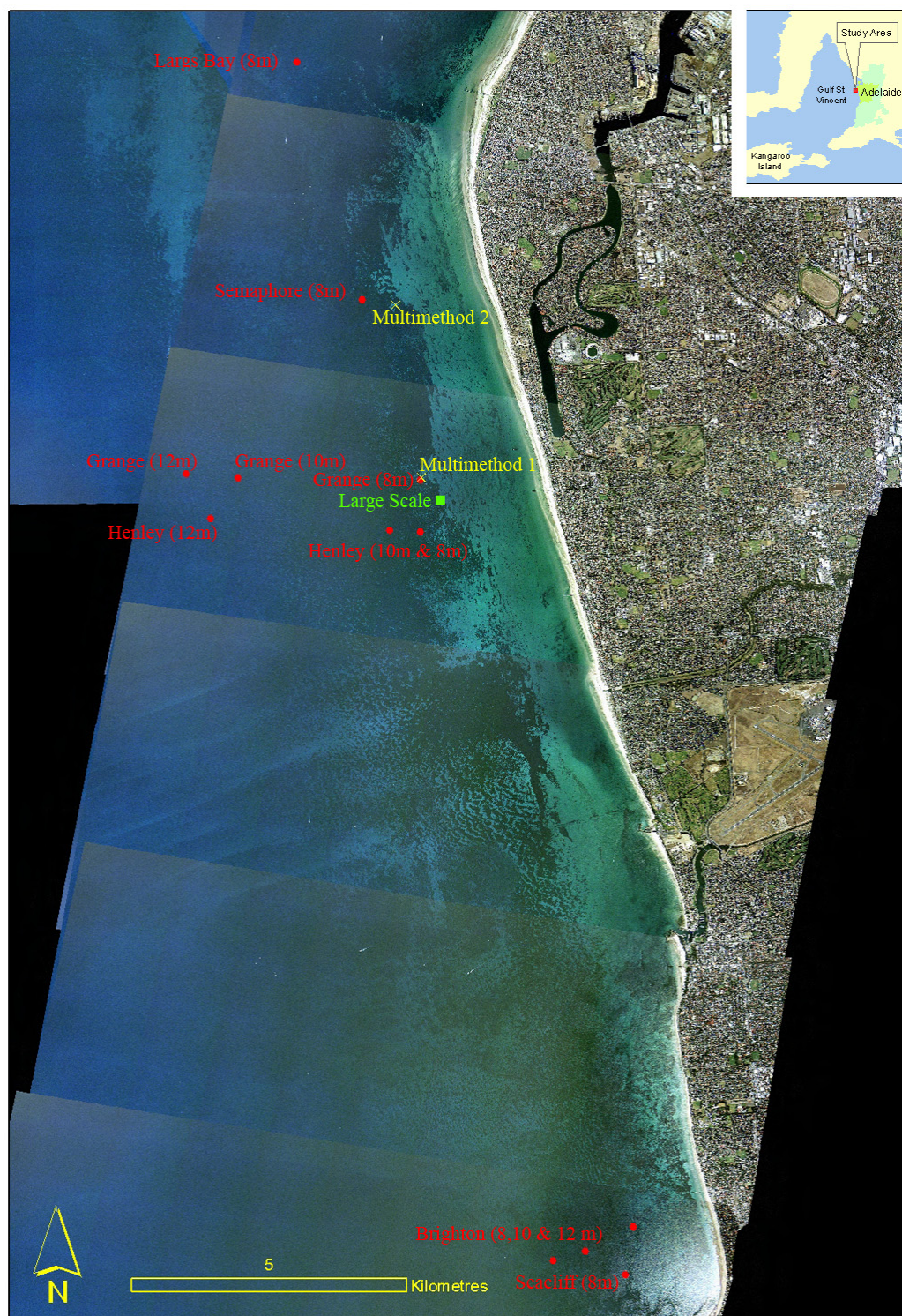


Figure 4. Positions of all sites used in this trial (in red), and sites used for other seagrass rehabilitation trials, the methodological trial of Wear et al. 2006 (in yellow) and a large scale rehabilitation trial currently underway (in green). Aerial photograph from S.A. Department for Environment and Heritage

2.1.2. General Light Climate

Whilst shallow water is associated with greater irradiance at the seafloor, this effect may be muted by the greater turbidity found at shallow sites because they are closer to the shore. Whilst light meters were not deployed at each of these sites, a general description of the light climate of the region may be gleaned from irradiance data collected to support the trial of Wear et al. (2006). Figure 6 demonstrates the changing average light climate, in terms of photosynthetically active radiation, across the 4 months from July to October 2005, at two sites in Holdfast Bay (see Figure 4 for position). The precise methods used may be obtained from Wear et al. (2006).

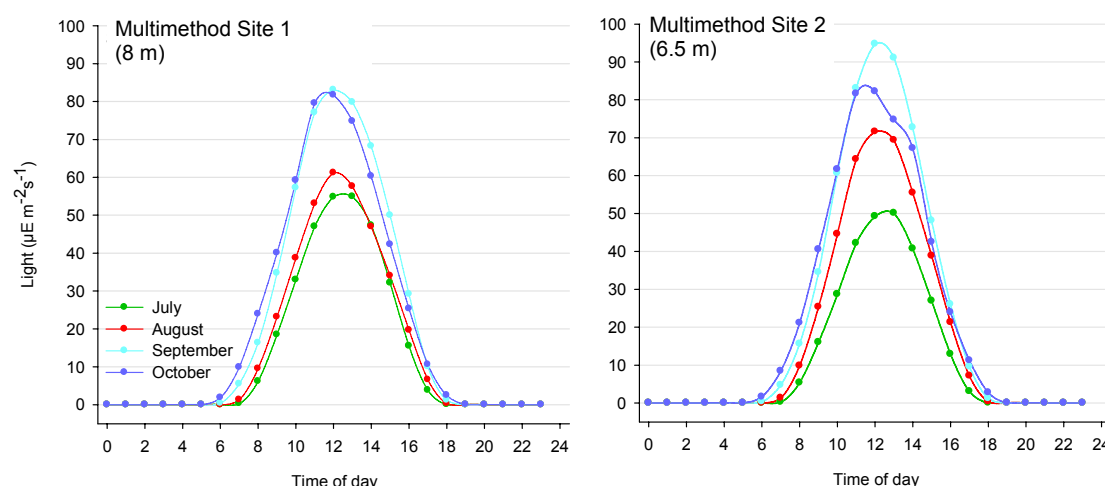


Figure 6. Average light availability at both sites, during July, August, September and October 2005.

2.1.3. Biotic Environment

The success of recruitment efforts may depend on the proximity of donor plants from which recruits are derived. To make an assessment of this situation, a series of 4 transects was run from the site of the bags to points 50 metres away in northerly, westerly, easterly and southerly directions. A diver swam along each transect (tape measure), making note of where the habitat changed. Habitat was classified as one of the following types: Sand; *Amphibolis*; *Posidonia*; *Zostera*; *Halophila*; macroalgae and binary combinations of these. This is essentially the Line Intercept Transect (LIT) method of English et al. (1997).

It is unknown whether *Amphibolis* recruitment is likely to respond to the distance to nearest plant, or the density of donor plants within a given radius. For this reason, several measures were calculated (see Figure 5 for a pictorial representation):

1. Shortest distance to any potential donor *Amphibolis* plants
2. Proportion of linear metres of transect (across all four 50 m transects) containing *Amphibolis*.
3. As for 2, but using only the nearest 20 m of each transect (instead of full 50 m)
4. As for 2, but using only the nearest 10 m of each transect (instead of full 50 m)

The description of each site can be found in the Results section (Chapter 3).

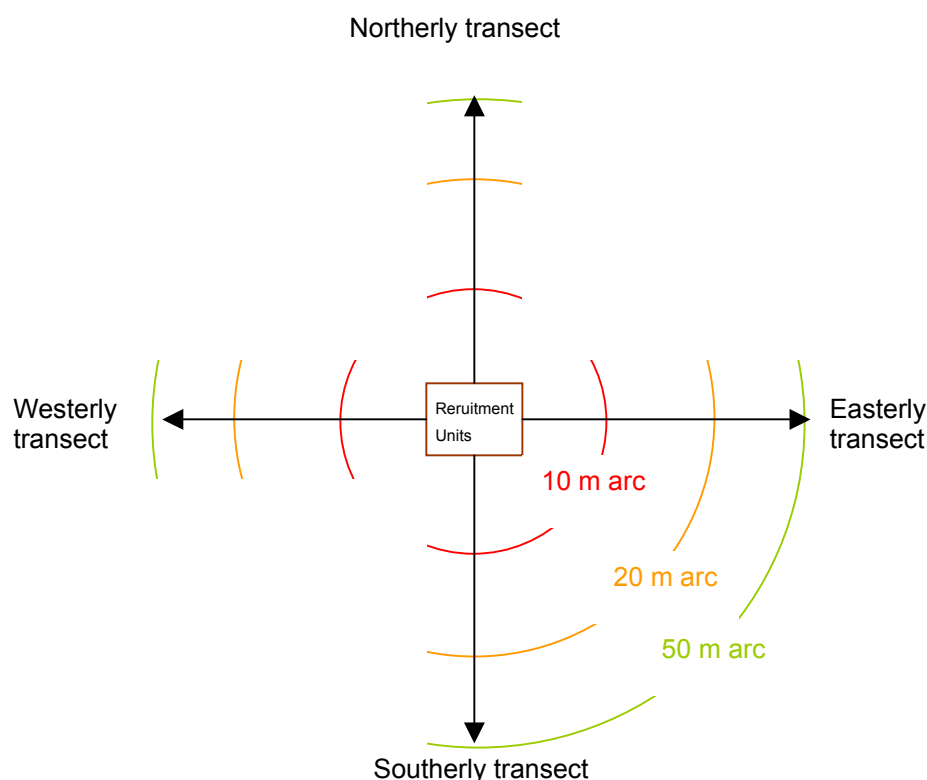


Figure 5. Description of the amount of surrounding *Amphibolis* was made by calculating the proportion of linear metres of transect which contained *Amphibolis*. This was calculated for the area within 10 m, 20 m and 50 m of the recruitment units.

2.2 Methods of Analysis

A variety of statistical analyses were utilised to investigate different aspects of recruitment and survival on recruitment units at sites along the Adelaide metropolitan coast. The relationship between the percentage cover of *Amphibolis* at different distances from the recruitment units was analysed using linear regression on untransformed data. Recruitment success after 2 and 12 months was analysed using two different methods. In order to assess any interactive effects between location and depth, a two way ANOVA was employed using location and depth as independent variables and recruitment density (recruits/bag) as the dependent variable. As only 3 locations had multiple depths, a separate analysis was undertaken across all six locations where an 8 m site was present. This allowed a broader geographic range to be investigated and was analysed using a one way ANOVA with location as the independent variable and recruitment density as the dependent variable. Mortality (seedlings lost between 2 and 12 month surveys as a proportion of 2 month recruitment density) was assessed in the same manner. Data were transformed via natural log (for recruitment density analysis) and arcsin (for mortality) transformations. Whilst these transformations improved the homogeneity of variances, significant heterogeneity still existed and could not be removed. As a consequence, Games-Howell post hoc tests were utilised as they do not assume homogeneity of variances.

Linear regression was employed to examine relationships between recruitment success and surrounding *Amphibolis* cover. As there was no *a priori* reason to suspect any particular scale might be important to recruitment success, linear regressions assessing recruitment success as a function of *Amphibolis* cover were carried out measuring cover at distances of 10, 20 and 50 m from the recruitment units to see which was best related. Backward stepwise multiple regression was also applied (using an exit criteria of $p > 0.1$) as an alternative method of analysis. When multiple regression was applied, independent variables were cover within a radius of 10 m, cover from 10 to 20 m from the recruitment units, cover from 20 to 50 m and also the proximity to nearest *Amphibolis*.

A null model was utilised to demonstrate the effect of initial density on percentage mortality under conditions of equal likelihood of individual seedling mortality. This model was created by simulating a set of recruitment units with initial population sizes equal to those of the two month survey, and then applying a likelihood of mortality of 92% to every seedling. Thus every seedling had an 8% chance of surviving based entirely on random chance. Mortality was then calculated for each bag as the percentage of seedlings which had died. The output was a plot of mortality as a function of initial recruitment density with each recruitment unit representing a point on the plot.

A second model projected recruitment unit success (defined as a situation where one or more *Amphibolis* individuals exist on a bag) after 5 years on the basis of the mortality demonstrated across the 12 months to date. As surveys were conducted at three points in time, it was possible to assess how mortality had changed across time and to extrapolate this beyond our current position. An S-curve (SPSS 2005) was utilised to fit a significant line of best fit to the recruitment data measured at 2, 5 and 12 months. Using the formula represented by this line of best fit, it was possible to predict how many more seedlings would die between 12 months and 5 years on the basis of the current pattern. The number of projected losses was determined as a function of the total number of existing seedlings after 12 months to provide a percentage mortality over this period. A model then began with a simulated set of recruitment units identical to those represented at the 12 month survey and randomly applied a likelihood of mortality equal to that predicted by the S-curve analysis to every seedling on each bag. The number of bags still supporting *Amphibolis* after this mortality was then calculated for each site. As mortality was a random event, this model was run 100 times and the average number of bags still supporting *Amphibolis* was calculated.

3 RESULTS

3.1 Proximity and density of donor *Amphibolis* plants to recruitment units

This section simply provides a description of the site in terms of variables which may explain the recruitment success detailed in later sections.

Of the 12 sites surveyed, all but two had a potential recruitment source of *Amphibolis* nearby (i.e. within 2 m of the bags; Figure 7). Of the two without nearby *Amphibolis*, Seacliff (8 m) had relatively close donor plants (5.5 m) and the other, Henley (10 m) was more distant from the nearest recruitment source (28 m).

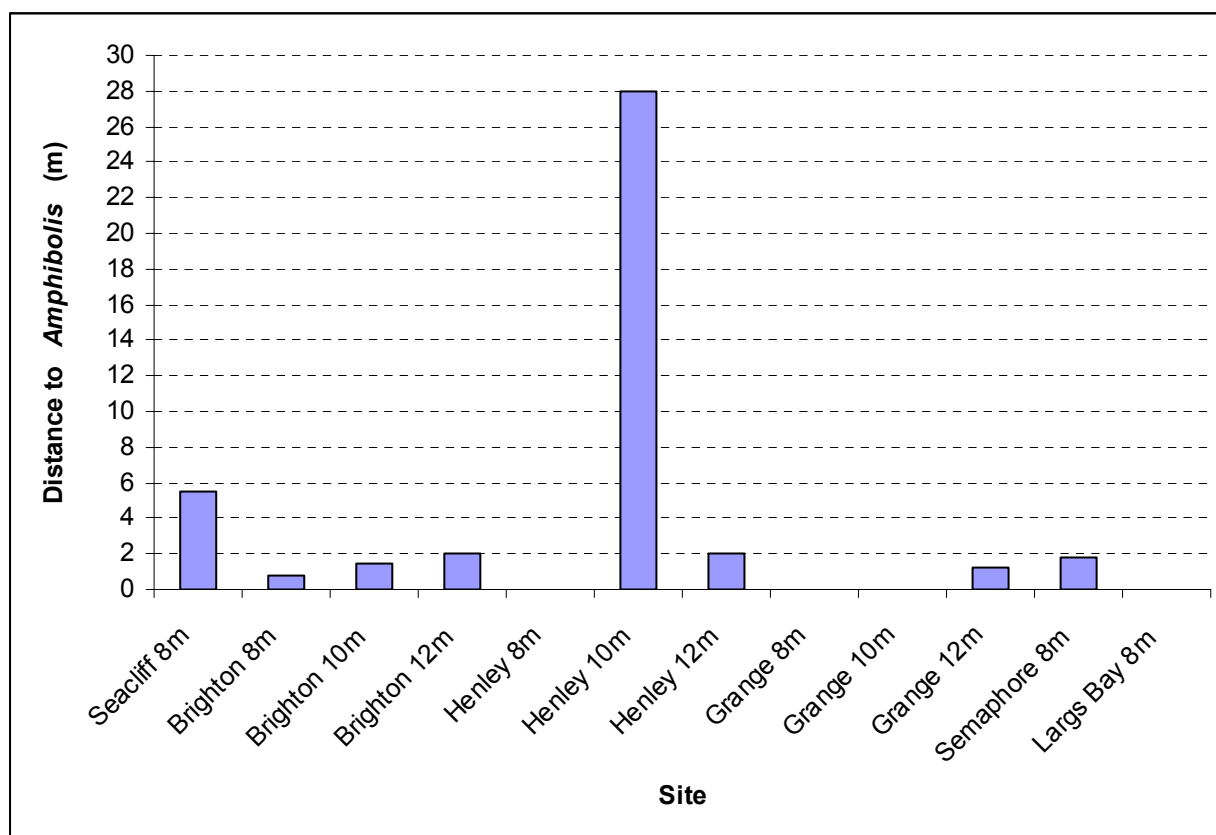


Figure 7. Distance from recruitment units to nearest *Amphibolis* plants.

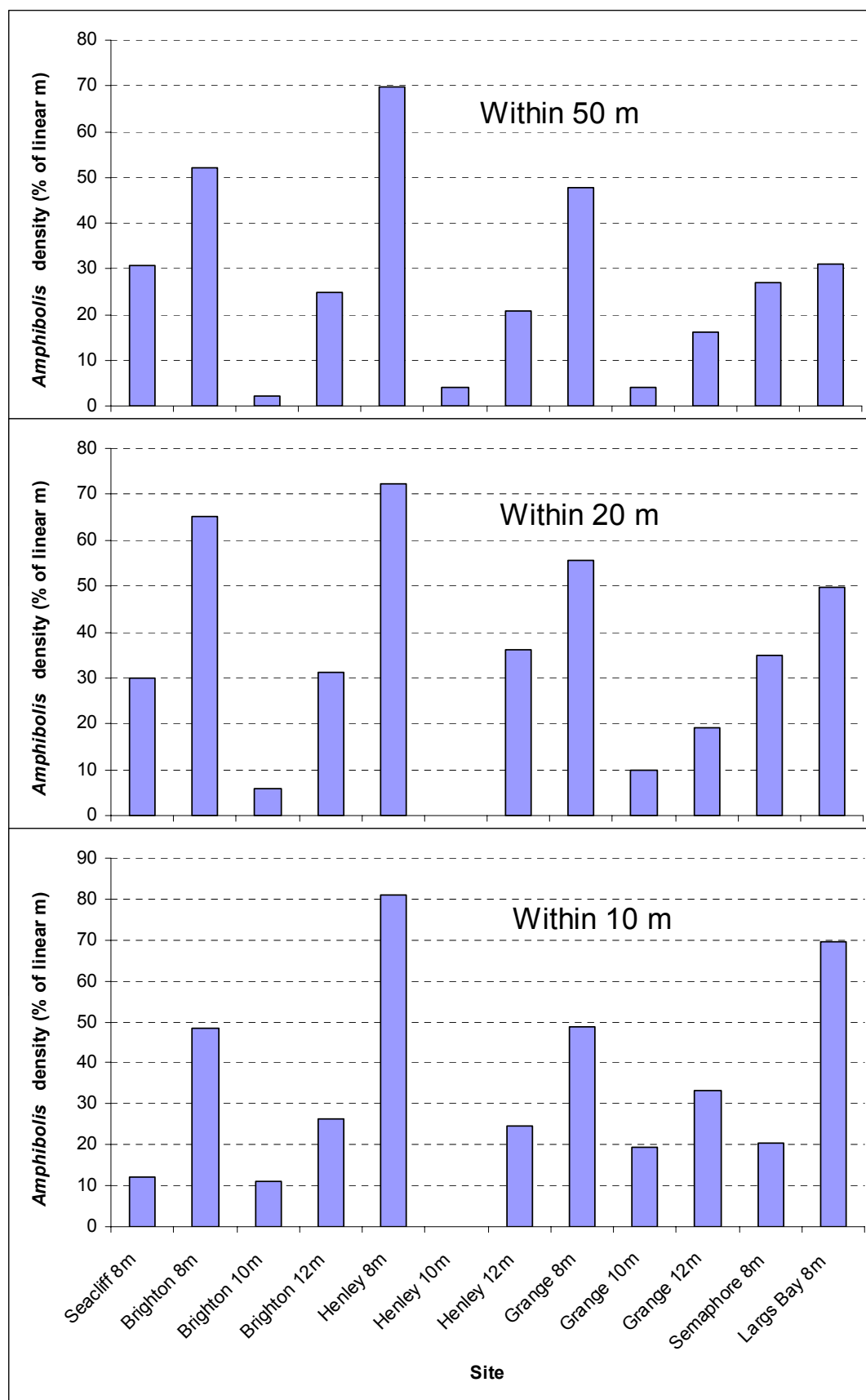


Figure 8. Density of surrounding *Amphibolis* within 50 m, 20 m and 10 m of each recruitment facilitation site.

The quantity of *Amphibolis* was assessed at three different scales (within 10 m, 20 m and 50 m of bags) as we have no prior knowledge about the scale that is likely to be most influential on recruitment. Regardless of what scale was used, similar patterns between sites were evident (Figure 8) with very few exceptions. In general, all of the 10 m sites had less *Amphibolis* in the vicinity than the 8 and 12 m sites (<15% substrate cover); the Brighton, Henley, Grange and Largs Bay sites at 8 m had a large proportion (>45% substrate cover) of the surrounding area covered in *Amphibolis*; and the other sites were intermediate (15-45% substrate cover). Only two sites differed slightly according to what scale was examined: Seacliff 8 m dropped from intermediate to low at the 10 m scale, and Largs Bay 8 m dropped from high to intermediate at 50 m. A linear regression could be used to predict cover at the 50 m and 20 m scales on the basis of the cover at the 10 m scale and did so with R^2 values of 0.29 and 0.48, reflecting a similarity in pattern across the scales.

3.2 Recruitment success after 2 months

Recruitment success after 2 months varied from 3 seedlings per bag at Brighton (10 m) to 122 seedlings per bag at the Henley (8 m) site (Figure 9). Analysis of the three sites with multiple depths (Brighton, Henley Beach and Grange) demonstrated a significant interaction effect between depth and site (Table 3), indicating that there was no consistent effect of depth across all locations. A separate analysis of all sites at 8 m depth demonstrated that there were significant differences between locations (Table 4). The southern sites (Seacliff and Brighton) showed lowest initial recruitment. The highest recruitment occurred at sites with high cover of *Amphibolis* (>45%; Fig 9), although high cover didn't always lead to high recruitment. Brighton (8 m) displayed very low (6.8 seedlings/bag) recruitment despite having a high cover of *Amphibolis* (65% at 20 m scale). This, however, is consistent with overall low recruitment in the southern area (Brighton and Seacliff).

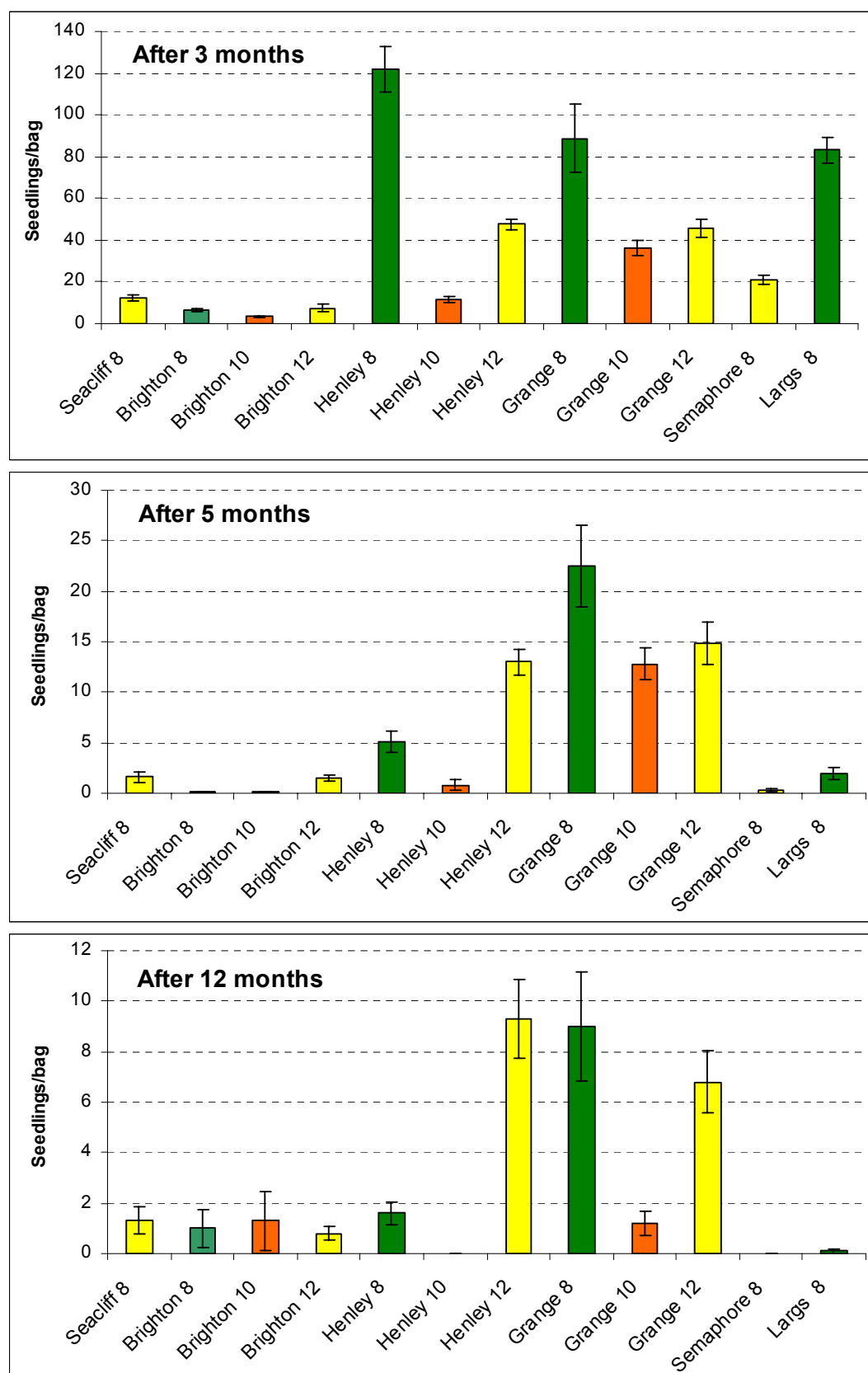


Figure 9. Average recruitment success (\pm S.E) at each site after 3, 5 and 12 months. Colours of bars indicate the density of *Amphibolis* at each site as described in Section 3.1. Green indicates high density (generally $>45\%$, depending on scale); Yellow is intermediate ($15-45\%$) and Orange is low density ($<15\%$). Note the varying scale of the Y axis.

Table 3. Results of two-way analysis of variance testing effects of site and depth on recruit density (ln transformed) after 2 months across the three sites at which multiple depths were investigated

Variable	d.f.	SS	F	P
Depth	2	3.676	3.600	0.128
Site	2	14.671	14.37	0.015
Depth X Site	4	2.042	6.875	<0.001
Error	82	6.09		

Levene's Test: $p < 0.001$ (i.e. variances are non-homogeneous)

Table 4. Results of one way analysis of variance testing and post-hoc tests for the effect of site on density (ln transformed) of recruits after 2 months across all sites at a depth of 8 m.

Variable	d.f.	SS	F	P
Site	5	11.475	25.922	<0.001
Error	55	4.869		

Levene's Test $p = 0.002$ (i.e. variances are non-homogeneous)

Post-hoc Games-Howell tests

	Brighton	Henley	Grange	Sempahore	Largs
Seacliff	0.011	<0.001	0.062	0.016	<0.001
Brighton		<0.001	0.01	<0.001	<0.001
Henley			0.622	<0.001	0.078
Grange				0.321	0.961
Sempahore					<0.001

3.3 Recruitment success after 5 months

After 5 months, the average number of seedlings per bag varied between 0 and 22 (Figure 9). Success appeared to be at least partially geographically related, with Grange and, to a lesser extent, Henley being the most successful. Grange (8 m) was clearly most successful (22 seedlings per bag), and other Grange sites (i.e. 10 m and 12 m) were moderately successful (averaging 13 to 15 seedlings per bag). The only other site with similar success was Henley (12 m). Henley at 8 metres supported 5 seedlings per bag, and all other sites supported less than 2 seedlings per bag. Statistical analysis is not utilized here as the 5 month survey represents only an intermediate step.

Success did not appear as closely related to the amount of surrounding *Amphibolis* after 5 months as it did after 2 months. Whilst the site supporting most seedlings (Grange (8 m)) was a high cover site, success at the other high cover sites (Brighton (8 m), Henley (8 m) and Largs Bay (8 m)) was moderate at best and usually poor (<2 seedlings per bag). Furthermore, these three sites performed more poorly than sites of medium and even low *Amphibolis* coverage.

3.4 Recruitment success after 12 months

The final survey, after 12 months provides a longer term assessment of recruitment success, which includes both initial recruitment and then a substantial period of subsequent mortality. With few exceptions, success was low at all sites: Grange (8 m and 12 m) and Henley (12 m) supported between 6 and 9 seedlings per bag on average, and no other site supported more than 1.6 seedlings per bag. Furthermore, two of the sites supported no recruits whatsoever. Of the 3 most successful sites, one ranked as a high cover site and the other two as medium. Statistically, a two way ANOVA on those sites with multiple depths demonstrated a significant interaction (Table 5), indicating that any effect of site was not consistent across depths. Analysis of the 8 m sites demonstrated significant differences according to location (Table 6). Rather than indicating any north-south gradient, this was a reflection of consistently low recruitment at all 8 m sites except Grange.

3.5 Trends across time

Mortality resulted in a major decrease in the density of seedlings on each recruitment unit across the 12 month period. At the site of highest initial recruitment (Henley 8 m), the density of seedlings decreased from 120 seedlings per bag after 2 months of recruitment to 22 seedlings per bag after 5 months and 9 seedlings per bag after 12 months (Figure 9).

The pattern of success between sites remained relatively constant at each point in time (Figure 9). Exceptions to this generalization are the relatively high initial success at the Henley Beach (8m) and Largs (8m) sites that is not apparent after 5 months. Conversely, the Henley Beach (12m) site has the highest density of seedlings after 12 months despite having markedly less success relative to some other sites after the initial 2 months.

Table 5. Results of two-way analysis of variance testing effects of site and depth on recruit density (ln transformed) after 12 months across the three sites at which multiple depths were investigated

Variable	d.f.	SS	F	P
Depth	2	4.466	3.026	0.158
Site	2	3.660	2.481	0.199
Depth X Site	4	2.952	10.662	<0.001
Error	82	5.675		

Levene's Test: $p=0.035$ (variances are significantly non-homogeneous)

Table 6. Results of one way analysis of variance testing and post-hoc tests for the effect of site on density (ln transformed) of recruits after 12 months across all sites at a depth of 8 m.

Variable	d.f.	SS	F	P
Site	5	5.891	19.32	<0.001
Error	55	3.354		

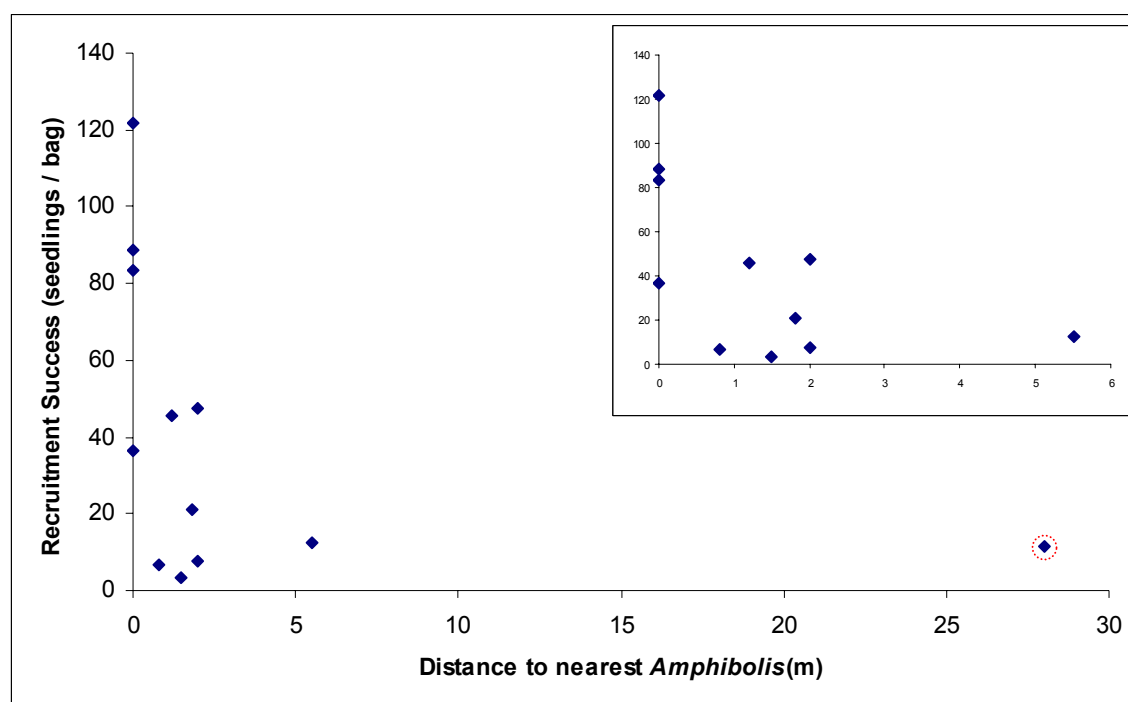
Levene's Test $p=0.007$ (variances are significantly non-homogeneous)

Post-hoc Games-Howell tests

	Brighton	Henley	Grange	Sempahore	Largs
Seacliff	0.959	0.979	0.002	0.093	0.169
Brighton		0.644	0.001	0.547	0.751
Henley			0.006	0.010	0.017
Grange				<0.001	<0.001
Sempahore					0.907

3.6 Effect of surrounding *Amphibolis* cover on initial recruitment success.

The initial success of recruitment was not related to the distance to nearest *Amphibolis* (Figure 10), but was strongly dependent on the proportion of *Amphibolis* in the immediate vicinity (Figure 11). While linear regressions between *Amphibolis* cover and recruitment were significant at each scale (10 m, 20 m and 50 m), a stepwise multiple regression indicated that cover to a distance of 10 m was the best predictor of recruitment success after 2 months ($p=0.001$, $R^2=0.67$). After the variation caused by this factor was taken into account, none of the other variables (distance to nearest *Amphibolis*; proportion of cover between 10 - 20 m and 20 - 50 m) provided any additional explanatory power.

**Figure 10.** Relationship between recruitment success after 2 months and distance to nearest *Amphibolis*. Inset is the same relationship, omitting the outlier Henley 10 m, (circled).

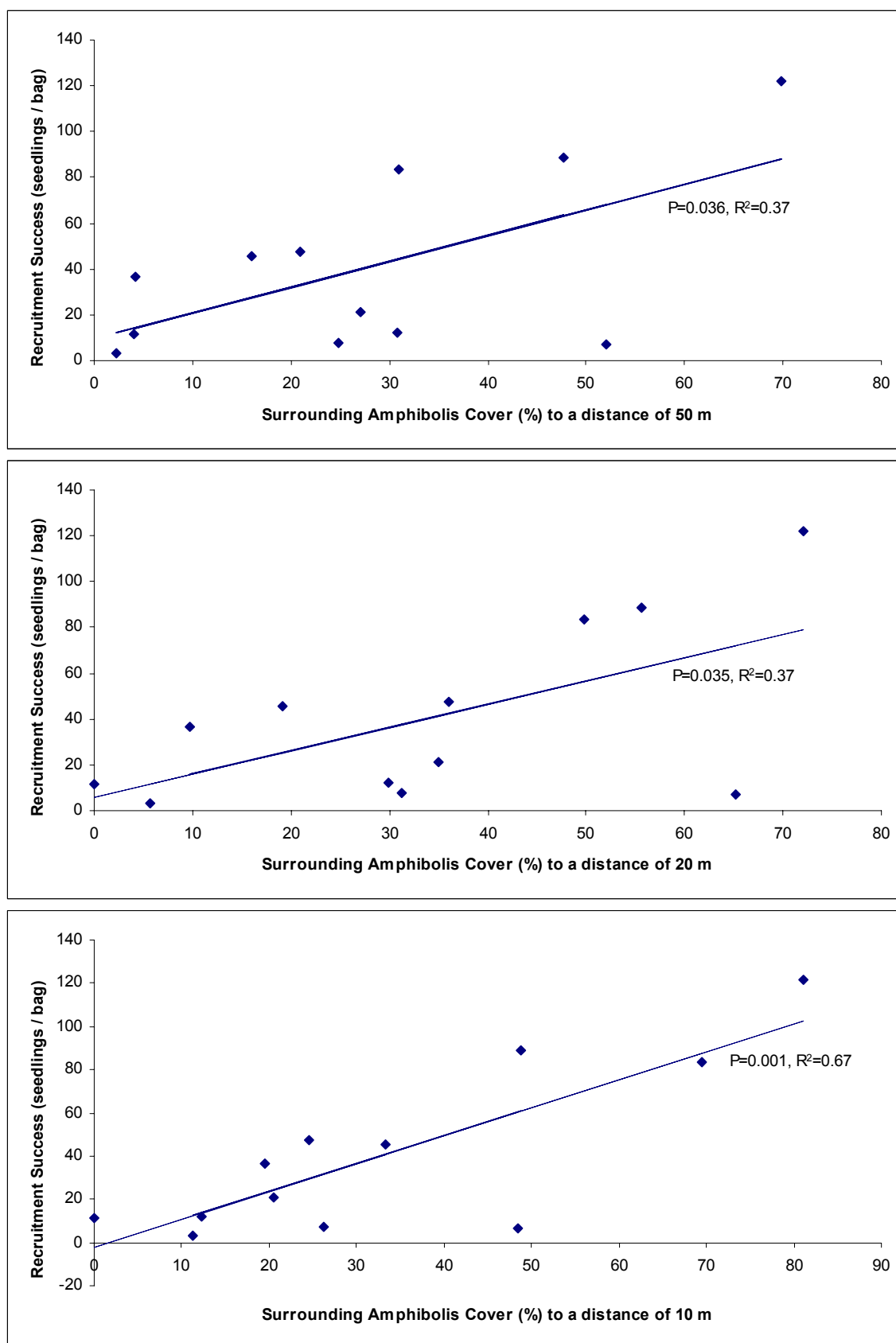


Figure 11. Relationship between recruitment success after 2 months and the amount of *Amphibolis* surrounding the recruitment units to different distances. Statistics show significant explanatory power of a linear regression in each case.

3.7 Effect of surrounding *Amphibolis* cover on long term recruitment success.

Recruitment success to 12 months was poor in low density *Amphibolis* areas (Figure 9), but most of the high density sites demonstrated similarly poor recruitment. Of the “more successful” sites, two were of intermediate density and only one of high density. Thus, the amount of *Amphibolis* is a poor predictor of the long term (12 month) success of recruitment (Figures 12 and 13). There is no significant relationship between recruitment success after 12 months, and any of; proximity to *Amphibolis* or the proportion of substrate covered by *Amphibolis* out to 10, 20 and 50m from the units (regression, $p > 0.10$, all independent variables).

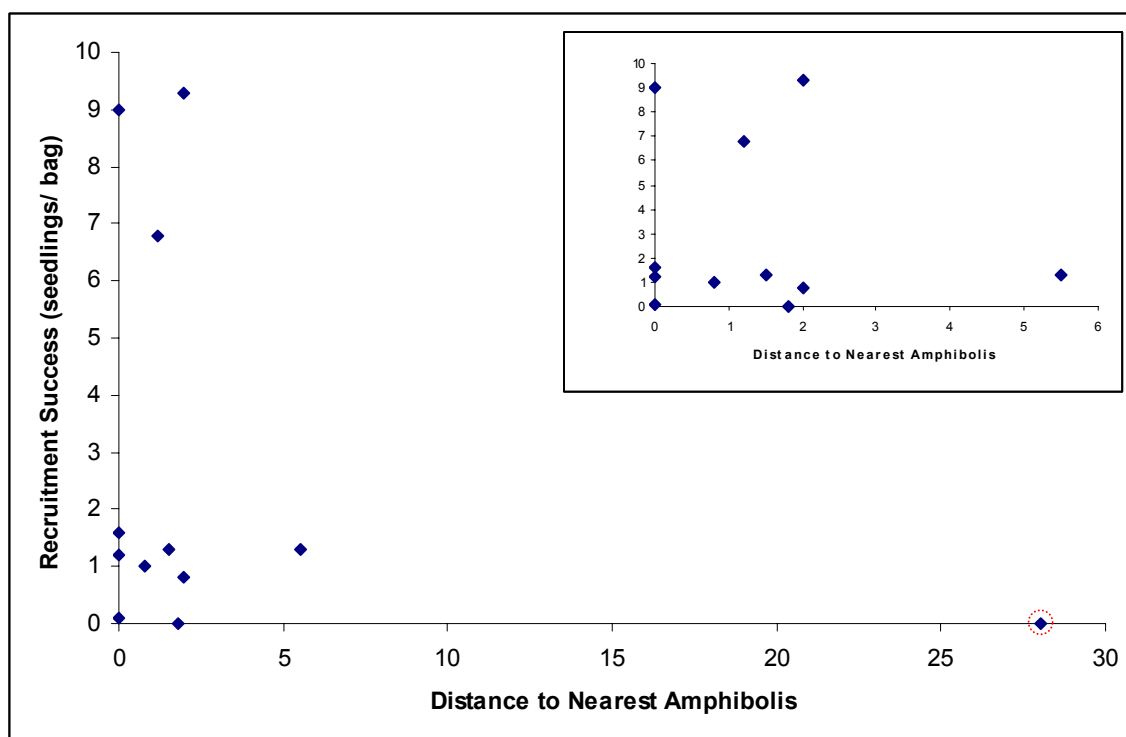


Figure 12. Relationship between recruitment success after 12 months and distance to nearest *Amphibolis*. Inset is the same relationship on a reduced scale, omitting the outlier Henley 10 m. (indicated with a red circle).

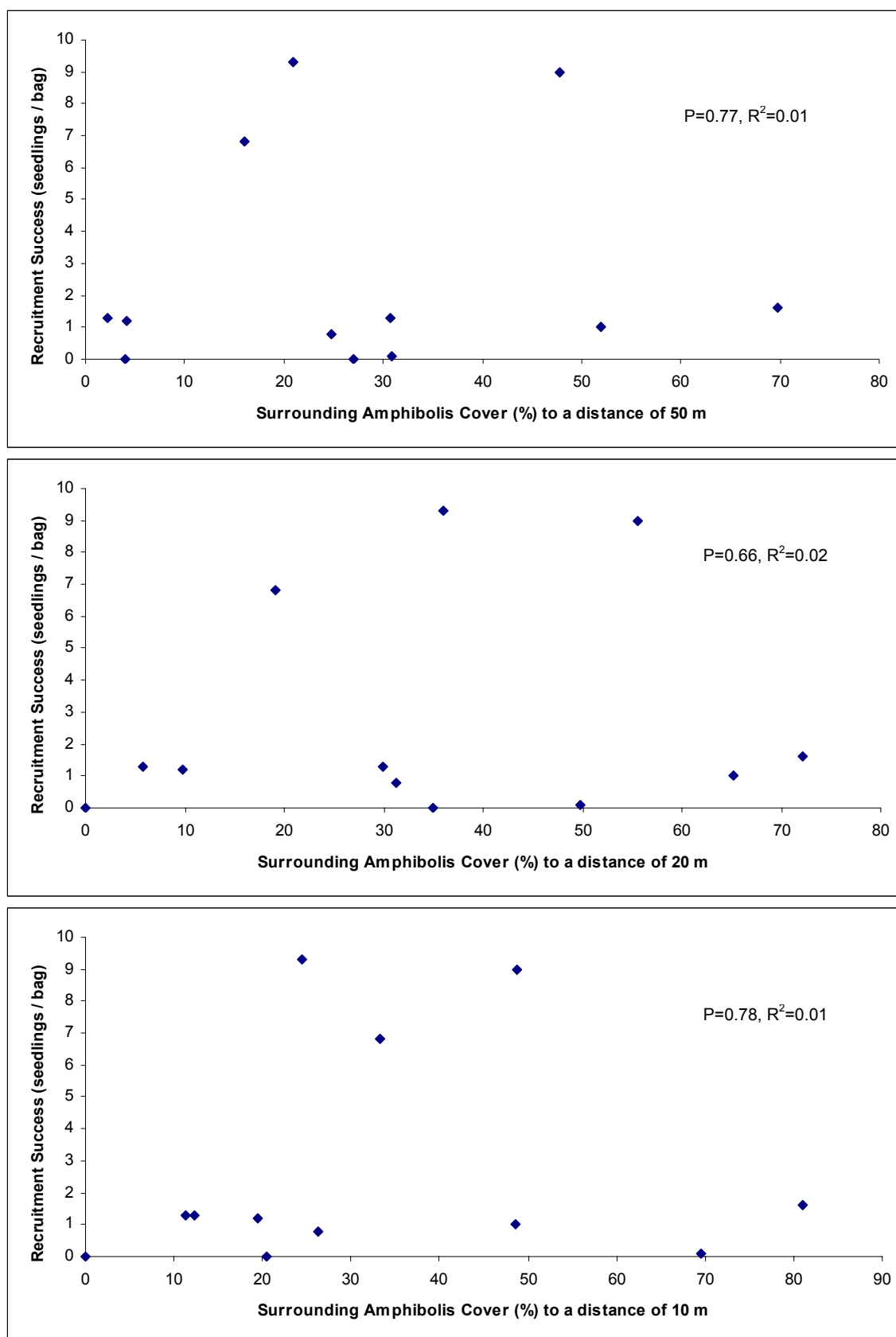


Figure 13. Relationship between recruitment success after 12 months and the amount of *Amphibolis* surrounding the recruitment units to different distances. Linear regression demonstrates a lack of significant explanatory power in all cases.

3.8 Mortality

Mortality, defined in this instance as the percentage of seedlings lost between the 2 month and 12 month surveys, was high along the Adelaide metropolitan coast (Figure 14). Greater than 80% mortality was evident at every site and most suffered more than 90% mortality, with two sites suffering 100% mortality. At a depth of 8 m, sites differed significantly in terms of mortality, ranging from 87% at Grange to 100% at Semaphore (Table 7). Whilst the sites differed, this did not reflect a north-south trend. At those sites where multiple depths were assessed (i.e. Brighton, Henley Beach and Grange) there was no effect of site, but there was a difference associated with depth. There was no interaction effect. Subsequent post-hoc tests identified that the 12 m site had significantly lower mortality than the 8 or 10 m sites (which were not significantly different – Table 8).

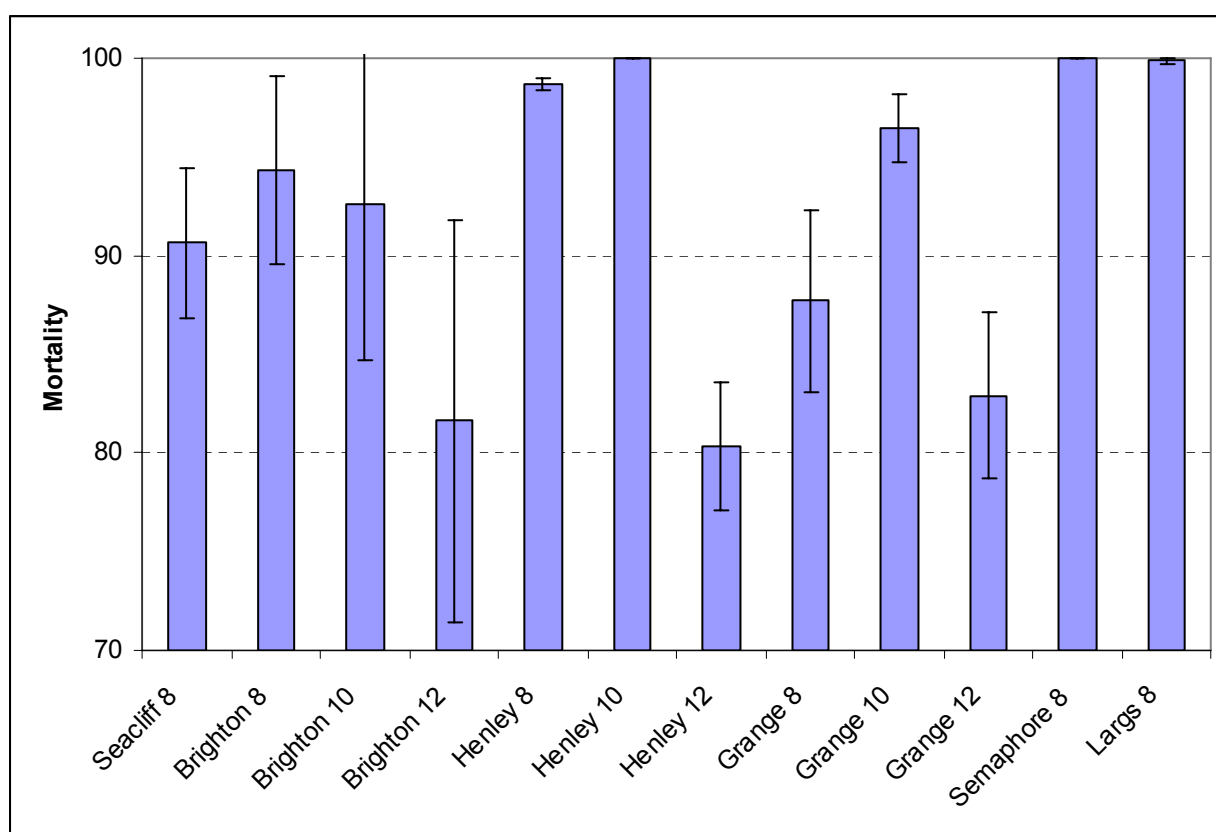


Figure 14. Mortality at each site. Mortality is defined as the percentage of seedlings lost between 2 months and 12 months. Error bars represent standard error. Note the truncated Y-axis.

Table 7. Results of one way analysis of variance and post hoc Games-Howell tests, testing for the effect of site on mortality (arcsin transformed) of recruits from 2 to 12 months across sites at 8 m depth.

Variable	d.f.	SS	F	P
Site	5	.308	5.779	<0.001
Error	53	.566		

Levene's test: $P < 0.001$

Significance of Games-Howell post-hoc tests

	Brighton	Henley	Grange	Sempahore	Largs
Seacliff	0.902	0.503	0.948	0.091	0.112
Brighton		0.999	0.448	0.731	0.797
Henley			0.072	0.004	0.009
Grange				0.010	0.012
Sempahore					0.907

Table 8. Results of two way analysis of variance testing for the effect of site and depth on mortality (arcsin transformed) of recruits from 2 to 12 months at all sites with multiple depths

Variable	df	SS	F	P
Depth	2	0.711	14.509	0.015
Site	2	0.063	1.286	0.370
Depth * Site	4	0.098	0.836	0.506
Error	79	2.314		

Levene's Test: $P=0.009$

Significance of Games-Howell post-hoc tests

	10 m	12 m
8 m	0.188	0.008
10 m		<0.001

Mortality was not significantly related to the initial density of seedlings (Figure 15; $P=0.68$; linear regression). It appears from Figure 15 that whilst sites with low initial settlement may have either high or low mortality, sites with high initial settlement can have only high mortality. However, modeling indicated that this was likely to be a mathematical artifact.

To determine if the above pattern is likely to be biologically meaningful, we created a neutral model of mortality, where each individual seedling had the same probability of dying. When this was applied using the observed frequency distribution of initial densities and the average observed mortality rate of 92%, the same pattern of variable mortality at the bag level was found for low initial densities, with only high mortality at high initial densities. This indicates that in the absence of any effect of density on the likelihood of mortality, it is possible to observe a situation where low mortality only occurs when initial density is low. Logically, this is because where only one seedling is present, there is an 8% chance of it surviving and providing a 0% mortality for that unit. If two seedlings are present there is only a 0.64% ($8\% \times 8\%$) chance of 0% mortality and 0.0512% ($8\% \times 8\% \times 8\%$) chance if there are three seedlings. Thus it is unlikely that the pattern observed in the real data is any more than a reflection of this effect, and consequently it cannot be ascribed to any biological phenomena.

Mortality is not constant across time. The proportion of recruits lost across a given period of time decreases as the population establishes. Across the first three months after the initial 2 month settling period, mortality was 46% per month. In the following seven months, mortality decreased to only 11% per month. A rate of mortality which varies as the population establishes can be modeled using a variety of curves. In this instance, an S-curve (SPSS 2005) was utilized to provide a formula for a line of best fit. The general formula of this curve is $\text{Popn}_{(t)} = e^{(a+(b/t))}$, where t represents time and a and b are derived constants. For *Amphibolis*, it was determined that $a=5.309$ and $b= 6.424$. Thus $\text{Popn}_{(t)} = e^{(5.309 + 6.424/t)}$. This provided a significant ($p=0.027$) line of best fit (Figure 17) which explained 99.9% of the variance. Extrapolation of this curve (which assumes the relationship is accurate into the future) indicated that a further 120 recruits would be lost over the next 4 years. As a demonstration that mortality had indeed decreased, this curve was compared with a simple constant mortality of 46% per month, which predicted only ten plants remaining after 12 months (c.f. 333 which *actually* remained) and a complete loss of *Amphibolis* recruits within 18 months.

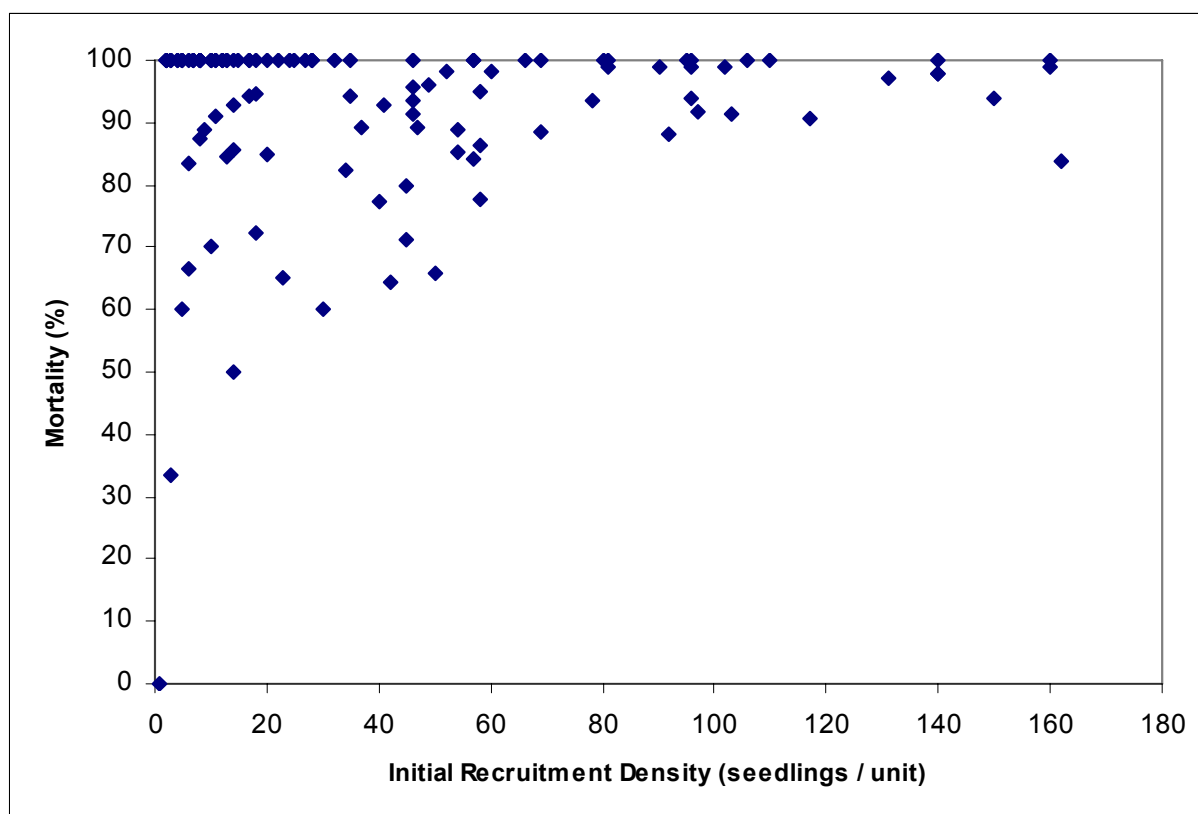


Figure 15 Relationship between initial settlement density and mortality of seedlings identified in the current study.

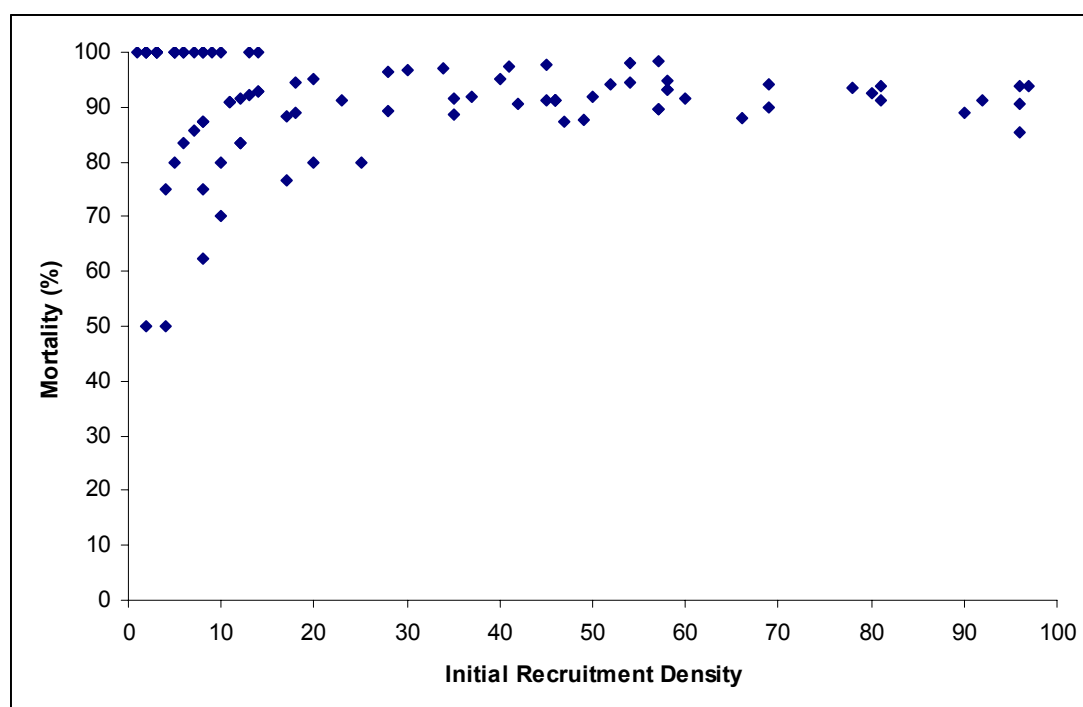


Figure 16. Modelled mortality on each recruitment unit assuming constant probability of individual loss as a function of initial recruitment density. Note the increased variability at low initial recruitment densities and the similarity to the pattern demonstrated in the real data.

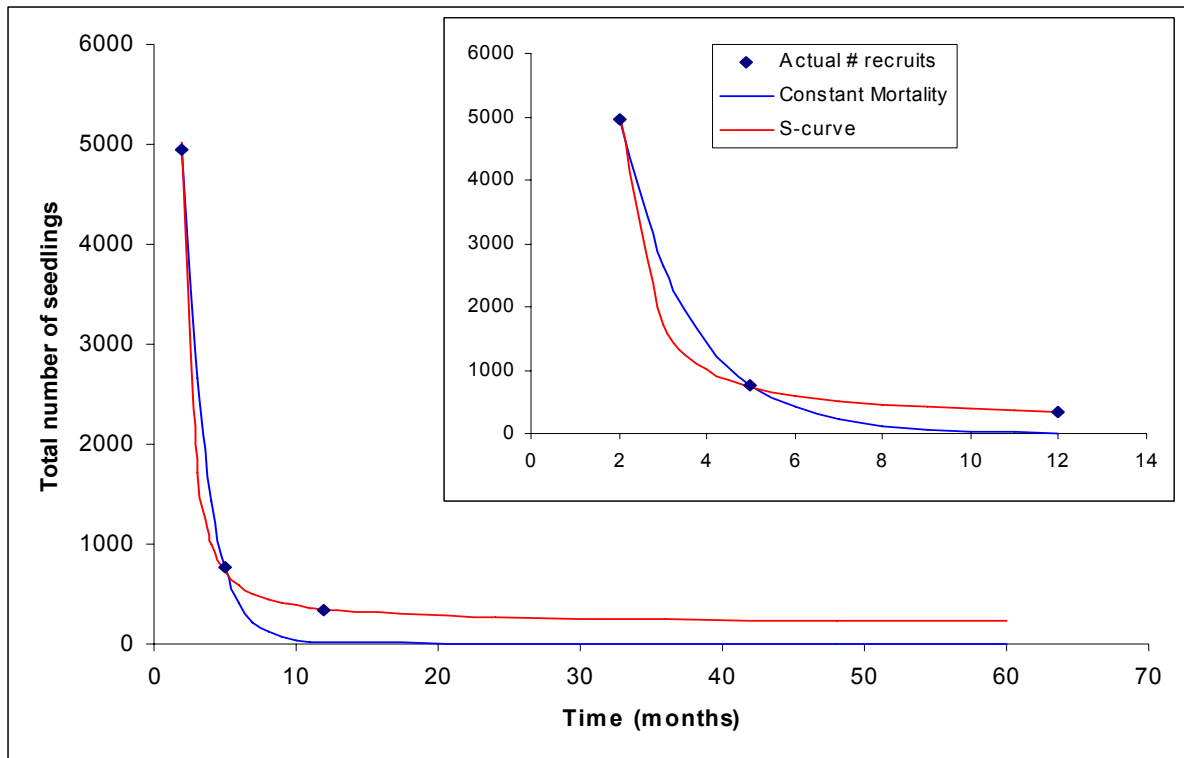


Figure 17. Survivorship across entire study. Points represent actual total numbers of recruits at the three points in time. Blue line represents predicted numbers if constant mortality (of 53.7% month⁻¹ as measured across first three months) operated across time. Red line is a survivorship curve (S-curve) fitted statistically to the measured data. Large graph demonstrates predictions to 5 years. Inset is the first 12 months to better demonstrate the fit of the lines across the measured period.

3.9 Recruitment Unit Success

Recruitment unit success was defined as the percentage of recruitment units which support any *Amphibolis* at any given point in time (as opposed to the density of recruits). After 12 months, 50.4% of recruitment units across the entire geographic range could be considered “successful” on the basis of the fact that they supported any *Amphibolis*. This figure was in contrast to the mere 8% of seedlings which survived across the same period. Recruitment unit success varied widely, from 0% at Henley (10 m) to 100% at the Henley (12 m) site (Figure 18). Only 5 of the twelve sites had recruitment unit success of less than 50%.

Extension of these findings to predict recruitment unit success after 5 years was made possible by application of the survivorship curve (S-curve) calculated in the previous section to predict the magnitude of the loss of individuals over the ensuing 4 year period. This work demonstrated that 120 further individuals could be expected to disappear from the recruitment units over this period (see previous section). Using a model which began with the populations on each bag after 12 months and then randomly allocated the loss of those 120 recruits, it was possible to predict the effect of this mortality on recruitment unit success (i.e. the number of bags still supporting some level *Amphibolis*).

After 5 years, the average percentage of bags retaining one or more individuals was 45% across the geographic range (c.f. 50.4% after 12 months). This varied widely, between zero at Henley (10 m) and Semaphore (8m) to 99% at Henley (12 m) (Figure 18). The poor results at Henley (10 m) and Semaphore (8 m) were inevitable as they had lost all recruits after only 12 months. With these exceptions, the results are positive – recruitment unit success appears unlikely to be reduced greatly in the four year period following the initial 12 months of the current study. Furthermore, we can expect recruitment unit success rates in excess of 40% after 5 years at the majority (7) of sites, assuming survivorship follows the modelled S-curve.

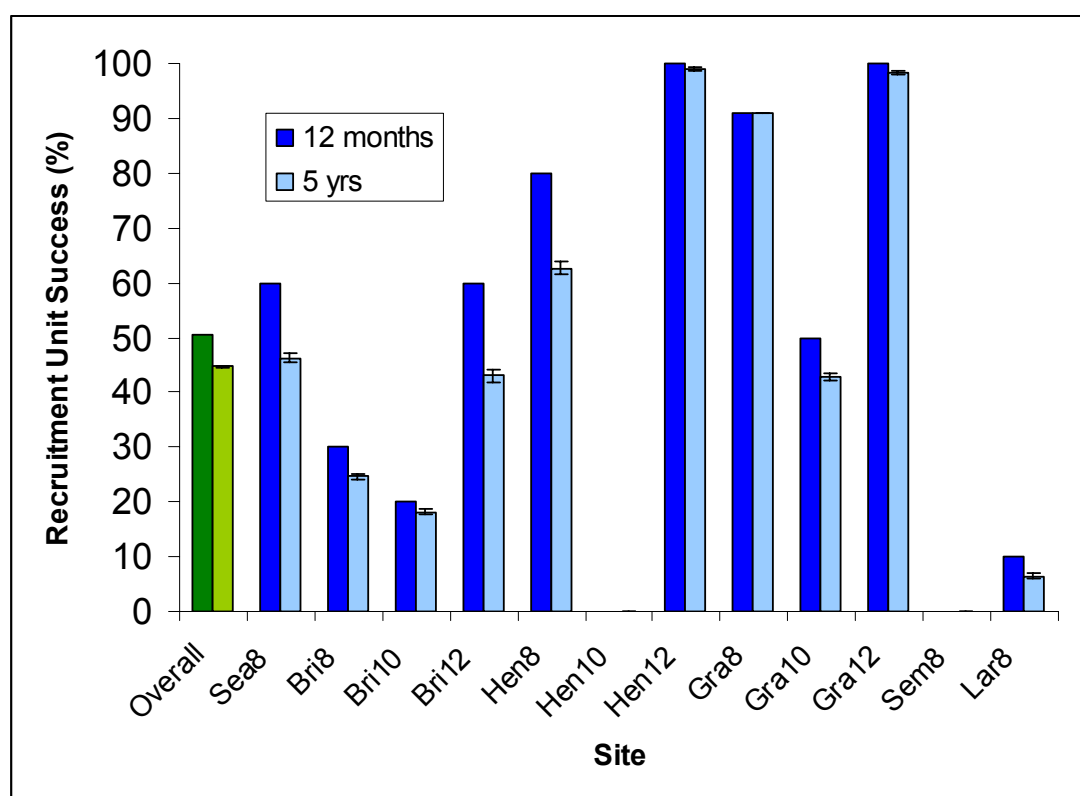


Figure 18. Recruitment Unit Success overall and at each site. Recruitment unit success is defined as the percentage of recruitment units still supporting *Amphibolis*. Dark columns represent the measured situation after 12 months, light bars represent the average situation after 5 years predicted using the survivorship curve fitted in the previous section. Error bars represent standard deviation across 100 runs of the model.

3.10 Temporal Variation in Recruitment Success

By resurveying the sites of Wear et al. (2006) (set up a year earlier) we were able to obtain information on success of a recruitment event measured after two years (Figure 19) and, additionally, make a comparison between recruitment and mortality in different years and in different aged plants. The two year old units, established by Wear et al. (2006), did not show the S-curve predicted on the basis of the results of the current study (Figure 19). In fact, mortality actually increased in the second year (Figure 20). Mortality in the first year was only

45% and 25% at Sites 1 and 2 of Wear et al.'s study, whilst in the next year it rose to 88% and 99%.

Whilst mortality across the first twelve months was very different between the 2004 recruits and the 2005 recruits, it is interesting to note that initial recruitment was far more similar (Figure 21). Whilst differences existed between sites, they were relatively consistent between years, with Sites 1 and 2 of Wear et al.'s study recruiting 98 and 40 seedlings per unit after approximately 2 months, whilst the equivalent sites of the current study recruited 89 and 21 seedlings per unit.

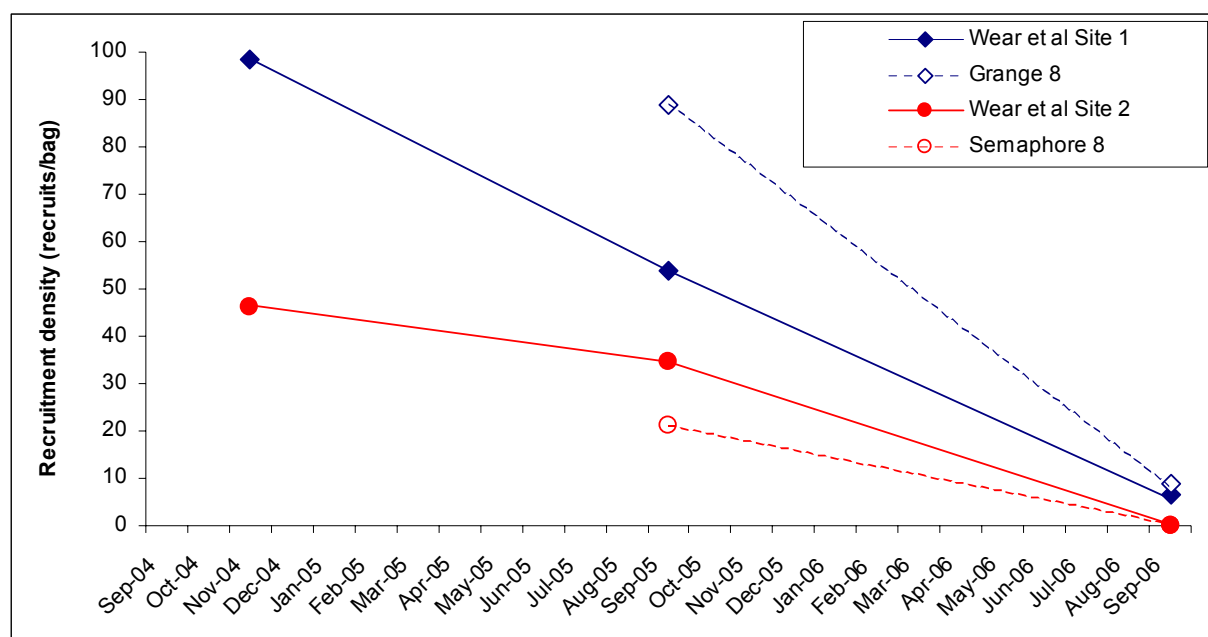


Figure 19. Recruitment density of *Amphibolis antarctica* on units deployed in 2004 (Wear et al. sites 1 and 2) and the equivalent sites in the current study (Grange and Semaphore at 8m), deployed in 2005.

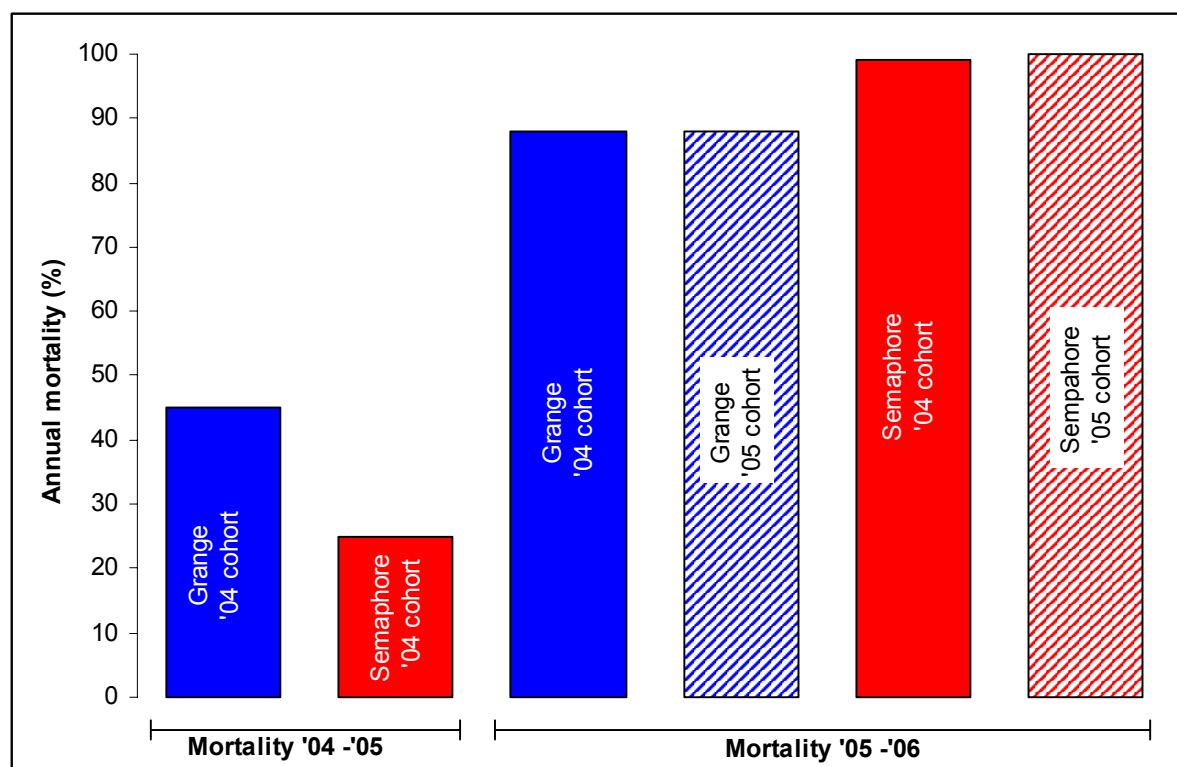


Figure 20. Mortality at Grange and Semaphore (8 m) across 2004-05 and 2005-06. Colours identify sites, patterns identify the cohort. The '04 cohort data comes from Wear et al. (2006). The mortality indicated in '05-'06 is, by definition, of plants up to 1 year old in the '05 cohort and a year older for the '04 cohort.

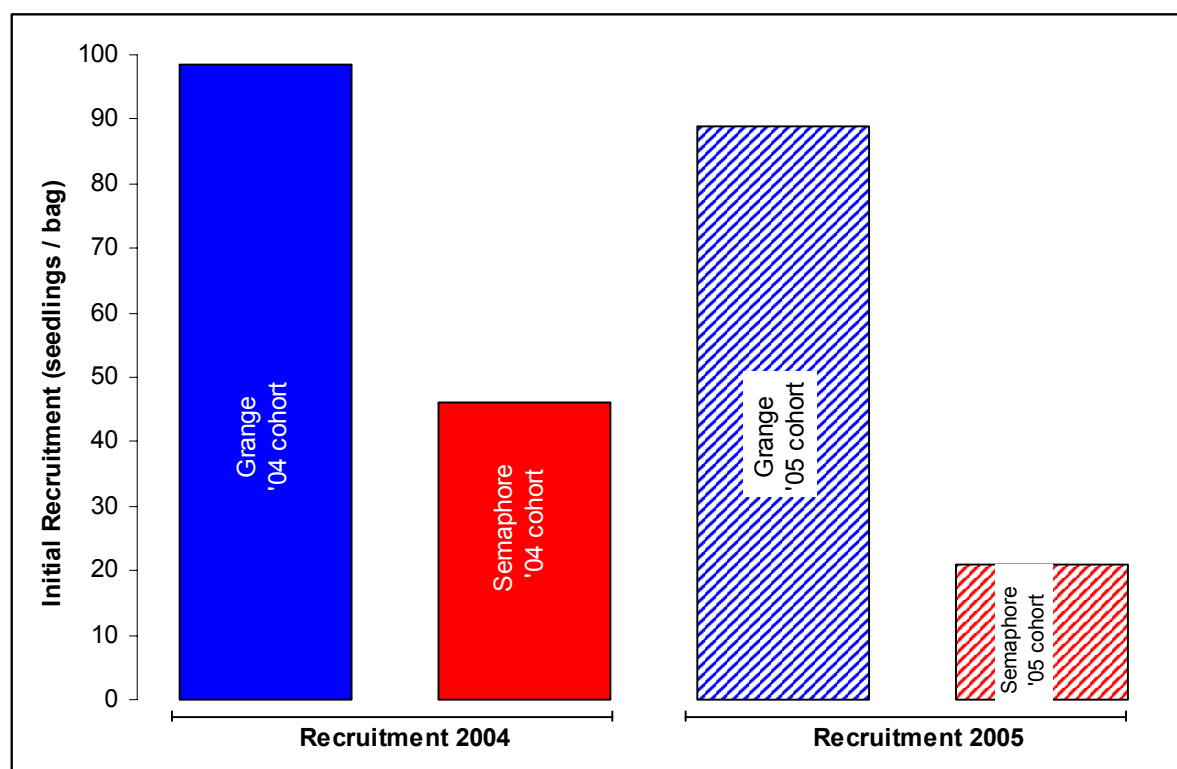


Figure 21. Recruitment levels at Grange and Semaphore (8 m) in 2004 (from Wear et al. 2006) and 2005 (from the current study). Whilst sites differed, there was little difference between years within a site. Colours identify sites, patterns identify the recruitment year.

4 DISCUSSION

This work has identified substantial temporal and spatial variability in the recruitment of *Amphibolis* seedlings along the Adelaide metropolitan coast. Recruitment after 2 months varied, on a geographic basis, from 3 seedlings per recruitment unit at Brighton (10 m) to 122 seedlings per unit at the Henley (8 m) site. After 12 months, substantial mortality had occurred, with maximal recruitment being recorded at Henley (12 m), which averaged 9.3 seedlings per unit. Comparison of this year with that of the previous year (see Wear et al. 2006) in closely adjacent sites indicates that survival varies greatly from year to year. Despite the apparently high mortality evident in the current study over twelve months, the pattern within this time indicates that mortality can be expected to be much reduced in the future, assuming that conditions remain constant. This is likely to be due to the remaining plants having developed root systems capable of better anchoring. This, however, is not consistent with the higher mortality of recruits in the second year.

4.1 Geographic Variability

Whilst all sites recorded some recruitment after 2 months, it varied almost 40-fold, ranging from 3.3 seedlings per recruitment unit to 122 seedlings per unit. Differences in initial recruitment between sites did not appear related to any north-south geographic gradient. However, there was a significant relationship between initial recruitment success and the density of surrounding *Amphibolis*. This is unsurprising as several authors have commented on the propensity for a great proportion of reproductive material of marine macrophytes to settle close to the adult plant (e.g. Anderson and North 1966; Deysher and Norton 1982; Schiel 1988; Kendrick and Walker 1991). Clearly large amounts of nearby *Amphibolis* are able to supply a greater number of potential recruits, thereby increasing initial settlement density. Such a finding has implications for the design of any revegetation efforts, as it indicates that successful initial recruitment is more likely reasonably close to a donor bed. The success of recolonisation efforts in broad-scale areas denuded of *Amphibolis* is likely to vary, with those recruitment units at greater distance from the edge of the existing meadow unlikely to be as successful as those close to the edge.

After 12 months, the complex effects of mortality had erased any relationship between recruitment success and surrounding *Amphibolis* density. Recruitment success varied significantly between sites, but not in a way that suggested any particular geographic gradient, nor any relationship to the cover or proximity of surrounding *Amphibolis* stands. It can be said that the southern sites demonstrated consistently low recruitment after 12 months, but the northernmost sites were even lower. Only the Grange and Henley Beach sites demonstrated high recruitment levels (6.8-9.3 seedlings per unit) after 12 months, and even within these sites the pattern is unclear, with the deepest site at one location recording highest recruitment and the shallowest at the other.

Whilst mortality varied significantly between sites, it was characteristically high, ranging from 80% at Henley Beach (12 m) to 100% at Semaphore (8 m) and Henley (10 m). No relationship between mortality and north-south location could be determined, but depth did appear to exert a significant effect, with the deep sites suffering less mortality. This is consistent with the effects of water movement being ameliorated at greater depth, resulting in the loss of fewer seedlings. Other studies measuring mortality of recruits make it clear that high mortality amongst seagrass recruits is common (e.g. Kirkman 1999; Alexandre et al. 2006; Duarte and Sand-Jensen 1990, 1996; Orth et al. 2002).

Mortality may be either density dependent or density independent. Density dependent thinning refers to those factors which become more severe at higher densities (Begon et al. 1986). Examples of these factors might include competition for light and other resources such as nutrients. Such factors ensure that population numbers cannot increase indefinitely. They also ensure that, as the plants get bigger and require more resources, fewer plants can be supported and therefore the population size decreases. Conversely, those factors which cause mortality that are not related to the number of individuals are known as density-independent factors (Begon et al. 1986). Examples of these types of factor include storm events, epidemic disease and herbivory.

In this instance, there is good evidence that the factors causing mortality are density-independent. Firstly, there was no increase in mortality rates with increasing recruit densities. Furthermore, the density of recruits reached a maximum of approximately 540 plants m⁻². In mature stands of *Amphibolis*, where plants are far larger, more than 600 stems per square metre are supported (Collings et al. 2006a). Thus it is unlikely that the populations on the recruitment units are undergoing density dependent thinning. Rather, it appears that mortality is dependent upon locality, and in particular, upon depth, with deeper sites suffering less mortality. Such a pattern suggests that removal via the effects of water movement is likely, as wave energy is ameliorated at deeper sites. In a study of survival of transplanted units of *Amphibolis griffithsii*, Paling et al. (2000) found that hydrodynamic stress was likely to result in substantial mortality. In the present study, removal may have been due to failure of individuals to maintain attachment, or it may have been due to structural failure of the hessian recruitment unit, and subsequent loss of groups of recruits. Certainly there was evidence, after 12 months, of a substantial number of bags having been torn or rotted. Again, this is in contrast to the persistence of the recruitment units placed a year previously by Wear et al. (2006). Probably a combination of both individual mortality and recruitment unit fabric failure is responsible.

If this technique was to be successful, the recruits would need to grow to a size where they would be well rooted by the time the hessian substrate degraded and no longer assisted adhesion. However, it appears that recruits did not grow to this size before many of the recruitment units degraded. Additionally, it is clear from examination of intact units, that there was substantial loss of recruits even when the hessian bags remained intact. Water

movement can be expected to remove a significant proportion of recruits, even if the units remain intact.

To put the recruitment rate of this study into context, natural recruitment rates into disturbed areas vary widely (e.g. 0.07 seedlings m⁻² (for *Thalassia testudinum*; Whitfield et al. 2004, Kaldy and Dunton 1999) to 22-32 seedlings m⁻² for *Thalassia hemprichii*; Rollon et al. 2001). This latter figure is considered extremely high for a late successional species (Whitfield et al. 2004). The general trend is for far higher numbers of sexually produced recruits in early successional species and fewer in late successional species. Where *Amphibolis* fits in terms of succession is debatable. Clarke and Kirkman (1989) consider the species to be mid-successional. However, this species demonstrates viviparous reproduction, releasing seedlings rather than seeds. This fact implies a major investment in energy on behalf of the adult plant and that relatively few seedlings are likely to be produced. Thus, in terms of density of seedlings, it might be reasonably expected that *Amphibolis* will demonstrate a low density of initial seedling recruitment, but that these seedlings will, with time, become more dominant in the manner of a later successional species. It should be noted that successful recruitment was not observed on the sand at the study sites.

On the basis of these findings, the clearest thing that can be identified is that recruitment is a patchy process, characterised in its early stages by the size of the surrounding seedling source. However, within a year, the overriding effects of the characteristically high mortality rate, related to some degree to the depth of the site, result in an unpredictably patchy mosaic across large scales. Given the heterogeneous nature of established seagrass stands (see, for example, Di Carlo et al. 2005, Bostrom et al. 2006), this is surprising.

4.2 Temporal Variability

Wear et al. (2006) reported similar initial recruitment at sites adjacent to the Grange (8m) and Semaphore (8m) sites of the current study, but subsequent mortality was far greater in the current study. The sites of their study supported 98 and 40 seedlings per unit respectively after 5 weeks, which is quite comparable with the 89 and 21 seedlings per unit reported at these sites in the current study (Figure 21). However, over the following time period far greater mortality was seen in the current study – in the current study mortality over the first twelve months at these sites was 88% and 100% while it was only 45% and 25% respectively in the study of Wear et al. (2006), conducted a year earlier (Figure 20). Interestingly, mortality of the cohort studied by Wear et al. (2006) in the second year (which was concurrent with the first year of the plants of the current study), was far higher than it was in the first year and almost identical to that of the current site. Across this period, mortality of Wear et al.'s populations was 88% (c.f. Grange (8m) which also suffered 88%) and 99% (c.f. Semaphore (8m) which suffered 100% mortality). Thus, within a site, mortality is highly variable *between* years, but *within* a year appears to equally affect cohorts separated by 12 months. In contrast, initial recruitment appears to be relatively consistent, at least between

the two years which we were able to compare in this study. The implications for this finding are discussed further in the succeeding section dealing with predictions of success.

While there has been substantial work investigating temporal patterns of growth and flowering in seagrasses, most has concentrated on seasonal variability and has not been extended to include any analysis of interannual variability. Campey et al. (2002) provide some rare evidence which indicates that flowering, at least, is a variable event (for *Zostera tasmanica* and *Posidonia coriacea* in Western Australia), but the current study represents the first account of interannual variability in recruitment of *Amphibolis*.

4.3 Trends and Predictions for Recruitment Success

Whilst a simplistic analysis indicates discouragingly low survivorship of juveniles, it is necessary to view these results in an appropriate biological context. Seagrasses are clonal in nature, an individual plant consisting of an ever-growing stolon system which produces regular vertical shoots, eventually producing a dense mat of stolons and roots. While a stolon may break, resulting in two independent plants, these two individuals are derived from the same plant and are clones of one another, genetically indistinguishable. The relative importance of sexual reproduction (resulting in new seedlings) and clonal growth differs from species to species and between locations (e.g. Procaccini et al. 1996; Waycott et al. 1996; Vidondo et al. 1997; Marbà and Walker 1999).

Alberto et al. (2005) proposes that different species of seagrass occupy different positions along a continuum defined by the extremes of Eriksson's (1993, 1997) "Repeated Seedling Recruitment" (RSR) and "Initial Seedling Recruitment" (ISR) models. The ISR strategy places an emphasis on an initial recruitment event, followed by clonal growth, whereas the RSR strategy describes a situation where seedlings regularly recruit into the population. Whilst there are some accounts to the contrary, the general consensus is that sexual reproduction in seagrasses is sparse and clonal growth is the most important mechanism (Sintes et al. 2005; Hemminga and Duarte 2000; Vidondo et al. 1997). This results in large areas that are covered by many shoots belonging to one or a few plants. Work by Reusch et al. (1998) and Procaccini and Mazzella (1996) demonstrated (albeit in other species) that a single clone can extend over 160 metres in length, or even across entire extensive meadows (Procaccini et al. 1996). Rasheed (1999; 2004) reported that artificially created disturbances in beds of *Zostera capricornii*, *Halophila ovalis* and *Syringodium isoetifolium* in Queensland were recolonised almost entirely via vegetative reproduction.

Much of the lack of success of sexual reproduction as a mode of recruitment in seagrasses can be attributed to extremely high mortality following seed production. Hemminga and Duarte (2000) estimated the average likelihood of success of a seed to grow into a reproductive adult as considerably less than one in ten thousand. Even if initial recruitment is high, mortality of the recruits is correspondingly high (e.g. 80-90% annually; Duarte and

Sand-Jensen 1990, 1996). Mortality of *Thalassia* recruits in a naturally recolonised area in Florida was reported to be 83% over two years (Whitfield et al. 2004), and 89% across 1 year in Laguna Madre (Kaldy and Dunton 1999). Similarly, Alexandre et al. (2006) reported 90% mortality in *Zostera noltii* between the germling and seedling stages.

Marbà and Walker (1999) examined the flowering, growth and population dynamics of a range of temperate seagrasses in Western Australia and concluded that there was great variability in the strategies employed by different species. However, in *Amphibolis antarctica*, *Posidonia angustifolia* and *P. sinuosa* (three important species on the Adelaide metropolitan coast), sexual reproduction had a negligible contribution to meadow maintenance. They concluded that the persistence of beds of these species would rely almost exclusively on clonal plant growth and furthermore that “the recovery of disturbed *P. sinuosa* and *A. antarctica* meadows should involve timescales of centuries.” This is supported by the work of Waycott et al. (1996), who demonstrated a complete lack of genetic variability in *Amphibolis antarctica*, a feature which Marbà and Walker et al. (1999) point out may be caused by long term clonal growth from one or only a few initial seedlings. Similarly, Kendrick et al. (1999) considered seedling recruitment to be of minor importance in the expansion of *Posidonia* and *Amphibolis* meadows onto bare sand. Clearly *Amphibolis antarctica* appears to employ the ISR strategy, relying on vegetative growth from a few rare recruiting individuals to create extensive meadows or rehabilitate degraded ones.

With time, and as each individual grows, intraspecific competition is likely to result in a decreasing number of individuals. For example, the lack of genetic diversity in the ancient (2000 yr old) *Posidonia oceanica* beds of Ischia (Procaccini et al. 1996) may be an indicator that as the bed ages, intraspecific competition results in the survival of only a single genet. Thus, in anything but the short term, it matters very little whether one or a hundred seedlings successfully recruit. Rather, the critical point is whether a recruitment unit supports any seedlings. If it does, then within a few years, that recruitment unit should be covered with *Amphibolis*, given horizontal extension rates of 5.5 cm yr⁻¹ (Marbà and Walker (1999). Furthermore, the vegetative growth process is a self-accelerating one (Bostrom et al. 2006), with increasing growth rates likely as the plant gets larger. It is therefore appropriate to view the proportion of units supporting *Amphibolis* as a measure of the success of the method. In contrast to the 8% survival of seedlings, 51% of bags still supported recruits after 12 months across all sites (ranging from 0% at Henley Beach (10 m) to 100% at Grange (12 m)). This provides more optimism about the success of the technique than simply analysing the survivorship of individuals.

Whilst we believe recruitment unit success to be the most appropriate gauge of the success of recolonization efforts, individual mortality measurements provide important information which may allow better prediction of future success. This is because a knowledge of individual mortality rates can allow us to better model the likely success of recruitment units into the following years. Allowing the assumption that most mortality is a result of individual

loss, rather than the wholesale loss of an entire recruitment unit, it is evident that a unit with a single plant on it is more likely to eventually support no seedlings than a unit with many seedlings on it.

By predicting how many individuals are likely to be lost we can apply this loss to the current population of individuals as it is distributed across the recruitment units of all sites. This allows an assessment of the likely recruitment unit success to any given point in the future, a useful exercise for any manager concerned with seagrass rehabilitation. Application of a mortality curve (S-curve; SPSS 2005) to the survivorship of the recruits over time, can provide an indication of future mortality under the assumption that the trends being modelled by that curve over this year continue into the future. In this instance, mortality has rapidly decreased, suggesting that over the next 4 years, only a further 120 individuals will be lost (Figure 17). This curve provides a good fit to recruit survivorship, with an r^2 of 0.999. The relationship described is one in which mortality decreases with age as plants grow larger and become more able to anchor themselves securely. By randomly allocating the loss of each of these individual to the populations on the recruitment units, it is apparent that after another four years there will still be a 45% recruitment unit success rate. This represents the optimistic scenario.

The implicit assumption in the acceptance of the relationship in Figure 17 as a long term survivorship curve is that as the plants get older, they are less likely to be lost. This cohort certainly demonstrates lower mortality as the plants become older and larger. However, the fact that the two year old recruits of Wear et al. (2006) fared no better in terms of mortality than the one year old recruits of the current study is direct evidence to the contrary. Thus, the survivorship curve measured across the course of the year may not be indicative of future years as it implicitly assumes that older plants are less likely to be lost. Using the resampled sites of Wear et al. (2006) to provide two years worth of mortality data provides another estimate of mortality. Across all individuals at both sites, across two years, the average annual mortality is 78.5% (95.4% across two years). If this mortality rate is applied to the remaining individuals across all recruitment units, we can expect only 3 individuals to remain after the next 3 years, and by the end of the fifth year, less than one surviving individual is predicted. This obviously provides a recruitment unit success rate of zero.

It should be noted that this extremely low success rate is based on one apparently good year and one bad year. With such a wide range observed across two years, a simple average of the two yields a result in which we can have little confidence. The critical question in this case becomes how often do good and bad years occur. Without this knowledge, it is impossible to accurately predict survivorship and subsequently recruitment unit success. The best that can be said is that the true success rate is somewhere between 0 and 45% after 5 years. This range must be narrowed through an understanding of interannual variability through continued re-census of recruitment events before we can accurately gauge the likely success rate of restoration efforts making use of this technique.

It remains a goal of this program to decrease the timeframe involved in seagrass rehabilitation. Thus, even if the few remaining recruits are eventually successful “germ patches” which grow into large established patches, optimisation of the recruitment will provide a greater number of patches, each of which becomes established, thereby accelerating progress toward the overall goal. For this reason, attention needs to be paid not only to the growth of established recruits, but also to refinement of the facilitation method, which is clearly not universally efficient, either in time or geographically.

5 CONCLUSIONS

Whilst recruitment success is strongly influenced by location along the Adelaide coast and by depth, across the period of this study it has not been particularly successful anywhere in comparison to the original success reported in Wear et. al. (2006). The technique cannot therefore be considered universally applicable throughout the region. Given that revisitation of the sites of Wear et al. (2006) also demonstrated poor survival, it is evident that there is substantial temporal variability in mortality.

Initial recruitment success is strongly influenced by the density of nearby *Amphibolis* plants. Therefore the “sowing” of large areas with bags is unlikely to result in significant initial capture of seedlings other than adjacent to existing beds. This effect is being examined in more detail in an ongoing study by SARDI Aquatic Sciences.

Regardless of initial recruitment success, subsequent mortality is extremely high. There appears to be increased mortality in regions shallower than 12 metres, which is unfortunate as it is in the shallower regions that most *Amphibolis* is considered to have been lost. Most indications point to physical removal through water movement, sometimes assisted by hessian bag deterioration, as the principal cause.

In light of the relative importance of vegetative (as opposed to sexual) reproduction, it has become clear that the appropriate goal of these techniques is to produce a successful recruitment unit, rather than to produce many individuals on a recruitment unit. However, whilst the timescale of rehabilitation is unlikely to change substantially depending on whether there is a single successful recruit or many per unit, ultimately recruitment unit success is affected by recruitment and mortality of individuals (high individual mortality will result in a lower likelihood of a single successful recruit). For this reason, it is important to continue to research methods for improving the high mortality rate noted amongst the recruits in the year 2005/2006.

This study represents the first attempt to gauge recruitment success across more than a single year at a range of locations. It has indicated that there is an extremely wide range, both geographically and between years. It is critical that any future management of seagrass rehabilitation be conducted in light of a knowledge of the variability involved in time and space. Not only will this assist with accurate estimation of the costs involved, but it also will provide invaluable insights into both where recruitment facilitation is likely to be successful (as opposed to other methods of rehabilitation) and the timing of these efforts (multiple deployments over successive years as opposed to a single large deployment).

It is evident that future research in this area must be targeted in two general areas – a continued attempt to improve the success rate of the long term recruitment of individuals in order to increase the likelihood of high levels of recruitment unit success and a concurrent study of the temporal variability beyond the two years already studied.

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